THÈSE

UNIVERSITE DE PAU ET DES PAYS DE L'ADOUR

École doctorale Sciences Sociales et Humanités (481)

Présentée et soutenue le 1er Février 2017 par

Charles REGNACQ

Pour obtenir le grade de docteur en

Sciences Economiques

Sur le sujet :

Coûts de Transaction dans les Marchés de l'Eau : Le Cas de la Californie

Laboratoire

Centre d'Analyse Théorique et de Traitement des données économiques (CATT)

MEMBRES DU JURY

Directeur	Professeur Jacques LE CACHEUX	*Université de Pau et des Pays de l'Adour*
Rapporteurs	Professeur Ariel DINAR Professeur (Associé) Anita CHAUDHRY	*University of California, Riverside* *California State University, Chico*
Suffragants	Maître de Conférence (HDR) Fabien CANDAU Professeur Mazhar MUGHAL	*Université de Pau et des Pays de l'Adour* *Ecole Supérieure de Commerce de Pau*

University of Pau (UPPA)
Doctoral School of Social Sciences and Humanities (ED SSH-481)

Ph. D. dissertation in Economics presented by

Charles Regnacq

and publicly defended

February the 1st, 2017

Transaction Costs in Water Markets: The Case of California

Research Center:

Centre d'Analyse Théorique et de Traitement
des données économiques (CATT)

Jury Committee

Professor Jacques LE CACHEUX *Université de Pau et des Pays de l'Adour*	Supervisor
Professor Ariel DINAR *University of California, Riverside*	Rapporteur
Associate Professor Anita CHAUDHRY *California State University, Chico*	Rapporteur
Assistant Professor Fabien CANDAU *Université de Pau et des Pays de l'Adour*	Examiner
Professor Mazhar MUGHAL *Ecole Supérieure de Commerce, Pau*	Examiner

Acknowledgement

First and foremost, I would like to express my gratitude to my supervisor, Professor Jacques Le Cacheux for his support all along this thesis and in my endeavor in this research. He gave me the opportunity to conduct this research at the end. I am also deeply indebted to Professor Ariel Dinar who shared with me his knowledges and invited me in his research center. The time spent at the University of California, Riverside under his supervision and among other researchers and Ph.D. students of the WSPC has been incredibly enlightening and is something I will never forget.

I would like also to thank the Professors and researchers of the CATT and more specifically, I am deeply grateful to Fabien Candau who gave to me the passion for studying economics. He helped me and pushed me to get the best of myself.

This acknowledgement would not be complete without thanking Alexandra, Ilyes, Julie, Geoffroy, Kildine (la coach de thèse), Elisa, Farid and Mazhar who are such supportive colleagues, but more than that, they are friends who are always there. The good mood and welcome of colleagues and friends as well from the ITEM and PASSAGE research centers, Tiphaine, Anaïs, Idrissa and Lionel have also been critical in the success of my endeavor. Not less important has been the support of the UPPA's doctoral school of social sciences and humanities with their directors, Jean-Yves Puyo and Jacques Jaussaud all along my thesis and more specifically during the last steps of it.

Last but not least, I would like to thank my parents and my brother who gave me all their support for almost thirty years as well as Simon, Maxime, Agatha and Magali who have been such friends from the beginning of this thesis, and before. I will never forget the bolster in time of struggle.

Contents

List of Figures

List of Tables

Introduction

Acting as a necessary condition for the subsistence of any society, water resources flow across the whole set of human activities at the whim of the different needs of consumption and production specializations. From such ubiquity of uses, concerns grow in many arid regions around the world of an inadequacy between the multiple water demands arising from their development path and the inherent versatility of their water supplies. Impacting upon the latter to meet the increase of the former has been the preferred paradigm for decades in most of these regions to sustain their economic activities through the construction of physical infrastructures (Saleth and Dinar, 2004). However, by asserting that a water system may fluctuate only within an unchanging envelop of variability, many solutions to solve the problems of water scarcity in the past have been based upon the assumption of environmental and societal stationarity. Yet, with the present structural and climate changes, it can be said that "the assumption of stationarity is dead" (Milly, Betancourt, Falkenmark, et al., 2008 p.573).

To overcome such issues, policy makers in most of these arid regions focused their attention to develop an institutional infrastructure sufficiently flexible to cope with the rapid change of the new millennium. Water markets, where willing buyers and sellers interact within a decentralized system of price to exchange water rights have been of growing interest among policy makers (Easter, Rosegrant, and Dinar 1998; Easter and Huang 2014; Griffin, Peack and Maestru, 2013 and Msangi and Howitt 2006). Indeed, in line with the traditional trade theory, the transfer of water among users through a decentralized management system is seen as an efficient reallocation mechanism, not only enabling it to move from lower to higher value uses through an equalization of its marginal productivities, but also providing the incentives in conservation and technological improvement of its uses (Brown 2006; Chong and Sunding, 2006).This way, water markets could foster the connection between the different places of use and provide an interactional interface with the motivation to equilibrate the divergent demands with the limited supply of water (Garrick, 2015 p.181). But, given the intricateness of the relationships between a society and its hydrological resources with important difficulties in deciphering the multiple interdependencies between users (Smith, 2008 p.445), water markets need strong institutions to operate properly (Challen, 2000 p.205; Garrick, 2015 p.9; Livingston, 1998 p.19 and Howitt, 2014 p.95).

An institution can be broadly defined as the "prescriptions that humans use to organize all forms of repetitive and structured interactions" (Ostrom, 2005 p.3). Since such prescriptions are providing pro-forma roles and thus, are reducing the required effort to decipher the societal and natural environment in which individuals are evolving, they are improving the predictability of interactional situations through a clear delineation of rights and duties between these transacting individuals. In that sense, prescriptions are the result of the institutionalized rules that underlie property rights by giving each individual an accurate set of expectations upon the behavior of others (Commons, 1934 p.58; Hamilton, 1932 p.84; Schmoller, 1900 p.149 and Veblen, 1919 p.239). The more intricate are the interdependencies between individuals, the more precise need to be the institutionalized rules underlying the property rights to avoid unintended and thus to avert the unhandled consequences of individual's actions upon others, the so-called externalities. One of the main issues arising from the establishment of water markets is the question of these externalities that such transfer may cause (Challen, 2000; Garrick, 2015; Libecap, 2012; Livingston, 1998 and McCann and Garrick, 2014).

An adequate set of institutionalized rules need to be settled to foster and sustain a certain predictability of actions undertaken by water users (including the act of trading water). Yet, defining such institutionalized rules requires to gather a substantial amount of information upon the circuitous hydrological cycle and the multiple interconnections with the societal and the environmental systems. Due to its fluid characteristic, which induces the resource to be difficult to measure (Libecap, 2012 p.400) and the permanence of its molecule which induces it to be reusable (Griffin, Peck and Maestru, 2013 p.5), water resources cannot be easily divisible and thus cannot be partitioned into well-defined shares upon which individuals could have complete control. In light of such difficulties to decipher the complex nature of the hydrological cycles and the circuitous interactions with the societal and biological phenomena, the multiple interdependencies between individuals will likely not be adequately handled by the set of rules underlying the property rights (Garrick, 2015 p.43). In that respect, water markets will likely never be perfectly competitive, and despite their potential advantage over other types of institutions more centralized, these decentralized instruments cannot bring the full benefits that the traditional theory of trade have predicted (Garrick, 2015).

Thus, while, Hayek (1945) stated that the interest in a system of decentralized price mechanism with a minimum level of rules resides in "how little the individual participants need to know to be able to take the right action" (p.527), Ostrom (2005) has pointed out in the very first pages of her book that, "[t]he opportunities and constraints individuals face in any particular situation, the information they obtain, the benefits they obtain or are excluded from, and how they reason about the situation are all affected by the rules or absence of rules that structure the situation" (p.3). This implies that the market-based instruments are not the sole result of a spontaneous behaviors toward order, but are instead the outcome of a continual effort to design a set of rules to facilitate the decentralized exchanges of a complex resource (Challen, 2000; Garrick, 2015 and McCann and Garrick, 2014). Such efforts, otherwise termed transaction costs "include the costs of resources utilized for the creation, maintenance, use, change and so on of institutions and organizations" (Furubotn and Richter, 2000 p.48). In other words, it is the resources deployed or the necessary effort to fit the institutionalized rules to the interactional situation which they are supposed to regulate to handle the unintended interdependencies that arise from the interplay. It is well accepted that such transaction costs act as a major impediment in water markets, inducing in many of the arid regions that have implemented such decentralized management a deceptively low level of water trade (Carey and Sundin, 2001; Howitt, 2014; Sunding, Zilberman, Howitt, Dinar and Macdougall, 2002 and Young, 1986).

This thesis focuses on the iconic case of California to analyze the impact of transaction costs in water markets. Despite the very high difference of marginal value of water among users and an extensive support from the governmental agencies, water markets did not emerge as a major reallocation mechanism to cope with a growing imbalance between its increasing demand and its limited supply in this particular State (Howitt, 2014). As a result, water in California is being torn apart between one of the most productive agricultural sector of the world, several megalopolis accounting millions of inhabitants and an increasing recognition of environmental needs (Hanak, 2015 and Howitt, 2014). Consequences of such pressures are the inability to cope with extreme climatic events such as the recent drought that is considered to be the driest since weather condition is being recorded[1]. While cities have suffered from this recent drought with the mandatory cut-back of 25% of urban water consumption, the agricultural production and the environment have also been substantially hurt by such extreme events. Land fallowing due to the lack of water have been estimated to have cost $1.7 billion and 7,500 jobs in 2014 (Howitt, Medellin-Azuara and MacEwan, 2014), and it is no fewer than 18 species which are at risk of extinction if drought subsist[2].

While an extensive use of its water resources over the time has sustained the development path of this State to become one of the wealthiest regions in the world (Hundley, 2001), at the dawn of this new millennium and facing the growing challenges of climate change, California cannot anymore fulfill simultaneously all its water demands through large physical infrastructure as it has been doing in the past and has now to rely only upon the available water resources. It is thus during an acute drought in the 1990's that its policy makers attempted to adapt its water institutions by developing water markets. After a striking increase at its beginning, the level of water trades has stayed at a disappointingly low level, approximately 3 to 5 percent of the total water use (Hanak, 2015). Underlying reasons for such disregard by water users toward water markets are twofold and linked together. First the high risk of

[1] PPIC, California's Latest Drought

[2] Id.

technological externalities from trading water imposes to undertake substantial efforts by the right holders which deter many decisions to participate into the water markets. Indeed, the process of "balkanization" of the water management initiated more than a century ago made difficult the necessary connection to exchange information and as a result in the present time, lowers the predictability of all stakeholders of the water transfer. It increased the transaction costs of participation in water markets since a willing seller or buyer has to undergo a tedious and costly process of verifying that his action will not harm anyone else. While a minimum of rules is necessary, a simplification and a standardization of the procedure may help the voluntary transfer of water. The second reason has to do with the history of water institutions in California. Similarly to other States, California has supplied its increasing demand of water through the development of large physical infrastructure during the major part of the twentieth century. At that time agriculture accounted for the bulk of the water demand and represented an important share of the State's economy such that rural areas benefited largely from the supply-enhancement policy and have shaped the strategic opportunities of all water users into a complex web of formal and informal interdependencies driven principally by the beneficiaries of these engineering solutions (Freyfogle, 1989 p.1545). It resulted a path dependency where "water use patterns may become fixed in historical locations, principally for irrigation and often for crops and communities chosen for political and regional development purposes, not strictly for economic efficiency in welfare-maximizing terms" (Garrick, 2015 p.81). Such dependency does not solely influence the trend in water uses, but more broadly the whole water institutions underlying the wide variety of interactional situations among users. Indeed, the balkanization of water management in California has been combined with a decentralization and a dilution of power among a wide variety of local organizations and many of them have benefited from the initial allocation of water. The reallocation of water implied by the water markets to maximize the global welfare now implies important political tension since past beneficiaries would lose part or all of their advantages. Resistance to change has emerged, increasing the difficulties to align the institutions with new requirements and thus, increasing the cost of transacting water through markets.

The link between these two causes is the inadequacy of institutionalized rules that cause the property rights over water to be incomplete and importantly increase the transaction costs to handle the multiple interdependencies. Therefore, the point of departure of this thesis can be drawn from the conclusion of Coase (1960) in his seminal article: "let us study the world of positive transaction costs" (p.717).

In a first chapter, this world of positive transaction costs in water management is being viewed from an institutional perspective, and explanation is given for the existence of rules to avoid the detrimental externalities that may arise from water trade. More specifically, the blurry concept of externality is more clearly defined through the important notion of transaction costs that limit the possibility of handling all interdependencies.

In the second chapter, the concepts developed in the first one are applied in the case of water institutions in California and help in understanding the different frictions that occur in this State to promote the water markets as a major reallocation mechanism. The path dependency of water institutions is presented as an attempt to scale-up the management of water in general and its reallocation in particular, such that prior reforms to promote small scale institutions now are an important component of the transaction costs.

Finally, in the third chapter, the question of the measurement of these transaction costs is directly addressed through an empirical analysis of the water markets in California over a seventeen-year period. To this end, the gravity equation, well-celebrated in international trade theory to estimate the frictions between countries is adapted and used in the context of water markets. First, a theoretical model is developed distinguishing between variable and fixed costs of trade, which allows to disentangle between the decision to enter the water market (extensive margin) and the decision on the quantity of water to be transferred (intensive margin). Then, a test of the theoretical prediction is derived from the basic principles of the gravity equations and implemented. Transactions costs and conveyance costs are being approximated with multiple institutional variables and the distance between water rights holders. Results validate the theoretical predictions and show the importance of these two types of explanatory variables in the decision to trade.

Chapter 1: Water Institutions for a World of Positive Transaction Costs

Due to its fluid characteristic, as much as its pervasive use in society and nature, water is probably one of the most challenging resource to manage (Smith, 2008). Institutional infrastructures such as the property rights which provide the required behavioral reliability upon the use of water are as important as the physical infrastructures which provide the necessary reliability of water supply (Saleth and Dinar, 2004 p.9). Indeed, as pointed out by Ostrom and Ostrom (1972 p.1) "[t]he engineering problems associated with the design and operation of water works as physical facilities are always accompanied by problems in design and operation of organizational arrangements concerned with the conduct of people associated with the enterprise. Any system of water works must be accompanied by a system of human enterprise that involves the allocation, exercise and control of decision making capabilities in the development and use of water supplies." In other words, whatever will be the capabilities of a society in building physical infrastructures for water management, it will simply turn out to be empty cathedrals if the institutional infrastructure to manage the behaviors upon water resources is absent or ineffective (Easter, Rosegrant, and Dinar, 1999). The underlying reason for such complementarity may be understood with the well-known quotation of Hardin (1968 p.1224) "[f]reedom in a commons brings ruin to all". The absence of suitable institutions leads the individuals to misbehave in an illusion of freedom because of an inadequately ruled situation that does not account for all of the real effects that an action may have upon others, inducing what is commonly known as externalities (Griffin, 1991).

The problem lies in the inherent disability of individuals in easily deciphering intricate situations such as those occurring in water use. This is even more true with water markets in which private decisions of reallocating a substantial amount of water may lead to severe and unintended effects upon others due to the circuitous hydrological process which often requires more knowledge than what a sole individual can access (Libecap, 2012; Maestru, 2013 and Griffin, 2016). Because of the complexity and the versatility of the hydrological resources, any action may have unintended effects upon other users of the resource as well as on the originator of the action himself and giving the freedom of action to all individuals generally means to increase dramatically the risk of misbehaviors because of such unintended effects. Constraining the behaviors through the medium of institutionalized rules steers individual actions toward mutual benefits by providing a property right system and handling the external effects. Property rights are "the expectation a person has that his decision about the uses of certain resources will be effective" (Alchian and Allen, 1969 p.158). In an interactional situation, individuals may be required to undertake great efforts to decipher the multiple interdependences and to control the effects that their actions may have upon others, as well as the actions of others that may affect their own ability to act. The prescriptions issued by the establishment of property rights help individuals in finding their path of actions within an intricate societal or natural environment and the difficult task of gathering a large amount of information is no longer required (Heiner, 1983 p.580). The goal is to avoid the ruins to all by limiting the freedom of some individuals to better fit the reality of a situation and thus to avoid potential misbehaviors from misinformed individuals.

The underlying reason for the existence of property rights are thus the lack of information (Dahlman, 1979) and opportunistic behaviors that come along with such deficiency (Williamson, 1985). Indeed, as stated by Coase (1960), the problem of defining property rights is irrelevant in a world of perfect information because omniscient individuals would be always able to easily forecast the future natural conditions as well as accurately predict the behavior of others. Therefore, property rights that normally substitute the lack of knowledge or the disability to formulate accurate expectation upon the use of a resource by institutionalized rules will be useless (Cheung, 1992 p.54 and Allen, 2000 p.899). Yet, for normal individuals, their inherent ignorance upon many of the natural and societal phenomena gives rise to the so-called transaction costs defined as the resource losses incurred due to the imperfection or simply to the lack of information (Dahlman, 1979 p.148). Such transaction costs are pervasive in all interactional situations and increase with the complexity of these situations. Therefore, the need for property rights as well as their failures lies upon the ubiquitous existence of transaction costs which are restraining agent in undertaking action in complex situation.

Such transaction costs are even more prevailing within water management since this particular resource is characterized by its rivalry feature (or substractability) and its difficulty of exclusion which classified it as a Common Pool Resource (Libecap, 2012). Indeed, the rivalry feature implies that the use of the resource by one or more individuals may lead to external and unattended effects upon some others since the mining of the resource by the former is not anymore available for the use of the latter (see Ostrom 1990, 2005, 2010 and Griffin, 2016). While the easy exclusion would turn this resource into a classical private good where a market can be settled, and the rivalry issue resolved through price mechanism which would exclude individuals with a too low willingness to pay, such exclusion in water resources is not an easy task and often conflictual (Ostrom, 1990).

This excludability, defined as the ability "to determine who will have an access right, and how that right may be transferred" (Schlager and Ostrom, 1992 p.251), represents the core issue of water management (Smith, 2008). The societal and often non-marketable value attached to this resource (Bloomquist, 2012 and Hanneman 2006) as well as the intricate biological and hydrological mechanisms (Smith, 2008) induce the challenging task of deciphering the multiple interdependencies that link the water users. It thus very difficult to know who affects who and how much (Libecap, 2012). Consequently, water has been perceived as being different from other commodities, not only because of the technical difficulties in excluding some agents from extracting the resource, but mostly because of its indisputable aspect of being the most basic need for any life to subsist (Gardner and Simmons, 2012). Therefore, any attempt to exclude someone from using water may be perceived as unethical and may raise intense conflicts (Griffin, Peck and Mestru, 2013). Such conflicts greatly increase the transaction costs of establishing adequate institutions since it requires the deciphering of unknown effects from excluding someone from using water to cope with the rivalry feature of water.

Until the end of the twentieth century, emphasis has been placed upon the engineering part of the water management with innovative ways to enhance the supply, but leaving aside the required institutional flexibility with the establishment of heavily centralized and bureaucratic allocation mechanisms (Saleth and Dinar, 2004 p.9). In that way, careful avoidance of the potential issues and conflicts from reframing the institutions and defining adequate exclusion tools (at that time, often costlier than the development of physical infrastructures)[3] have been the strategy of policy makers for decades. However, the growing imbalance between demand and supply that led to the multiplication of water crises these past years induced policy makers to reconsider their strategies of water management through institutional changes (Saleth and Dinar, 2004). Key measure of these changes has been the development of water markets to provide sufficient flexibility in water allocation and to cope with increasing scarcity (Garrick, 2015 and Knutson, 2013). This implies that some form of exclusion mechanisms need to be settled to foster the decentralized exchanged of water inducing an important effort in changing the institutionalized rules (Challen, 2000; Garrick, 2015 and Libecap, 2011).

In the reminder of this chapter, we first introduce the concepts of institutions, transactions costs and externalities which are at the core concepts of property rights issues. In a second section, we then develop further the institutional aspects of the property rights through their underlying rules. The third section uses the concept defined in the two prior sections to explain the fundamental role of property rights in solving the issue of externalities and how such property rights may evolve within an

[3] see Libecap (2011) and Ostrom (2011) for a deeper analysis of water infrastructures and institutional change in the Western States of the United States.

institutional change. Finally, we depict the challenges that represent the adequate definition of property rights for water to foster the development of water markets.

1.1. Institutions, Transactions Costs and Externalities: The Highly-Intertwined Concepts

In an attempt to defend the predictability of the different behaviors which fashion the multiple economic activities, Heiner (1983) derives a paradoxical conclusion: "uncertainty is the basic source of predictable behavior" (p.585). This might be somewhat surprising because by definition, uncertainty is a situation of non-measurable risk which prevents any calculation of expectations upon the occurrence of some events due to the impossibility of attributing objective probabilities to these very same events (Knight, 1921 and Keynes, 1936, 1973)[4]. From this radical view of uncertainty, the condition of optimizing behavior, fundamental to the neoclassical paradigm, is flawed because of the inability to assign numerical attributes to the likelihood of events and thus the impossibility for the agents to locate an optimum or even to take a decision rationally grounded (Hodgson, 1997 p.671). As a result, it seems unlikely that the ignorance that flows from uncertainty allows to improve the predictability of the environment (Arrow, 1951 and Lucas, 1981). However, the key to the Heiner's paradox might be found in a much older and well-known paradox from Plato's account of Socrates that the true wisdom lies in acknowledging our lack of knowledge[5]. Indeed, accounting for our own ignorance allows to conscientiously bound a subset of all possible outcomes and then to define a subjective but workable set of probabilities in order to draw some opportunities of action (Knight, 1921; Keynes, 1936, Hayek, 1948; Hodgson, 1997; Shackle, 1972; Simon, 1957 and Veblen, 1919). While

[4] An important literature has been built on the right terminology and the distinction between uncertainty and risk (North, 2005). Interesting literature reviews and as much complete as possible on this topic are Manski (1996) and Davidson (1991). Discussion upon the Keynes' vision of the rise of conventions to cope with uncertainty can be found in Littleboy (1990 pp.28-34, 269-271) and Shackle (1972 pp.220-228).

[5] This so-called Socrates' paradox first attributed to the Greek philosopher by Cicero (Fine, 2008 fn.1 p.49) is often reframed as "I know that I know nothing" but this is most likely a misleading interpretation and should be understood as the acknowledgment of a lack of knowledge (Fine, 2008 p.85). While Heiner also provides argumentation for the establishment of rules in an unconscious way in nature (pp.574-575), the purpose of his reasoning goes beyond that to provide rational ground for the existence of man-made and consciously designed rules and institutions. In that way, the Socrates' paradox is a good analogy.

useful to decipher the complex environment, such approach has too often the drawback of "acting upon opinion rather than knowledge" (Knight, 1921 p.268).

Individuals, with their immanent limitations to collect and process the relevant information that they are constantly receiving, are doomed to rely solely on this bounded rationality to ascertain the underlying reasons of their decisions (Simon, 1957). On one hand, this obviously limits the possibility of action of individuals because some actions lying outside the boundary of the perceived opportunity set might be actually possible but on the other hand, it facilitates the prediction of other's behaviors through a shrinking of possibility of action and eases the calculation of expected outcomes (Heiner, 1983). The main problem is that the delineation of a subset of possible outcome from the entire possibility set is not always intuitive and never innate when it comes to complex processes such as some biological, physical or societal phenomena and therefore brings under scrutiny the very basic behavior of optimizing (Tintner, 1941). It is actually the result of an evolving process from imperfect individuals to decipher the real mechanisms of nature and to prescribe the acceptable set of possible actions when it has been proven to be superior to other kind of subsets (Alchian, 1950; Winter, 1964, 1971; Hirshleifer, 1977 and Nelson and Winter, 1974, 1982). Such process can only occur through the mental model of each individual which drives her interpretation and structures the information in order to derive a series of useful meanings from such information in the form of opportunities of action (Holland, Holyoak, Nisbett et al., 1986; Denzau and North, 2000; Frohlich and Oppenheimer, 2001; Schiemann, 2002 and Ostrom, 2005). A convergence of an originally heterogeneous set of interpretations from the widely diversified mental models of individuals gives rise to an agreement upon a specified subset of opportunities which is the result of an effort to define the subset of subjective but commonly accepted probabilities (Ostrom, 1986, 1997). Without any convergence of interpretation from these mental models, no one can draw sufficiently clear and objective predictions on the behaviors of others and therefore, it is unlikely that coordination among individuals can occur. However, if these multiple individuals can all agree on a set of subjective probabilities, predictability increases despite the spread of uncertainty because expectations upon behaviors of all other individuals converge toward a commonly accepted set of expectations and then coordination might be possible (Ostrom, 2005).

The key concept to provide such convergence of expectations and thus the predictability of behaviors is found in the institutional structure that prescribe the adequate behavior through the establishment of formal and informal rules (Simon, 1957; Heiner, 1983 p.561 and North, 1990 p.3-4). Such a system of rules can be defined as a set of constraints (and reciprocally opportunities) which are "the result of implicit or explicit efforts to achieve order and predictability among humans by creating classes of persons who are then required, permitted, or forbidden to take a class of action in relation to required, permitted, or forbidden outcomes" (Ostrom, 2005, p.18). Thus, there is an attempt to improve the reliability of individual's behaviors by reducing the flexibility of these very same individual's capabilities to act through the establishment of rules and the creation of a hierarchical structure (Schmid, 1972). The greater is the uncertainty, the more stringent the constraints are likely to be until the behaviors become sufficiently easy to predict to foster coordination. In that respect, institutions are reflected by its constituent bundle of rules, the latter being the foundation of the formers (Ostrom, 2005) and give a set of expectations over specific actions (Bromley, 1989 p.42). In other words, institutions are the humanly devised constraints that structure the multiple and diverse interactions within the political, social and economic sphere (North, 1990 p.3).

However, sur-imposing such constraints in the form of rules to the inherent biological and physical ones requires a certain amount of resources to assess the real mechanisms upon which the economic activities are based (Busemayer and Myung, 1992). Indeed, the simple fact that uncertainty is still existing implies a certain difficulty to increase the predictability of natural and societal events, otherwise such uncertainty would be immediately and naturally reduced to zero by a series of perfectly defined rules that would avoid any misbehaviors. Instead, human actions are crippled with inadequate endeavors as well as hesitations to act for fear of undertaking the wrong action. Such ubiquity of uncertainty is the result of an arbitrage in using the available resources either to reach the actual production possibility frontier or to expand it through the establishment of better rules (Griffin, 1991). In other words, the resources which were originally dedicated to increase the opportunity set of individuals through the improving reliability of predictions about specific events and demeanors, is also weighing upon the production possibility set for some activities which decreases the opportunities for some other individuals.

When such opportunity set concerns the structuration of an interaction between two or more individuals, the dedicated resources are otherwise termed *transaction costs*. These costs account for the definition, the measurement, the agreement and the enforcement of the relevant attributes of an exchange (Coase, 1960; Dahlman, 1979; Barzel, 1982; Williamson, 1985; Niehans, 1987 and Stavins, 1995). The neoclassical literature considers these costs as the resources that directly enter in the action of trading with others and should be analytically analogous of transportation costs (Demsetz, 1968 and Niehans, 1987). To the contrary, the property rights literature adopts a broader approach by considering these costs as the resources required to establish and maintain property rights (Cheung, 1969 and Alchian and Woodward, 1988). The principal difference between both approaches lies in the focus of analysis. The neoclassical literature is viewing transaction costs solely when costs are incurred through market interactions while the property rights literature considers any type of interactions as potentially source of transaction costs (Allen, 2000). But such an opposition gets hazy when it comes to analyze the creation of property rights for markets as in the multiple works of Demsetz (1964, 1967 and 1968) which is particularly relevant in the case of water markets creation and development (Libecap, 2012). This is because market itself is the product of rules to drive individual's behaviors toward an expected attitude during the exchange (Alchian, 1950, Bowles and Gentis, 1988 and Gode and Sunder, 1997). Indeed, market institutions in their pure forms are fully decentralized institutions which entirely rely upon the trust of "a charmingly Victorian but utopian world in which conflicts abound but a handshake is a handshake" (Bowles and Gentis, 1993 p.83). But whenever uncertainty and asymmetric information give the possibility of opportunistic behaviors (Williamson, 1985 and Stiglitz, 1987) or simply lead to innocently misbehave (Alchian, 1950), specific rules are needed to ascertain the "correct" behavior (Heiner, 1983). Therefore, there is no fundamental differences in the requirement of using part of the available resources to establish rules and ascertain the predictability of individual's behaviors, whether it is in actual markets through an adequate delineation of the exchange's attributes or in future markets through the adequate delineation of property rights. Firstly, both approaches give the opportunity to increase the efficiency of the situation through market interactions, contingent on the resources required to rule the behavior of others in such interactions (Barzel, 1977, 1982, 1985 and Williamson, 1975, 1985). Secondly, both approaches agree on the lack of information as the principal source of transaction costs which requires to dedicate part of the available resources to collect, apprehend and enforce the rules, either in prevention of trespassing a property right (Cheung, 1969 and Barzel, 1985) or in thwarting of opportunistic behaviors during an exchange (Niehans, 1987, Barzel, 1977 and Williamson, 1985). As pointed out by North, (1990), "[t]he costliness of information is the key to the costs of transacting, which consist of the costs of measuring the valuable attributes of what is being exchanged and the costs of protecting rights and policing and enforcing agreements. These measurement and enforcement costs are the sources of social, political, and economic institutions" (p.27).

In that respect, these transaction costs outline the limits of institutions through the impossibility to completely escape from the uncertainty and to draw perfect rules that will adequately handle any interactions. As a result, external effects, often termed *externalities* are emerging not solely as an unintended coordination but more as an inadequately ruled interaction (Dahlman, 1979 and Griffin, 1991). The problem associated with such externalities is that "[t]he larger they are in range and magnitude the smaller is the faith that can be reposed in the virtues of the market mechanism even when working under ideal circumstances" (Mishan, 1965 p.3). Indeed, and as mentioned above, due to the fact that the efficiency of market institutions is resting on the reliability of behavior from interacting individuals, the impossibility to adequately rule the aforementioned externalities leads to a certain defiance upon such decentralized organization of the economic activity. Then, a preference toward more centralized institutions with less autonomy for individuals might be developed in order to avoid potential inefficiencies from imperfect markets. Such inflexibility limits the occurrence of possible external damages from decentralized coordination of individuals but is nevertheless not free of external effects when centralized processes of decision restrict the opportunity set of these very same individuals through the required effort to establish rules (Coase, 1960 and Demsetz, 1964). Institutions, in their decentralized or centralized form of regulation have to be constantly adapted from the changing conditions. Whenever the underlying parameters of a specific institutional setup are changing, the associated rules have to evolve in order to adequately handle the new situation, at the risk of increasing the gap between the reality of the actual context and the bundle of rules designed for the past context. For Heiner (1983 p.580), the interactional evolution would stop there if no institutional changes are undertaken. But, from the theory of property rights developed by Demsetz (1967), the increasing obsolescence of the bundle of rules enlarges the gap between what is actually ruled and what should be ruled. At some point, the increasing costs of this gap turn to be larger than the transaction costs of changing the rules and foster the institutional change. Therefore, institutions taken as a unique concept are simultaneously the consequences and the causes of transaction costs (Griffin, 1991) and affect all types of interactions in the economic, societal and political spheres through the inevitable emergence of externalities (Coase, 1960 and Demsetz, 1967). Consequently, the main reason for such institutional change to occur is an externality that weigh upon the aggregate welfare so much that it becomes beneficial to bear the transaction costs of collecting and processing the relevant information and changing the rules toward a Pareto-improving restructuration of the interactions (North, 1990). The question then becomes to have the adequate rules within the right institution rather than simply having the right prices (Williamson, 1994 p.3).

These three concepts: transaction costs (as the efforts to rule the interactions), institutions (as a bundle of rules to regulate the interactions) and externalities (as the inadequately ruled interactions), are thus highly intertwined since one is the consequence of the others. Indeed, institutions, that limit the flexibility of individual behaviors are the attempts to handle the externalities which cannot or is not beneficial to be solved from fully autonomous agents because of the prevalence of transaction costs (Papandreou, 1994). Consequently, rules and the inevitable costs in establishing them are at the heart of the economic organization which opens as much as restricts the opportunities offered to economic agents (North, 1990). But despite the assertion of Zerbe (1976 p.32) that "[t]ransaction costs are an appropriate and useful phenomenological category [but] externalities are not", the externalities are actually particularly relevant as the observable consequences of such limits of behaviors' predictability inherent of human organizations. As pointed out by Papandreou (1994 p.181), "[u]ltimately, an understanding of the complex notion of externality will help to clarify some central methodological issues and notions of economic theory (optimality, market failure, etc.), and place at center stage institutions and behavioral choices for resource allocation." The persistence of detrimental externalities is the expression of institutional failure and ill-defined property rights due to the inherent transaction costs of running an economic system (Arrow, 1969). In that respect, the concept of externalities is not deprived of interest since it highlights the problems faced by an economic system in allocating scarce resources in a world of non-zero transaction costs.

It is thus particularly important to have an appropriate definition of externalities which appears to be quite elusive and controversial in the existing literature. From the institutional approach, which generally saw such concept as synonymous of interdependencies (Demsetz, 1964 and Griffin, 1991), to the general-equilibrium approach which took a narrower path by explaining their existence by the sole absence of markets (Arrow, 1971 and Heller and Starrett, 1976), both agreed upon the detrimental effect that externalities may have upon a productive system (Papandreou, 1994). More importantly, they both recognize the major impact that transaction costs have upon the unintended or inadequately handled interdependencies (Papandreou, 1994).

In what follows, we discuss more in depth the controversy over an adequate definition of the concept of externality and the importance of transaction costs which will help to explain the underlying reason of assuming externalities as an inadequately ruled situation. The underlying motivation of dedicating a whole section to this issue is that water markets are often crippled with such externalities due to the great difficulty of defining adequate property rights (Garrick, 2015; Griffin, 2016). In the following section, we link the existence of transaction costs with the problem associated with property rights through an adequate definition of externalities. This will allow to show later on in the text that, since water property rights arise from the establishment of rules to drive the interaction between individuals upon the use of water resources, the costs emerging from the establishment of such rules will likely cause such property right to be incomplete which will result to the sustenance of externalities in the use of water resources and more particularly in water markets (Blomquist, 2012 and Libecap, 2012). We begin by skimming the importance of rules in regulating the interactions in a situation of imperfect information and their relation to property rights. Then, we move on to explain how some inadequacies in ruling these interactions may lead to the so-called externalities.

1.2. The Bundle of Rules at the Core of Property Rights

Rules are usually viewed as the most salient and often one of the most important components of an institution (Commons, 1934; Grief, 2006; Hodgson, 1997, 2004;

Knight, 1992; North, 1990, 2005 and Ostrom, 1990, 2005). From their objective of assigning specific positions in which individuals are prescribed to undertake or to forgo specific actions, such rules structure the societal environment to "provide shared cognition, articulate expected behavior, frame the situation, and specify normatively appropriate actions" (Grief, 2006 p.383). In that respect, they represent the basic foundations for property rights since the latter provide the authority to undertake specific actions related to specific domains, while the formers refer to the prescriptions that create such authority (Schlager and Ostrom, 1992 p.250). Motivation to follow these rules, and more generally to organize an interactional situation can be found in the immanent difficulties of individuals to formulate accurate beliefs and to gather sufficient information upon the world that surrounds them (Simon, 1957 p.199).

1.2.1. Regulate Behaviors in an Interactional Situation

It is generally the case that individuals, being aware of their informational dearth when formulating their own beliefs, will seek the supplemental information into the expression of others' beliefs and aggregate these latter within a subjective weighting system, otherwise called mental model (Denzau and North, 2000 and Holland, Holyoak, Nisbett, et al. 1986). It then allows the individuals to draw a coherent picture and to decipher a specific pattern of the natural and societal phenomena to formulate accurate expectations and to derive adequate behaviors (Ostrom, 2005 p.106). This is an even more crucial aspect of the rules underlying an institution as they allow the convergence of beliefs and expectations from heterogeneous individuals. Indeed, in a state of nature, agents develop specific beliefs which are inherently subjective and motivate individuals to act in certain ways rather than other (Grief, 2006 p.36). Such systems of beliefs encompass the opinions and intuitions of individuals upon situations faced by them and from this personal perception of the reality, a pattern for the natural and societal phenomena can be roughly deciphered about the behavior that should be followed in future but presumably identical situations (Hodgson, 1998 p.185; Denzau and North, 1994 and Heiner, 1983). They are essential components of the institutions as they give the motivation to act but are nevertheless not what constitutes the rules of an institution because the underlying causes of such motivations are most likely unique to each individual due to the learning process from the sole singular experiences and is not always in harmony with others' system of beliefs (Schotter, 1981 p.52 and Young, 1998). Rules, to be named as such, should handle the behavior of more than one individual (Schlager and Ostrom, 1992 p.250). The potential gathering of individuals with differing beliefs and thus diverging ways of acting is likely leading to a chaotic confrontation of behaviors sometimes not compatible with each other. "When people don't know one another's tastes or opportunities, then experience, theory and experimental evidence all confirm that negotiations may be protracted, costly and unsuccessful" (Farrel, 1987 p.115). This is obviously not a concern if these individuals will actually never interact (like multiple human beings secluded in a series of close islands who never communicate, exchange or even acknowledge the existence of other individuals in other islands). Indeed, if individuals do not share any attribute or have conjoint expectations which would require an interaction, no convergences of their systems of beliefs are necessary. To the contrary, if some interdependencies between two or more individuals are presumed to exist, it calls for a structuration of the multiple beliefs toward a convergence of behaviors to facilitate the coordination and develop a common system of expectations. Such a convergence conveys a certain regularity of behaviors and therefore a better predictability of individual actions within the interactional situation. In return, increasing the predictability of the outcomes' situation facilitates the pursuit of the behavioral convergence through the reinforcing beliefs that others will have the expected behavior.

The purpose of such rules is thus to improve the coordination within a collectivity by providing a social structure to share and aggregate the multiple and often heterogeneous beliefs upon the biological, physical and mostly societal phenomena faced by the individuals of this collectivity (Commons, 1934 p.58; Hamilton, 1932 p.84; Schmoller, 1900 p.149 and Veblen, 1919 p.239). More specifically, the rules define specific positions of individuals in which they are permitted, required or forbidden to undertake certain actions and in that way, allow any participant of an interactional situation to formulate accurate expectations upon the behavior of others. Consequently, a bundle of rules can be viewed as institutions and may be termed as "institutionalized rules" only if they are used by individuals to formulate common expectations. This basic idea has been coined by Grief (2006) when he stated that "rules that prescribe behaviors, however, do not influence behaviors unless people are motivated to follow them. For rules to be part of an institution, individuals must be motivated to follow them" (p.31). He reasserted later on in the text that "institutionalized rules aggregate [the] information and knowledge and reflect the trade-off between the psychological and social benefits of following normatively sanctioned and socially appropriate behaviors and its materialized costs" (p.383). The benefit of following these institutionalized rules can be found in the success of the multiple interactions that a society supposes.

However, focusing on the interactional structures have more implications than just triggering the design of a structural convergence of beliefs but can be an integral part of the design itself. Indeed, a transaction might be defined as an "action taken when an entity, such as a commodity, social attribute or piece of information is transferred between individuals or other social units and has an external effect on the recipient" (Grief, 2006 p.383). The external effect of a transaction is simply the interdependency which is created in part by the institutionalized rules and in part from the natural system upon which are based most of the social activities. Individuals being able to assemble or dismantle some of the working rules that link them to others, this implies that private decisions and actions (individual beliefs and behaviors) are an integral part of the evolution of the social structure (institutional change) while being also subjected of some of the same working rules. In that respect, institutions constituted by their bundle of working rules are "subjective ideas in the heads of agents and objective structures faced by them… Actor and structure, although distinct, are thus connected in a circle of mutual interaction and interdependence" (Hodgson, 1998 p.181). For instance, Veblen (1899 p.190-191) considered that "[t]he situation of today shapes the institutions of tomorrow through a selective, coercive process, by acting upon men's habitual view of things, and so altering or fortifying a point of view or a mental attitude handed from the past." In other words, institutional rules might cause to change the beliefs of some individuals to transform something unusual to something habitual (Hodgson, 2000 p.325). While being obviously true and straightforward, the main issue with such a reasoning is that it contributed to further blur the distinction between the agent having the ability to interact with the structure and the structure itself influencing the agent in a seemingly exogenous fashion (Vanberg, 1989). Consequently, one can easily fall into an infinite regress similar to deciphering "which came first: the chicken [institutional rules] or the egg [individual's ideas]" (Hodgson, 1998 p.184). This issue of the institutional evolution and the correlative question of its origin have been acknowledged by a contemporary of the development of the Institutional Economics (IE) such as John R. Commons and Thorsten Veblen and have then been reasserted by the founders of the New Institutional Economics (NIE), such as Oliver E. Williamson and Douglas North (see Rutherford, 2001). However, where the IE does not specifically stand for a clear answer upon the origin of institutions, the NIE unambiguously adopts a methodological individualism approach where limited but rational individuals attempt to design a bundle of rules to cope with their ignorance (Hodgson, 1988). In that respect, the latter generally embraces an agency perspective (North, 1990 and Schotter, 1981) while the former has a structural approach of institutions (Hodgson, 1998 in the line of the sociologist perspective such as Durkheim, 1895 and main authors of the IE such as Veblen, 1899, 1919 and Hamilton, 1932). Despite being highly questionable to study the true origin of institutions or the primitive sparkles of the institutionalized rules, the NIE approach has the advantage of setting up a beginning of the social structures for analytical purposes. This beginning is developed by "given individuals" (Hodgson, 1998 p.181) who try to create devices to cope with their ignorance about the natural as much as their societal environment (Hayek, 1976 p.29).

In summary, the bundle of institutionalized rules that constitute an institution is different from the biological and physical constraints in being endogenous structures composed by a set of correlative legal relations among individuals in a society (Bromley, 1989; North, 1990 and Challen, 2000) purposely designed to cope with the difficulties of predicting the behavior of others in an interacting situation. When adequately settled, these institutionalized rules "can be understood as devices for reducing uncertainty, simplifying decision making, and promoting cooperation among human agents so that the costs of coordinating economic and other activities can be lowered" (Furubotn and Richter, 2005 p.7). They steer human actions in a particular direction by structuring the regular activities toward a reduction of uncertainty in human interactions (North, 1990 p.239). Yet, if such institutionalized rules do not come under scrutiny, the behaviors selected by the individuals may be optimized for the current set of institutional constraints but nothing guarantees that different type of rules inducing other behaviors cannot do better.

1.2.2. The Rules Behind the Property Rights

Broadly defined, the property rights are the set of rules that gives individual the rights and duties associated with the use of a scarce resource and are essentially a social construct (Alchian, 1965 p.817). Using the concept of rules rather than property rights helps to clarify this notion because the definition of property rights can be vague and sometimes misleading (Challen, 2000). The reference to scarce resources in the Alchian's definition of property rights is an important aspect due to the insufficient supplied quantity to meet the demand which imposes to create a sort of discrimination between individuals. This determines who can access to the resource and how much he can extract from the available stock (Challen, 2000).

Bromley (1991 p.2) defines property rights as "a claim to a benefit stream that the state will agree to protect through the assignment of duty to others who may covet, or somehow interfere with, the benefit stream". Thus, the support of some higher authority for specific rights give *de jure* rights of use recognized by the legislative authorities and thus enforced if these rights are challenged in court. To the contrary, *de facto* rights of use correspond to a system designed by the resource users themselves but is not recognized by any higher authorities (Schlager and Ostrom, 1992). This last distinction reveals a third aspect of property rights: the inalienable entitlement in which a party is not allowed to interfere with an action undertaken by another party if this later does not go beyond its property rule (Bromley, 1991 pp.42-45). While a *de jure* system is protected by a State legislation, a *de facto* system may not be inalienable as a third party can challenge it in court and therefore is less secure until it is recognized by legal authorities as a *de jure* right (Schlager and Ostrom, 1992 p.254). However, this is not to say that a *de facto* property rights are less suited to manage a common resource. Rules emerging from users in a bottom-up fashion can outperform the State's laws if the former are better fitted into the local context in which these *de facto* rules are applied (Ostrom, 2005).

Property rights can be decomposed into two fundamental rules: the *property rules* and the *liability rules* (Calabresi and Malamed, 1972). The property rules confer to an owner of a specific asset the absolute power (hierarchy) to exclude others while the liability rules deny such power an owner and calls for compensation whenever this owner wish to keep the asset for himself (Epstein, 1997). Although, the property rules value the asset before the interdependences to occur and thus are the foundation of any market-based allocation, the liability rules are ex-post instruments that necessitate a judicial system to settle the value and resolve conflicts (Griffin, 1991). More formally, if an individual i is part of a group of a size N agents which all share a resource R, a property rule can allow for the agent i to extract a maximum quantity $\bar{w}_i = R/N$ (we choose the simplest way to divide the resource among multiple users as an illustrative example). If he extracts a quantity superior to $\bar{w}_i$, he encroaches upon the property rule from one or more other agents, which implies a compensation in virtue of the liability rule. Thus, in a society of two or more individuals, both concepts are complementary and can be depicted as points that separate a finite segment of all possible choices given by the natural or technical constraints (R) into two or more finite and smaller segments (given by the divisibility rule R/N), each representing the property rule (extracting a maximum quantity of $\bar{w}_i$) for each individual in the society. This insure a certain security in which no one is allowed to interfere within the property rule of another and implicitly, the right from one party implies the duty for other parties to respect the right given to the first one (Common, 1924). Because liability rules are particularly subject to the holdout problem, the property rules are often the natural way to devise the property rights and liability rules are the exception when property rules work badly (Epstein, 1997). Since such property rules give control, they can be decomposed into multiple sub-categories for each use of a resource. Property rights and authorized relationship will be shaped from the strength of control induced by the property rules (Epstein, 2012).

There is as many authorized relationships as there exists particularities of the resource regarding the objective that such rules try to achieve. Such multiplicity gives to the property rights their metaphor of a "*bundle of sticks*" (Griffin, 2016 p.152). Adding, suppressing or modifying one stick from the bundle and the property rights regime can shift from a common to a private system and vice versa. Thus, there exists a continuum of possible combination of property and liability rules which will be shaped to meet the goal of these rules. The key point is that each property rights regime will be adapted from the physical and socio-economical context in which it has been created and will evolve within this context (Ostrom, 2005). Such multiplicity makes difficult the comparison between the continuum range of property rights regimes. Scott (1989) considers six type of specificities to compare the different form of property rights regimes. Within each of these feature, a system of property rules and liability rules are more or less well-defined and gives to the individuals the underlying reason of their behaviors. The definition of these six features are as follow (Scott, 1989 cited by Challen, 2000):

1. The divisibility determines the ability to subdivide or to parcel up the resource into multiple pieces. It broadly corresponds to the capability of differentiating multiple property rules as previously stated. Such divisibility relies on the ability to measure appropriately the resource. If not, the rights of use will overlap on each other because of a fuzzy delineation of property rules (Smith, 2008).

2. The exclusivity (or excludability) determines the ability for one party to exclude others from using the resource. The capability of exclusion is one of the characteristic that distinguishes the private good from a common good (Ostrom, 2005) and depends on the easiness of the resource divisibility. Indeed, when a resource is clearly parceled up between parties, the exclusion is facilitating because it can be clearly proved that one party is going beyond its right provided by the property rule. This allows to create groups of individuals in which intra-groups exchanges are much more intense than inter-groups exchanges. This later type of exchanges is worth ruling it when the interconnection between groups are high enough (Smith, 2008).

3. The transferability gives the right for a given party to use a specified amount of resource initially entitled to another party. In that case, the transfer can be very complex as it is not solely the resource which is transferred but the whole or part of the rights and duties associated to use of this transferred resource. It is therefore intimately linked to the divisibility feature as it needs to be parceled up and in some extent, it is also linked to the excludability if the decision to transfers comes from the individual, the community or a more centralized authority.

4. The quality of title defines how clearly the rules are stated and is again intimately linked to the divisibility and exclusion features of the property right regime. With a poor quality, the property right is likely incomplete and will suffer of externalities.

5. The duration is the period over which a right or a duty exists which does not imply the end of the rule attached to this right or duty. The rule can state that for a specific time, one or more agents are allowed or forbidden to undertake specific actions. This rule can be contingent to natural phenomenon such as forbidden groundwater pumping in case of drought but can also be uncorrelated with the context such as the authorization to lease a certain amount of water for one year. In this later case, the renter has a right to access the leased water for one year only.

6. The flexibility gives the set of possibilities allowed for a party or an individual to alter the use of the resource in another way than predicted by the property rule. In this respect the Common-law differ from the Roman-law system as the former brings restriction from the default condition (condition without humanly devised

property rights) while the later forbid almost all actions unless what is specifically permitted (Ostrom, 2005 pp.210-211).

These features are not independent from each other but are rather complementary. More specifically for the divisibility, exclusivity and transferability which are closely linked. Improving the divisibility means that property rules are better defined and it becomes clearer if another party can be excluded or not from the resource use. This facilitates the transferability as less parties can challenge the transfer. Reciprocally, an improvement of the divisibility (or property rules) can have the consequence of reducing or forbidding the transferability due to the recognition of large effects on other parties which would induce a compensation (liability rule) beyond the expected benefits of the transfer in question.

Schlager and Ostrom (1992 pp.250-251) draw another type of classification, close to the one presented by Scott (1989) but with the notion of rights rather than features of rights. The difference between these two classifications is that the former is more focused upon the legal relationship between extractors of the resource while the latter also encompasses the physical features and potential technical constraints from the resource. However, they both emphasize the importance of exclusion and transferability of entitled rights.

1. Rights of access and withdrawal: respectively the rights to enter into a specified area and the rights to capture income from it. It determines who can benefit from using a resource and who cannot. While both rights are often depicted separated, we can group them into a sole category as the rights to use the resource and are defined by institutionalized rules at the operational level (Shlagger and Ostrom, 1992 p.251). For such rights to be enforced, a certain excludability and to some extent a divisibility is required to avoid individuals who are not granted with such rights to bypass their duties upon those who have such rights. In that respect, rights of access and more specifically withdrawal are often contingent to the realization of some environmental or societal events which implies that an individual to get his rights must be in a certain position in a certain time (Bloomquist, 2012 p.371).

2. Rights of management: the right to take part into the regulation of the resource and therefore to be involved in the decision process of planning the resource use. Individuals being granted with such rights have the legal ability to determine the condition under which the rights of withdrawal may be granted such as the duration. Since shares of resource extraction must be calculated, a certain divisibility of the resource is often required or at least will help work of managing the resource.

3. Rights of exclusion: relatively close to the rights of management, the rights of exclusion give the legal ability to determine the condition under which the rights

of access may be granted. Such rights will provide the proxies that may be used to determine whether an individual can access or not the resource. Obviously, for these rights to be effective, a certain excludability is required.

4. Rights of alienation: dictate whether or not the two previous rights (rights of management and exclusion) may be transferred by the appropriators of such rights and thus define the transferability of the resource.

The position that an individual may hold regarding the resource will depends upon the number of rights he gets, which gives the extent of his control upon the use of this resource. Each type of position may trigger specific and predictable behaviors either by opening some opportunities or restricting some actions. The table 1.1 is depicting the relationships between these four types of rights and the position that an individual may hold.

Table 1.1: The rights giving specific positions

	Owner	Proprietor	Claimant	Authorized User
Access and Withdrawal	X	X	X	X
Management	X	X	X	
Exclusion	X	X		
Alienation	X			

An owner of a resource has in general a large amount of control upon this resource and thus, will have a large set of actions that he may use to take advantage of the resource. To the contrary, the authorized user has no rights at the collective choice level which implies that he cannot take part in the decision upon planning the management, exclusion and alienation of the resource, resulting in being permitted to access and withdrawal the resource with a high risk of being successfully challenged by individuals in other positions. In turn, this provides less risk for individuals in other positions to be dismissed of their rights by “squatters” (Schlagger and Ostrom, 1992 p.252).

Overall, the rules which lead to rights give a higher predictability of other’s actions and therefore diminish the uncertainty related to the other individuals which drives externality closer to their cancellation. The goal of property rules and liability rules are to facilitate the interactions and the exchange of information between individuals in a constant refinement of such rules (Challen 2000 p.29). Reciprocally, the lack of available information over a specific resource causes the property rights to be incomplete inducing miscommunication and misunderstanding (increasing the risk of externalities) and thus calls for a supplemental effort (a cost) to gather the missing information and reassess the ability (legal, financial or technical) to use this resource. In other words, the rules give a position for specific individual to act in accordance with a predetermined selection of a choice set. As pointed out by Bowles (2006 p.91), "[s]election processes implement a kind of hill climbing, but the hilltop need not bear any close relationship to normative criteria such as efficiency. There may be many hilltops, so a population may never explore much of the topography and may climb the wrong hill; the rate of ascent may be overwhelmed by shifts in the underlying topography so no hilltop is ever reached." This simple metaphor brings the core problem of externalities as a possible institutional configuration that could be changed so as to provide better outcomes.

1.3. The Property Rights to Cope with the Externalities

To understand how institutions in general and property rights in particular may help in limiting the externalities, it is important first to have a somewhat accurate definition of such a complex notion. However, defining precisely the concept of externality is a challenging task due to the variety of situations in which external effects are occurring. As pointed out by Baumol and Oates (1988 p.14), "[t]he externality is in some ways a straightforward concept: yet, in others, it is extraordinarily elusive. We know how to take it into account in our analysis, and we are aware of many of its applications, but, despite a number of illuminating attempts to define the notion, one is left with the feeling that we still have not captured all its ramifications." On the straightforward side, an externality can be defined as an unintended interdependency between two or more individuals. The problem does not lie upon the interdependency *per se* but from the lack of information to control such interdependency and the misallocation that most likely follows the absence of regulations (Baumol and Oates, 1988 p.17). This definition, relatively close to the one stated above is however not as simple as it would appear. To understand the hidden complexity behind this naïve statement, a review of the different notions successively encompassed by the concept of externality is necessary.

The definition of externality can follow two broad kinds of approaches, the general equilibrium and the institutional which encompass different normative analysis. In the former, the accent is put on the economic efficiency and how such external effects might affect the optimal output of a set of productive activities. To the contrary, the latter takes insight from the Coase theorem which highlighted the impact of transaction costs on coordination to derive a more institutionally based definition of externality. However, in both approaches, an externality is generally defined as a deviation from a perfect situation (Papandreou, 1994). In the general equilibrium approach, this perfect situation is the Pareto efficient equilibrium (Bator, 1958 and Arrow, 1971) while in the institutional approach, such perfect situation is given by unanimous decision (Buchanan and Tullowk, 1962). The institutional approach identifies an externality in a broader sense than the general equilibrium approaches and does not draw a distinction between technological and pecuniary externalities. Emphasis is put on the rights to impose a specific cost onto others and, while the institutional approach directly tackles this issue by assuming endogenous rules, the general equilibrium approach deals with it more implicitly and considers institutions as given. More importantly with regard to water resources and our work here, the institutional approach is looking at the creation of markets through the development of adequate rules. Our analysis will thus naturally tend toward the institutional interpretation of externalities in order to study the creation of water markets. In what follows, we explain our choice through the review of the different definitions proposed to describe the concept of externality to end up with definition that will fit more accurately the problem of water markets.

1.3.1. The Controversy over Externalities

The very basic concept of externalities has been laid down by Marshal (1890) through its idea of “external economies” in which some gains internal to the industry but external to the firms are existing and might be source of inefficiencies. Indeed, the downward-slopping supply curve would exhibit an equilibrium output inferior to the optimal one. While his goal was to reconcile the idealistic competitive structure with the reality of increasing returns, he also opened the path to study more in depth the kind of interactions that seem to invalidate the invisible hand principle coined by Adam Smith almost three centuries ago (Papandreou, 1994).

In his well-known book, *The Economics of Welfare*, Pigou ([1920]1932) refined the concept of external economies previously developed by Marshall. More specifically, he provided a first definition of such effects in the form of an incidental interaction (without regard from the originator) for which payment or compensation cannot be exacted or enforced (Pigou, [1920]1932 p.183). In other words, a divergence between the social marginal product and the private marginal product is occurring and needs to be corrected in order to come back to an optimal level of production or consumption. In this definition, no references to potential market for handling such external effects are transpiring because the solution he advocated is essentially a centrally based one through State involvement. The incidental interaction implies a social cost higher than the private one because the solution to internalize the external effect is out of reach from individuals and therefore necessitates the intervention of the government: “It is plain that divergences between private and social net product ... cannot … be mitigated by a modification of the contractual relation between any two contracting parties, because the divergence arises out of a service or disservice rendered to persons other than the contracting parties. It is, however, possible for the State, if it so chooses, to remove the divergence in any field by 'extraordinary encouragements' or 'extraordinary restraints' upon investments in that field. The most obvious forms which these encouragements and restraints may assume are, of course, those of bounties and taxes" (Pigou, [1920]1932 p.192). The goal of a tax-subsidy system is to force the accounting of the externality by individuals and to decrease or increase the output of the competitive equilibrium toward a Pareto-optimal situation (Mishan, 1971 p.7). A State, through its coercive power and larger financial resource than individuals can thus distort the existing distorted equilibrium through taxes-subsidies instruments to get back to a Pareto optimal equilibrium. In that sense and around forty years prior the seminal articles of Gordon (1954) and Hardin (1968), Pigou ([1920]1932) provided basic ideas of the tragedy of the commons that watch out in any open access resource situation through its famous examples of the congested roads. In this example, each owner of a vehicle driving on a road does not account for the cost imposed to other users of this road which is basically similar to the extractor of a resource not recognizing the costs he might impose on others by subtracting part of the resource from the common pool. The same solution of a governmental intervention has been envisioned by these three prominent authors as the only way. In that way, assumption is implicitly made that decentralized organization such as markets yield sub-optimal solution in comparison to what government can achieve and therefore that a centralized authority can do better (Dahlman, 1979 p.155).

Multiple criticisms have arisen from the Pigou's analysis of externality. One of the first has been Clapham (1922) who saw the concept itself as an "empty box" and questions the real existence of externalities. However, such external effects have become more present and visible in the next decades mostly through the increasing concern over the environment during the 1960's (Mishan, 1971). Another important criticism has been stated by Knight (1924) on the example of the congested road and more generally on the problem that free resources can cause an excessive investment by industries exhibiting upward sloping supply curves (Mishan, 1965). He demonstrated that, if the "free" resource were put under private ownership, the appropriation of a rent by the owner would serve the social welfare toward the optimal equilibrium which involve the governmental intervention to be useless. But as pointed out by Mishan (1971), the interpretation of Pigou or Knight are simply two different perspective of the same problem. In the former, emphasis is put on the variable factor (the trucks on the road) while the latter focuses on the fixed factor (the road itself). In that respect, an important insight from Knight (1924) and developed later by Demsetz (1967) is that the delineation of adequate property rights might resolve inefficiencies from such external effects[6]. The work of Viner (1931) clarifies further the basic idea of what should be considered as a problematic externality through the distinction between the *pecuniary* externalities and the *technological* externalities.

The former is often considered as a "pseudo-externality" in which the effect is a transfer of resource through market that might harm some user in the advantage of others but without decreasing the aggregate welfare (Baumol and Oates, 1988 p.29). Thus, it is more a question of redistribution and fairness than a misallocation of resource and is perfectly in harmony with the perfectly competitive model. To the contrary, a technological externality affects the ability to allocate efficiently the resource and is generally what is implied with the sole term externality. For example, in the case of a water transfer between two agents, a pecuniary externality takes the form of a negative effect upon the economy of the region of origin through the diminution of production from the water seller (and thus a decrease of input's demand to local businesses). But this effect is circumscribed to only some businesses and is compensated by an increase of welfare for the water buyer and the supplement of earning for the water seller (Hanak, 2003). The sole issue in that case is the fairness of the exchange which is evidently important but is considered to lie beyond the concept of externality because such effects are not uncontrolled. Real examples of such types of externalities and problem associated with fairness are legion in water markets (Hanemann, 2006). However, the most striking one in the history of California is the tedious Los Angeles-Owens Valley water transfers during the 1920's that sticks into

[6] Other kind of critics appeared later on. One in particular pointed out that the problem with tax-subsidy incentive is that it can be counterproductive if not well designed. Turvey (1963) following the work of Buchanan and Stubblebine, 1962) stated that the existence of a tax distorts the final outcome toward an inefficient equilibrium when negotiation or market between the affected parties is possible. The somewhat exhaustive survey provided by Bowles and Polania-Reyes (2012) pointed out that such explicit incentives can be either complement or substitute to the social preferences depending on how the agents subject to this instrument perceive it. In other words, a tax or subsidy might have the desired effect or the opposite contingent of the meaning attached to it by the targeted individuals "and this depends on the social relationship among actors, the information the incentive provides, and the preexisting normative frameworks of the actors" (Bowles and Polania-Reyes, 2012 p.418). Thus, the instrument itself is not the most important but more the information on the situation which is conveyed by the incentive (Tversky and Kahneman, 1981). Furthermore, the important task of collecting the information which is required to setup an optimal tax level at any time is challenging for the State as much as for the individuals. Despite this new solution proposed by Knight, the concept of externality itself is still hazy and quite difficult to apprehend its substantiality.

the mind of all Californian water policy makers even eighty years later (Hanak, 2003 and Libecap, 2008). This sale of water by the farmers in the Owens Valley to the city of Los Angeles not only has caused important environmental damaged in the valley (technological externality) but also has been considered as an unfair exchange (pecuniary externality) (Hundley, 2011). To the contrary, the technological externality occurs when the negative effect of such water transfer affects directly or indirectly third agents through the decrease of return flows, environmental degradations due to the reduction of water use in the area of origin or land subsidence due to an over-pumping of the groundwater resources (Griffin, 2016).

While the distinction between technological and pecuniary externalities is important, this sole characterization does not allow to grasp all the concreteness of this fundamental concept in economics and more particularly in water resources management. Indeed, considering the pecuniary externalities as a non-detrimental effect, implicitly assumes that any forces acting through markets should be regarded as efficient and not as an externality. This specific view has been developed more in depth during the 1950's and 1960's within the general equilibrium framework (Papandreou, 1994). In that respect, the definition provided by Pigou ([1920]1932) was not clear enough on what could represent an externality The parallel development of a general equilibrium approach to define an externality allows to bring new insights in how decentralized mechanisms can be elaborated to handle an external effect.

1.3.2. The General Equilibrium Approach of Externalities

Some prominent authors such as Bator (1958), Arrow (1971), Heller and Starrett (1976), and others argued that the consequences of a technological externality are unintended because there are not handled by any markets. From this conclusion, they tried to clarify the concept of externality within a general-equilibrium approach toward a sharpen but controversial definition of such effects through the formalization of the Arrow-Debreu general equilibrium framework. The basic insight from this approach is the necessity to handle the external effect through markets if such mechanism can effectively be efficient. This is in clear contrast with the primary approach through the work of Pigou ([1920]1932) which saw the intervention of the State as a necessity to handle an externality.

The general-equilibrium approach, developed successively by Meade (1952), Scitovsky (1954), Bator (1958), Arrow (1971) or Heller and Starrett (1976) defines an externality as the absence of market for a specific interaction between two or more individuals. Because no such regulatory mechanism exists for these interactions, no control through the medium of prices can be exerted upon the emitter or the receptor of the effect and inequalities of marginal utilities that characterize misallocations arise (Bator, 1958; Buchanan and Stubblebine, 1962; Arrow, 1971 and Heller and Starrett, 1976). The externality can thus be considered as a commodity (Arrow, 1971 p.14) which can be good (positive effect) or bad (negative effect) without market to regulate the supply and demand. : In that respect, the existence and the persistence of externalities within the economic activity are "central to the neoclassical critic of market organization" (Buchanan and Stubblebine, 1962 p.371) and the insights from standards theorems of perfectly competitive markets are inapplicable in these situations (Myles, 1995 p.312).

Such a simple definition has been the result of a sequential contribution by several authors who attempted to grasp the extensive meaning that can have an externality. A first notable effort to define externalities toward this general equilibrium approach has been done by Meade (1952) with the broad idea of "unpaid factor" between a bee-keeper and an apple-grower (pp.56-61). This bucolic example, as averred by Scitovsky (1954 p.145) settled some basic formalization for expressing an externality. Considering two producers 1 and 2, the output x_1 of the first producer is $x_1 = F_1(y_1, x_2)$ and the output x_2 for the second producer is $x_2 = F_2(y_2, x_1)$, where y_1 and y_2 are inputs specific to each producer Meade (1952 p.67). Therefore, an externality is a direct interaction (without going through price mechanism which automatically discards the pecuniary externality) between two producers. Nonetheless, his work has been typically in the Marshallian conception of external economies and diseconomies within specific industries. Scitovsky (1954) embedded the Meade's definition into a larger approach of the concept of externality which encompasses four categories of interdependences: consumers affected by other consumers, consumers affected by producers, producers affected by some agents (such as consumers) and finally producers affected by other producers. The external economies and diseconomies developed by Marshal and Meade fall into the fourth category. Then, Bator (1958) considerably widened the concept by seeing any market failures as an externality. More precisely, he gave a typology of externality into three different categories as the causes of market failure. The first is the "lumpiness" in input, output or process that makes the set of feasible production non-convex. The second category concerns the public good for which no optimal prices can be exacted. Finally, the last category is the ownership externalities in which institutions cannot settle adequately a set of property rights and thus "[t]here will be failure by 'enforcement'" (Bator, 1958 p.364). Despite this latter being relatively close the institutional approach with the concept of *non-appropriability*[7] instituted previously by Ellis and Fellner (1943), Bator considered this one to be quite irrelevant in comparison to the two other categories. He also explicitly

[7] Non-appropriability is defined as the "divorce of scarcity from effective ownership" in which it is difficult to exclude someone from the resource. In that respect, public good externalities and ownership externalities are overlapping (Papandreou, 1994).

developed the idea that markets are not always the panacea to handle interactions: "market efficiency is neither sufficient nor necessary for market institutions to be the 'preferred' mode of social organization. Quite apart from institutional considerations, Pareto efficiency as such may not be necessary for bliss" (p.378). This broad approach was meant to fit any kind of observed deviations from the perfectly competitive equilibrium and to give a more general framework to study such problems (Papandreou, 1994).

Despite this first step into the institutional approach, Arrow (1971) and the subsequent work of Heller and Starrett (1976) tightened the concept of externality by considering it as a subset of market failures (Papandreou, 1994). The point came from the two basic assumptions of the general equilibrium theory. The first is the convexity of individual's utility map and the possibility set of firm's production that guarantees the existence of a competitive equilibrium. The second important hypothesis is the universality of markets which insure the Pareto efficiency of the equilibrium. While Bator (1958) seemed to consider the violation of either of the two assumptions as externalities, the works of Arrow (1971), Heller and Starrett (1976) and Baumol and Oates (1988) took a narrower approach by viewing externality only as a violation of the second assumption. Arrow (1971) stated that "by suitable and indeed not unnatural reinterpretation of the commodity space, externalities can be regarded as ordinary commodities, and all the formal theory of competitive equilibrium is valid, including its optimality" (p.14). For him, a market failure is equivalent to market absence and externalities should only be considered as a subset of such market failures: 'The problem of externalities is thus a special case of a more general phenomenon, the failure of market to exist. Not all examples of market failure can fruitfully be described as externality" (p.16). In that respect, the analysis provided by Arrow (1971) restricts the concept of externality in comparison to the analysis of Bator (1958). While this latter equated market inexistence with externalities, the former saw such externalities as a smaller part of market inexistence. This is more than a semantic difference because the Arrovian approach excludes the cases where convexity of the possibility production set is not meet, contrary to Bator who considered such failures as externalities (Papandreou, 1994).

While such a simple definition of externalities allows to coin the problem of unintended interdependencies (absence of regulation) that links two or more individuals, it gives only a very broad idea of the concept but not its substantiality. The theory of general equilibrium considers the number of markets as given (Laffont, 1988) and agents as "market taker" (Makowski and Ostroy, 2001 p.490). From an Arrovian perspective, it is implicitly assumed that the sole response to reach a Pareto-optimum should be the creation of a market if it is efficient to create one. But if a market does not exist in the first place, it is probably because its creation would be sub-optimal given the costs (or transaction costs) associated with the initiation of an adequate price mechanism or the impossibility to derive equilibrium prices if such markets existed. This is basically the thesis implicitly advocated by Heller and Starrett (1976) when they defined an externality as "a situation in which the private economy lacks sufficient incentives to create a potential market in some good and the nonexistence of this market results in losses in Pareto efficiency" (p.10). The real problem lies in the non-convexity of costs to setup a market and not solely the non-convexity of costs within a market transaction (Papandreou, 1994). From this assertion, they conclude that whenever a market is naturally evolving, the marketed interaction should be efficiently handled. Otherwise, this market would not exist. Thus, the existence of a market can be view as a test of efficiency. However, for cases where markets are absent, different type of institutions should be compared in order to find the one with the minimum set-up cost. In that respect, Heller and Starrett (1976) joined up with Bator (1958) when considering the problem establishing the right institutions. However, they also differ with him in viewing a market as an efficient institution.

The first important point from the multiple and diverse definitions given successively by Bator (1958), Arrow (1971) and Heller and Starrett (1976) is that they all have in common to implicitly and at different degree, implement the institutions within the concept of externality as an alternative for markets non-existence. However, a strong separation between market and other types of institution (which can be centralized or decentralized actions) is advocated. In other word, every interaction under market institution cannot be considered as externalities and are thus efficient while other types of interactions might be considered as externalities if a market could more efficiently handle the interaction and the costs of establishing a decentralized price mechanism is too important (Papandreou, 1994). The second point related to the first one and more pronounced in the work of Arrow (1971) and Heller and Starrett (1976) is to stress the prevalence of transaction costs to create a market. These types of costs became the key to understand externalities in the 1960's with the fundamental work of Coase (1960).

1.3.3. The Insights of Transaction Costs to Understand Externalities

The concept of transaction costs as coined by Coase (1960) has been a big step to handle more effectively the concept of externalities. It provides basic reasons for such external effects to persist as interactions too costly or reciprocally too futile to account in a market transaction. It also opens the path toward a redefinition of the concept of externality through the institutional approach that takes a broader approach of the concept of externality than the General-Equilibrium approach.

1.3.3.1. An Attempt in Defining Transaction Costs

For Eggertson (1990 p.14), "[a] clear cut definition of transaction costs does not exist, but neither are the costs of production in the neoclassical model well defined." Like the controversy over the definition of externalities, the concept of transaction costs suffers as well from a lack of clear meaning in the literature (Allen, 2000). From the proto-definition given by Coase (1937) as the "cost of using price mechanism" to the very broadly one provided by Arrow (1969) as the "costs of running an economic system", transaction costs have first been viewed through the lens of the neoclassical literature as costs of transferring assets within markets. Yet, the rise of a property rights literature within the institutional movement have led to redefine the concept of transaction costs toward a broader understanding of transaction (Allen, 2000).

While Williamson (1985) defines transaction in a somewhat narrow sense as occurring "when a good or service is transferred across a technologically separable interface" (p.1), Grief (2006) provides a broader definition of transaction "as an action taken when an entity, such as a commodity, social attitude or piece of information is transferred between individuals or other social units and has an external effect on the recipient" (p.383). The main difference lies in the fact that the former implicitly considers solely the transaction of physical resources between individuals or entities, while the latter explicitly embeds any kind of interplays which can be upon physical resources or rights to use these resources (Furubotn and Richter, 2000 p.48)[8]. The important recognition from this last approach is to consider the transaction of the rights to perform certain actions upon a resource to be the focus of analysis rather than the sole transaction of the resource itself (Coase, 1992 p.717). Indeed, from the search of potential partner, the bargaining over prices and quantities, the enforcement of reached agreements and the control of potential third parties interferences due to side effects, the transferability of a resource can be understood as a series of actions in which adequate behavior must be adopted (Bowles, 2006 p.266). This last approach is more in line with the one of Commons (1934) who considered transactions as "the alienation and acquisition between individuals of the rights of future ownership of physical things" (p.58). Consequently, the transaction can be seen as a set of rules which produce some expected behaviors, and transaction costs is the costs associated with the establishment and the maintenance of such rules (Allen, 2000). Thus, transaction costs can be more formally defined as the resource used to obtain information, obtain a bargains' position and bargain to arrive at a collective decision

[8] It is important to note that the work of Williamson enlarges the definition of transaction provided in the first page of its well-known book and quoted here, toward a broader definition similar to the one depicted here. However, his quote is interesting because it induces an apparent bias toward considering only the transaction as the exchange of physical resources (Furubotn and Richter, 2000 pp.49-50).

and enforce this decision (Coase, 1960 p.15; Randall, 1972 p.176; and Allen, 2000). In other words, it corresponds to the effort produced in the elaboration of institutionalized rules to improve the reliability of behaviors within an interactional situation and adds up to the neoclassical production and transport costs (Furubotn and Richter, 2000 p.49).

It is generally accepted that ignorance and the lack of information are the main sources of transaction costs. Indeed, Dahlman (1979 p.148) provided a simple taxonomy to describe the transaction costs: *(i)* the search for relevant information costs, *(ii)* bargaining and decision costs, and *(ii)* the policing and enforcement costs. But he seemed to dismissed this classification in the next sentences as he stated that "[y]et this functional taxonomy of different transaction costs is unnecessarily elaborate: fundamentally, the three classes reduce to a single one – for they all have in common that they represent resource losses due to lack of information" (p.148). Thus, information has been considered at the heart of the concept of transaction costs and the ubiquity of ignorance is shared as the necessary condition for friction in transactions in the neoclassical literature as well as in the property rights literature (Allen, 2000 p.906).

But, notwithstanding it being a necessary condition for transaction costs to exist, the lack of information is not sufficient for its persistence and, despite of the Dahlman's assertion, opportunism and greedy behaviors is what makes ignorance so detrimental (Williamson, 1981, 1985). Indeed, it is straightforward to understand that a lack of information with fully trustworthy individuals would not cause specific problems because promises can be easily extracted from agents that they will respect their own words and change their behavior and wishes with respect to those of others (Williamson, 1981 p.554). In other words, such utopian world can be described by the Walras' paradigm in which a set of quasi-mechanical interplays may occur between self-interested but honest individuals who consider that "a handshake is a handshake" (Bowles and Gentis, 1993 p.83). Instead, the world is rather paved with individuals ready to undertake a "full set of ex ante and ex post efforts to lie, cheat, steal, mislead, disguise, obfuscate, feign, distort and confuse" (Williamson, 1985 p.51). To protect themselves from such detrimental behaviors, interacting individuals are also ready to undertake some efforts to provide specific arrangement that will limit the possibility of opportunistic behaviors from others and insure the respect of ex ante agreements. Such arrangements induce the policing and enforcement costs depicted by the Dahlman's taxonomy of transaction costs. In that respect, Papandreou (1994 p.145) critiqued the position of Dahlman (1979) for ignoring the possibility of opportunistic behavior as a cause of transaction costs while considering it as one of the three components of such costs. It is yet clear that Dahlman (1979) had understood the problem of opportunistic behaviors but framed it as a correlative problem of ignorance rather than an independent aspect of a relationship. Indeed, he stated that "policing and enforcement costs are incurred because there is lack of knowledge as to whether one (or both) of the parties involved in the agreement will violate his part of the bargain" (p.148). He then justifies his assertion that only information matters: "if there were adequate foreknowledge on his part, these costs could be avoided by contractual stipulations or by declining to trade with agents who would be known to avoid fulfilling their obligations" (p.148). This last assertion broadly corresponds to the Coase theorem developed two decades earlier by Coase (1960) in which decentralized contractual arrangement can always solve a problem of exchange if transaction costs are zero, or otherwise termed, there will be always the possibility for an agreement satisfying both parties if it can be asserted ex ante that such agreement will bring some gain ex post.

It is however important to note that, if both parties are devoured by greed (opportunistic behavior) and are perfectly aware of such behavioral trait in other's attitude (perfect information), they will probably not engage in any arrangements (even beneficial for both) if they believe that such interaction will turn out to be a chicken game for appropriating the maximum rent possible in which both parties hold out the agreement to finally end up in a failure (Akerlof, 1984 and Cooter, 1982). In that case, the sole existence of opportunistic behavior can ruin the potential coordination between two individuals but cannot be specifically treated as transaction costs. However, to avoid such situation to ever happen, rules of behavior can be enacted in a more general arrangement either by the parties themselves or by a third party. This is what Cooter (1982) have termed as the "Hobbesian Theorem" which "is illuminating because it suggests that legal rights should be structured to eliminate the most destructive noncooperative outcomes" (Cooter, 1982 p.28). This is particularly true in water markets which are crippled with such rules to avoid the worst scenario that can arise from the trade of natural resources (Bretsen and Hill, 2009). More specifically, a good example of the Hobbesian Theorem as developed by Cooter (1982) can be found in the tedious water transfer between the city of San Diego and the water rights holders in the Imperial Valley in Southern California. The process took eight years (1995-2003) of acrimonious negotiation to finally end up with the direct involvement of federal government through the Secretary of the Interior to "force the agreement" (Bretsen and Hill, 2009 p.758). In that specific case and more generally for almost any types of water transfers, a series of rules need to be drawn from parties involved in the exchange but also from government and other legal authorities to provide adequate conditions for such exchange to occur (Colby, 1990, 1995 and Easter, Dinar and Rosegrant, 1998). All these rules to protect certain rights makes spot water markets less available in comparison to other forms of regulation (Garrick, 2015, Libecap, 2012). However, while the depiction of Cooter (1982) may induce the feeling that such opportunistic behaviors are pure dishonest attitudes, Williamson (1985 p.47) asserts that such non-cooperative behaviors may originate from an honest disagreement as well. In the context of water markets, the hydrological resource has a wide variety of values from the different use and fulfilled needs with some of them being non-pecuniary (Blomquist, 2012 and Hanemann, 2006). From the controversial task of calculating a monetary valuation of such heterogenous benefits, conflicts emerge not solely because of greedy demeanors but also because of misunderstanding upon the real value of the resource (Dellapena, 2013). In such cases, the sole component of transaction costs is the effort to evaluate the resource to disentangle the "dishonest" from the "honest" unwillingness to participate in the transaction due to ignorance of an intricate situation. Such effort will produce rules made for "a world in which there are some sociopaths and some saints, but mostly regular folks who are capable of both kind of behavior" (Camerer, 2003 p.117). In other words, ignorance is a necessary but non-sufficient condition for transaction costs to occur (Papandreou, 1994).

In summary, transaction costs may be viewed as including "the costs of resources utilized for the creation, maintenance, use, change and so on of institutions and organizations" (Furubotn and Richter, 2000 p.48). It is the costs to produce, maintain, use or change a certain stability of the interactional situations in which individuals are involved through the creation, the maintenance, the use or the change of institutionalized rules. Thus, transaction costs are not solely the effort of making rules to cope with uncertainty and lack of information, it is also the effort to understand and respect the existing rules developed by other level of authorities. In most of the cases, such rules are established to increase the predictability of behavior either because of the lack of knowledge or because of the risk of misbehaviors from individuals (using or not the lack of knowledge) and are defined by contractual arrangement (Williamson, 1985).

1.3.3.2. The Coase Theorem and Transaction Costs

In his seminal article, entitled "The Problem of social cost" R. Coase (1960) acknowledged the specific issue of externalities[9] related to transaction costs in a well-studied demonstration subsequently named, the Coase theorem (Stigler, 1966 p.113). The theorem can be stated as follows[10]: "[I]n a regime of zero transaction costs, […] negotiating between the parties would lead to those arrangements being made which

[9] While Coase (1960) never used the term "externality" in his famous article, he studied de facto the externalities as in the very first sentence he stated that "[t]his paper is concerned with those actions of business firms which have harmful effects on others" (p.1). To the best of our knowledge, Coase did not define explicitly the concept of externality but gives some evidence on what is an externality in the form of one agent harming another agent.

[10] Nowhere in the original article of Coase is explicitly stated such theorem but is more a diffuse idea. This is the reason why we refer to later work from this authors for bringing the theorem and also the reason why "theorem" does not have an upper case T (Bowles, 2006 p.207).

would maximize wealth, and this irrespective of the initial assignment of property rights" (Coase, 1992 p.717). Put differently, if there are no transaction costs, a decentralized bargaining process can replace a market toward Pareto-improving allocation of resources. Therefore, a market is not anymore a necessary condition to get to an efficient equilibrium and negotiation between parties might perform as well when transaction costs are zero. At the first glance, the Coase theorem seems deceptively similar to the Fundamental Theorems of Welfare Economics in which decentralized coordination would lead to Pareto efficient equilibrium through perfect markets (the condition of universality of markets) (Arrow, 1971 pp.3-4). The apparent tautology of the Coase theorem (i.e. in perfect conditions, allocation will be perfect) has caused important criticisms regarding its relevance (see Sutton, 1986 and Feller, 1987). But the real insight from this theorem is the concept of transaction costs that flows from it and not its potential validity under idealistic conditions (Calabresi, 1968 p.68; Dahlman, 1979 p.142; Medema and Zerbe, 2000 p.874 and Bowles, 2006 p.229). As Epstein (1987) has pointed out "It is an open question, however, whether one can even understand what a world of zero transaction costs means, given the violence it does to our ordinary understanding of the importance of time" (p.2092). Farrell (1987) critiqued also the perspective that a strong form of the Coase theorem in which "the claim that voluntary negotiation will lead to fully efficient outcomes is implausible unless people know one another exceptionally well" (p.115). Obviously, when Coase (1960) stated "All solutions have costs" (p.18), he did recognize that a world without transaction costs is probably not worth thinking of. Therefore, "we have to take into account the costs involved in operating the various social arrangements, as well as the costs involved in moving to a new system" (p.44). The real breakthrough of the Coase theorem has not been to provide another way to deal with external effects but has been to raise the issue of transaction costs and more specifically, the cost of coordination to settle adequately the rights and duties of each protagonist over specific resource. In other words, it is the costs to access a sufficient amount of information to settle adequate rules given that individuals might have opportunistic behaviors (Williamson, 1981 and 1985). It is important to recognize that the sole condition of misinformation is not sufficient to create inefficiencies. Indeed, Cooter (1982) demonstrated that a market in situation of perfect information could still exhibit inefficiencies when mutual hold-out deters mutually beneficial exchanges. He considers, instead of a Coase theorem to have a Hobbes theorem in which people "will exercise their worst threats against each other unless there is a third party to coerce both of them" (Cooter, 1982 p.18). For Hobbes, such third party is the Leviathan but in the case of the aforementioned theorem, this third party can be the law from a State or other authoritative bodies which have to minimize the inefficiencies from failures of bargaining. Therefore, costs for enforcing property rights and agreements have to be added to the costs of gathering the required information (see also Williamson, 1985).

If transaction costs at the individual level are sufficiently lower than the transaction costs of State involvement, a decentralized interaction (bargaining or market) would be more effective than a governmental intervention. But the reverse might be true that an individual cannot or is not willing to determine precisely the best alternative for an increase of the aggregate welfare, inducing the involvement of the State. In that respect, Coase (1960) stated that "if market transactions were costless, all that matters (question of equity apart) is that rights of the various parties should be well-defined and the results of legal actions easy to forecast. But…, the situation is quite different when market transactions are so costly as to make it difficult to change the arrangement of rights established by law. In such cases, the courts directly influence economic activity" (p.19). Thus, whenever two or more individuals can agree on an exchange, it might be better to provide decentralized solutions, but otherwise, the involvement of the State through its judicial system influences economic activities toward an equilibrium presupposed optimal. Fundamentally, the question is how good is an individual or a State in deciding for the best alternative subject to the available information and knowledge each one gets.

1.3.3.3. Transaction Costs and Externalities

As pointed out by Coase (1960), a decentralized system of coordination such as the Arrow-Debreu general equilibrium framework needs the guidance of prices to foster a Pareto efficient equilibrium but these prices are not freely estimated. Arrow (1971) recognized in a later article that "[m]arket failure is the particular case where transaction costs are so high that the existence of the market is no longer worthwhile" (p.17). This conclusion can easily be applied to the State intervention of the Pigovian approach. Because prices are not freely available to individuals, this holds also true for the State which cannot freely estimate the efficient tax or subsidy to control for an externality and some of them might be better to not be internalized either in a market or through a governmental intervention. Therefore, in both approaches an externality can exist without leading to a suboptimal equilibrium. This fact is generally due to the existence of transaction costs and brings us to refine more precisely the definition of an externality into two categories between the Pareto-*relevant* and Pareto-*irrelevant* externalities. An individual or a group of individuals can be aware of a higher cost than the expected benefit from internalizing an externality which would induce a final Pareto-inferior situation in comparison to the initial state. To the contrary, if agents involved in the external effects are informed of the greater benefits than the costs of handling the externality, then action in that sense will be undertaken and the unintended interdependency will be no longer uncontrolled. Both types of externality have been characterized by Buchanan and Stubblebine, 1962 as respectively Pareto-irrelevant and Pareto-relevant externalities. In the former, the costs for internalizing the external effects offset the benefits of doing so and induce a sub-optimal equilibrium. Therefore, an externality is not always synonymous of market failure but can be rather the expression of a rational calculus in which some effects are better not marketed: "The observation of external effects, taken alone, cannot provide a basis for judgment concerning the desirability of some modification in an existing state of affairs" (Buchanan and Stubblebine, 1962 p.208). Thus, it is not because an externality is occurring that the situation is systematically inefficient. In fact, as stated by Demsetz (2011 p.9), "there exists an efficient amount of ignorance in an economic system if the cost of acquiring information is positive". To the contrary, a Pareto-relevant externality corresponds to a situation where the aggregate welfare could be increased if the external effect were accounted for. However, as pointed out by Dahlman (1979 p.147), while the determination toward a certain degree of relevancy of the externality explains the persistence of some of these latter, it does not give rational reasons for being concerned over these types of commodities. It is straightforward to realize that if a Pareto-relevant externality emerges from a new activity, it would be by definition Pareto improving to handle this new external effect and therefore, no Pareto-relevant externality should persist. In other words, "if the costs of organizing decisions voluntarily should be zero, all externalities would be eliminated by voluntary private behavior of individuals regardless of the initial structure of property rights" (Buchanan and Tullock, 1962 p.48).

However, things are different when the costs or the benefits are not clearly known in advance. In that case, the effort undertaken might be useless (Pareto-inferior situation) or useful (Pareto-superior situation) and individuals in that situation would probably prefer a potentially inefficient *status quo* rather than making the effort toward an uncertain benefit (Demsetz, 1967). An example of the distinction between Pareto-relevant and Pareto-irrelevant externalities can be found in the historical evolution of the groundwater management in the Western States of the US. During the nineteenth century, the limited capabilities to estimate and delineate underground water combined with the difficulties to extract it have induced this resource to be unregulated for several decades. The cost of doing so would have outweighed the gains and while there was unintended interdependencies, these externalities could be considered as Pareto-irrelevant. However, the technological improvement in the first half of the twentieth century caused the interdependencies to become Pareto-relevant as the cost to regulate groundwater could be inferior to the expected gains (Hundley, 2001). Thus, the Pareto-relevance of an externality depends on whether there is a possibility to access the information to handle the external effect which can only be known by undertaking a significant effort (Dahlman, 1979 p.150). In that way, transaction costs cause technological Pareto-relevant externalities through the persistence of a certain hesitation to create a market for these external effects. Thus, more than the transaction costs itself it is the inability to handle such transaction costs that cause the externalities to exist and to persist (Papandreou, 1994).

1.3.3.4. The Organizational Structure to Cope with the Transaction Costs

"Truly among man's innovations, the use of organization to accomplish his ends is among both his greatest and his earliest" (Arrow, 1971 p.224). While the general equilibrium approach assumes generally the creation of market to resolve any problem of externality, there is growing recognition that such a view is relatively limited in scope since it does not accurately depict the reality of the structuration of the actual productive space (Williamson, 1981). The main issue arises from the limited capability to get full and free information upon the attributes of the product or service exchanged in the market from which emerges the transaction costs (Williamson, 1971). In that respect, the organizations, defined as socially structured groups with common goals (Arrow, 1974; North, 1990 and Scott, 1998) often provide more effective ways to deal with such informational limitations than the markets do when the complexity of an interactional situation exceed the capability of the sole individual (Furubotn and Richter, 2000 p.296). This may be done through the definition of pro forma roles attached to each position in which individuals in those positions are required, permitted or forbidden to undertake certain actions (Ostrom, 2005 p.57). As have pointed out Simon (1991), such pro forma roles can be simply understood as rules promulgated under a certain authority which promote a stability of behaviors within the organizations: "[a] major use of authority in organizations is to coordinate behavior by promulgating standards and rules of the road, thus allowing actors to form more stable expectations about the behavior of the environment (including the behavior of other actors)" (p.30). In that way, correct expectation can be formulated upon the behavior of others which brings a certain degree of stability.

Organizations are often perceived as the "personal side of the institutions" (Smoller, 1900 p.61) because they foster the predictability of behaviors through the dissemination of rules promoted by the institutions, of information upon and links between multiple interactional situations and they influence the set of opportunities with a substantial differentiation between individuals inside and outside the organizations (Grief, 2006 p. 49). Disseminating the rules and linking the different transactions induces the organizations to be different from institutions as being the players of a game while the latter are the rules of these game (North, 1992 p.9). They coordinate the multiple and sometimes divergent behaviors through the sharing of knowledge and the communication of general decision rules toward a unique objective (Kreps, 1990 p.126). However, because they influence the demeanors of their members, organizations may also make the rules. Here lies the duality of organizations as being components of an institution as well as being institutions themselves since they gain some authoritative power to impose rules upon their members (Grief, 2006 p.31). Therefore, organizations will impact the behaviors of their members in a somewhat indirect way by sharing knowledge at low cost upon a specific situation, but also more directly by establishing rules which will require, permit or forbid some behaviors and in that way, diminish the opportunistic attitude. In both cases, organization can be view as attempts to open new opportunities for individuals by reducing the transaction costs of interacting with others (Coase, 1937 and Williamson, 1985, 2000). In other words, since such transaction costs reduces the opportunities, organizations allow the internalization of transaction within a unique hierarchical structure to reduce this (Williamson, 1971 p.114).

Yet, by providing support to individuals in deciphering a complex situation through rules and information sharing, the organizations also limit the possibility of action of individuals. This point has been supported by Hayek (1976) with the idea of superiority of the spontaneous order upon the organized order. However, from Williamson (1981 p.566) and Barzel (1982), the collective decision to structure the interaction within an organization will principally depends upon the difficulty of measurement of the asset being transferred: "what gets measured, gets managed" (McCann, Colby, Easter, et al., 2005 p.527). The higher is the cost of measuring or valuating the exact worth of an asset which is being exchanged between two or more individuals, the more interesting will be for these individuals to structure themselves into organization to internalize the risk of mismeasurement or misevaluation of the asset.

Such an asset may be a product intended to be sold in an existing market as envisioned by Williamson (1981) and Barzel (1982), but it may be an external effect as well between two or more individuals. In that case, the goal of an organization will be to embed the originator as well as the recipient of the effect either to ease the achievement of an agreement in a Coasian bargaining through a decrease of transaction costs or to establish rules toward an agreement whenever the participants of such interactional situation are too numerous (Smith, 2008). In summary, the market may be the solution if the cost to reach such agreement is sufficiently low, but this option requires that the measurement of the external effect as well as steering the others' behaviors toward the adequate action can be done with a relative easiness. For example, despite the rivalry nature of private good, the easiness of exclusion in consumption leads to an easy and effective resolution through the market. To the contrary, the Common Pool Resources where rivalry occurs but exclusion is difficult, often implies the need foster incentives to adopt the adequate behavior and limit the extent of the externalities. In such cases, the creation of organizations with varied bundles of rules may help in handling the external effects that the action of some individuals are imposing upon others as much as upon themselves (Ostrom, 1990 and Seabright, 1993).

1.3.3.5. The problem of the Reciprocal Nature of Externalities

Baumol and Oates (1988 p.29) gave several reasons to distinguish the Pigouvian approach from a market based approach to solve a technological Pareto-relevant externality. One important issue is when an externality is unidirectional. That is, when one agent or a group of agents harm another group through the external effect, imposing a price through a market system would implicitly require to charge the "victim" of the external effect with the market price due to the fundamental symmetry of a price. To the contrary, a tax has the asymmetrical property of a positive price for a "supplier" and zero cost for a "consumer" of an externality. However, in this argumentation that follows the Pigouvian tradition, a normative judgment has to be made to determine an agent as a "victim" and another as "guilty" for this external effect (Coase, 1960). "The traditional approach has tended to obscure the nature of the choice that has to be made. The question is commonly thought of as one in which A inflicts harm to B and what has to be decided is: how should we restrain A? But this is wrong. We are dealing with a problem of reciprocal nature. To avoid the harm to B would inflict harm on A" (Coase, 1960 p.2). Thus, the important question is to decide who should be the victim and who should be the responsible given that this choice should avoid the most serious harm.

Such reciprocal nature of externalities may be better understood from the work of Commons (1924) and Hohfeld (1913). Drawing upon these two authors, an institution can be depicted as set of legal relationship between individuals over two dimensions as in figure 1.1. The first dimension draws the correlative aspects of the legal relation between rights and duties or between exposure to these rights and liberties of individuals. A right given to an individual to act in a certain way implies a correlative duty for others to respect this rights. Thus, a right is given to B upon an external effect, A will be subject to this right and will thus have the duty to respect B's right. Similar logic underlies the correlative aspect between liberty and exposure. An individual having the liberty to act in certain ways does not have the duty to account for others who are therefore exposed to his acts. The second dimension depicts the limits implied by rules within the legal relationship. The exposure of a right corresponds to the limits of decision making for which the agent can rely upon his rights and is the correlative of liberty which is also the limit of a duty because, as it has been previously implied, a person without a specific duty is at liberty (Ostrom and Ostrom, 1972 p.4). In other words, when an interdependency exists between the two agents A and B, the one taking the liberty to act will impose the external effect upon the other who stand exposed to the liberty of the former. A restriction to limit A in harming B is similar to imposing a duty upon A from the correlative right granted to B

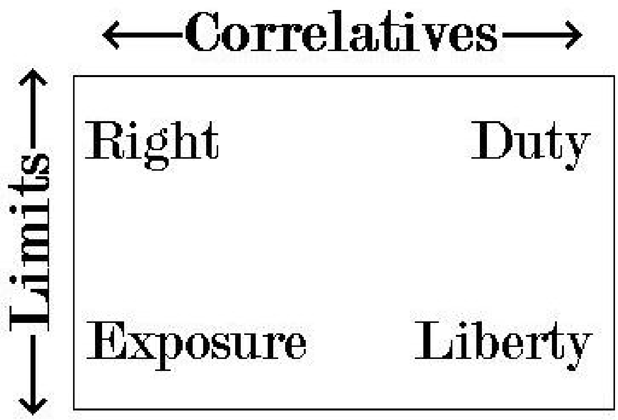


Figure 1.1: The Authorized Relationship (adapted from Commons, 1924 p.97)

The important insight from this classification is that, attempting to resolve an externality by granting the right to one party will induce the correlative duty to respect this right by the other party. This point is at the heart of the institutional analysis initiated by the study of external effects of Coase (1960) and further developed by Demsetz (1967) to delineate a comprehensive theory of property rights. They both emphasize that, giving a right to act to a specific individual is like imposing a duty upon other individuals to respect this right. Put differently, "Coaes's point is that there is an economic value to the activity that produces the externalities and the economic cost created by the externalities, and if (but only if) the former exceeds the latter, the activity will continue, independent of who pays the costs" (Coleman, 1990 p.261).

For example, in the aforementioned case of return flow problem as technological externality, the downstream appropriator of the return flow can be view as a "victim" (as it is generally the case) because right of use from the upstream user only concern the consumptive water and not the applied water (Hanak, 2015). However, if one considers the right of use over the totality of the applied water, then a downstream appropriator of the return flow is not anymore viewed as a victim of a negative externality from water transfer but as a profiteer of a positive externality which is diminishing due to the water transfer (Griffin, 2016). Without water markets, the least serious harm is generally achieved by giving the right of use to the downstream appropriator of the return flow because it allows a maximum use of water. But this logic might be reversed if the upstream user can get more earning from water sales. In that case, the least damage could be achieved by giving the full right of use to the upstream appropriator.

Such reciprocity of externalities calls for a more judicially based approach rather than a simple economic analysis undertaken by previous approaches. Indeed, either through the Pigouvian approach or the General-Equilibrium approach, an externality would be viewed as an interaction for which no compensation is exacted. A more judicially based approach would regard an externality as a trespassing of a property rule (the right for acting in certain ways) for which no liability rules exists (the right to be compensated) (Griffin, 1991). One might consider that both approaches are similar in their meaning and the difference being solely a semantic one. But the judicial perspective brings new insights into the exploration of the concept of externalities. While the sole economic analysis considers institutions as given, the judicial approach insists on the rights and duties to characterize an externality. In other words, what distinguishes a victim from a guilty individual is the delineation of rights and its correlative duties to respect the rights of others. In that respect, an externality is arising in a specific institutional context because rules that govern the interaction are becoming inadequate to the real context of the exchange (Papandreou, 1994). This is particularly true for water resources which have been largely subjected to institutional constraints due to their highly-centralized management (Saleth and Dinar, 2004 and Blomquist, 2012). The absence of markets has been common in the water sector and the subsequent externalities that arose from inadequate rules have been addressed through the specification of new rights and duties upon the resources, creating a new delineation of rights among individuals. Therefore, an institutional approach is necessary to understand the water sector and the externalities that arise from the use of this specific resource. As pointed out by Dahlman (1979 p.161-162), "[t]he analysis thus directs attention to the point that institutions fulfill an economic function by reducing transaction costs and therefore ought to be treated as variables determined inside the economic scheme of things. The question then ultimately becomes: how can economic organization be improved upon by endogenous institutional rearrangement?" Therefore, institutions should not be considered as exogenous of the equilibrium like in the Walrasian paradigm but as an integral part of the determination of such equilibrium.

1.3.4. The Institutional Approach to Understand the Importance of Property Rights

The institutional approach, developed in the 1960's by the work of Coase has a broader viewpoint on externality than the general equilibrium approach and severely critics the modern welfare theory initiated by Pigou in the 1920's. Contrary to the general equilibrium theory, the institutional arrangements are not anymore considered as exogenous but are an integral part of the economic analysis. Thus, markets are not anymore separate from other types of institutions but forms a certain type of institutional arrangement within a broader framework. "This is not the outlook of modern welfare theory where the government is seen as a force outside the economic system altogether, which will come to our aid and rectify the havoc wrought by endogenously working market forces, just like the classical *deus ex machina*. Coase opens the door for an economic theory of institutions, whereas modern welfare theory can only gaze into its crystal ball of mathematical abstraction and wisely state that heaven on earth is still far off – which is true, but of no particular consequence either for correct conduct of economic policy or for the theory of externalities" (Dahlman, 1979 p.162 emphasize in the original). In that respect, the institutional approach not only confutes the centralized action as the sole solution to solve any problem from externalities but also enlarges the concept of externality itself toward considering any kind of interactions, inside or outside markets institutions.

1.3.4.1. The Departure from the General Equilibrium Approach

As pointed out by Griffin (1991), "it is unacceptable to define externality as an 'interdependence without market'" (p.613) because "externalities do not emerge into institutional voids but are always being addressed by some, perhaps very subtle, coercive structure" (p.614). From this author, a radical but more correct view should be to define an externality simply as a general interdependence and regards it as the result of specific institutions instead of asserting the lack of the sole market institution (Griffin, 1991 p.602). This argument follows the important works of Dahlman (1979) and Buchanan and Tullock (1962) in which externalities are any collective decisions that deviate from an unanimity vote for the simple reason that some groups can be subject to the decision taken by others. Thus, an externality can potentially cover any kind of interactions and is commonly equivalent to the notion of general interdependence. Therefore, by definition this includes also the pecuniary externalities which was viewed by previous authors not as an external effect but as a market effect. However, at which point should we consider the deviation from the unanimity vote as a detrimental externality is more a normative question. With this sole aspect, the two terms interdependence and externality would be redundant. What causes an interdependence to be an externality is the inefficiency that arise from this specific interaction simply defined as the possibility to increase the welfare of one agent without diminishing the one from at least one another agent (Demsetz, 1964). "The classical examples of external economies and diseconomies constitute only a small set of activities, and no one has discussed carefully the criteria for determining when an externality resulting from private behavior becomes sufficiently important to warrant a shift to the public sector." (Buchanan and Tullock, 1962 p.62).

In the work of Buchanan and Tullock (1962), political aspects of the economic organization have a prominent place. Rather than looking at how an individual can serve the aggregate welfare through the design of adequate incentives, they considered how such incentives are designed through specific political organization subject to the ubiquitous transaction costs (Papandreou, 1994). If a decision situation within a community is deviating from the unanimity vote rule, some costs are imposed to some members of the community which represent a potential externality. The real inefficiency of such externality will depend on how well another decision will minimize the costs imposed to the non-willing members of the community. But the possibility of such comparison is constrained by the transaction costs of establishing new rules of decision leading to the persistence of potential inefficiency. Buchanan and Tullock (1962) distinguished between two types of costs: the *external costs* which can be viewed as the cost of the external effects and the *decision-making costs* which can be considered as the transaction costs. The sum of these two costs is termed *interdependence costs* by Buchanan and Tullock (1962 p.45). While the external costs will weigh upon the decision of economic organization, the decision-making costs will play a crucial role in determining the most effective institutional organization to handle the interaction. The decision toward voluntary (laissez-faire) or collective (governmental intervention) organization will depend on the relative decision making cost of these two alternatives. Thus, they bring the most important point in their analysis that transaction costs will determine whether an action should be centralized (collective or governmental action) or decentralized (private through markets): "The limit to voluntary organization, and thus the pure *laissez-faire* model of social organization, are not defined by the range of significant externalities, but instead by the *relative costs of voluntary and collective decision-making*" (Buchanan and Tullock, 1962 p.62 emphasis in the original).

While this point has also been skimmed by Arrow (1971, pp.18-19) who considered the State as not a unique and monolithic entity but rather a complex system of individual agents in which political interplays have an important role, the general equilibrium approach generally considers rules and other types of institutions as exogenous (Papandreou, 1994) and as the "reactions of society to compensate for market failures [including externalities]" (Arrow, 1971 p.20). To the contrary of the institutional approach which explicitly account for the endogeneity of institutions. In view of Buchanan and Tullock (1962), market is a specific institution among others that carries externalities as long as unanimity is not attained.

Buchanan and Tullock (1962) also made more evident the similarity between governmental institutions and market institutions. Their point was to demonstrate that government can fail in resource allocation and therefore, assuming that such a State can efficiently replace the market whenever this latter is absent and an externality is occurring is not founded. In that respect, the institutional approach stays away from the Pigou's solution in the sense that a governmental intervention is not always the panacea because it is subject to failures exactly like the market (Buchanan and Tullock, 1962). By focusing on the formation of institutions they, and soon after Demsetz (1964 and 1967), provided new insights to define and therefore analyze the externalities.

1.3.4.2. Property Rights Institutions and Externalities

In its seminal article "Toward a theory of property rights", Demsetz (1967) joined up the Buchanan and Tullock (1962) conception by considering an externality as an interaction between individuals or groups that convey harmful or beneficial effects to others. However, to the contrary of Buchanan and Tullock (1962), Demsetz (1967) insisted on the institutional change that will eventually occur to handle the externalities that originate from the actual institutions. Indeed, while the definition of externalities given by Buchanan and Tullock (1962) insisted on the inadequacy of institutions to handle specific interactions, the description of Demsetz (1964) refined the definition to consider the question of inadequate property rights as a cause of externalities. More specifically, he advocated the redefinition of property rights when incentives to do so will be sufficiently strong. The problem of externality becomes the issue of a costly appropriation of a right to act in a certain way. A good example might be the aforementioned return flows problem from a water transfer. As already pointed out in the reciprocal nature of externalities, neither the upstream originator, nor the downstream user can, a priori claim the right over the return flow and any decision that will support the view of one party will impose a cost (an externality) on the other party. Whether it is Pareto-relevant or not depends on the different opportunities offered by each party and therefore, will be conditional upon the property rights possessed by each protagonist. For Samuels (1972 p.52), the concept of externality comprises a certain coercive power in which an agent has the authorization to harm another agent. The Pareto-relevance of an externality will thus depend on the institutional context in which this latter is arising and is the outcome of a competition toward an appropriation of the right of coercion. "The history of prior discussion of the externality problem is replete with mistaken attributions of causation when the real source of the problem simply is resource scarcity" (Demsetz, 2011 p.5). A Pareto-relevant externality can thus be defined as the result of an inadequate system of property rights in comparison to another system. Demsetz (1964) proposed to change the denomination from "external effects" to "side effect" in order for any reader to "avoid the flavor of location and of being *necessarily* outside of the market place that seem to be associated with the more common names for these effects" (p.11 emphasis in the original). This is more than a semantic question because it makes clear that he tries to avoid any confusion between the general-equilibrium approach that emphasizes market solution and institutional approach which encompasses the broader sense of general interdependencies. For convenience, we are using the two terms "external effects" and "side effect" interchangeably in the rest of this work.

In a later article, Demsetz (1967) defines externality as "the concept including external costs, external benefits, and pecuniary as well as non-pecuniary externalities […]. Every cost and benefit associated with social interdependencies is a potential externality" (p.348). In that way, an externality can be view as any expression of power to impose constraints over some individuals by other individuals. This corresponds to the general interdependency he pointed out in its previous article and the notion developed by Buchanan and Tullock (1962). This will be taken over by Samuels (1972) when he states that "externalities comprise the substance of coercion, namely, the injuries and benefits, the costs and gains, visited upon others through the exercise of choice by each economic actor and by the total number of economic actors" (p.52). In that respect, an externality can be viewed as the exercise of a power in the Lukes' sense: "A exercises power over B when A affects B in a manner contrary to B's interest" (Lukes, 1974 p.30). This notion of power is the basic idea of property rights in the sense that it provides exclusive rights to use a resource in a certain manner and therefore gives the authorization to potentially harm others whenever the use of the resource is contained within the boundary of the authorized actions. Umbeck (1981) and Sugden (1989) explain that without any legal embodiments and prior hierarchical order, the determination of a property rights system will arise as a spontaneous order from efforts undertaken by interacting individuals to get the control upon a common resource. An equilibrium will thus emerge from the confrontation of the different powers to impose and maintain the right to produce external effects and thus limit the possibility for others to interfere in the activity. "Ultimately, all ownership rights are based on the ability of individuals, or group of individuals, to forcefully maintain exclusivity" (Umbeck, 1989 p.39). In that respect, the authorized relationship depicted in figure 1.1, is the result of authoritative forces as depicted in figure 1.2.

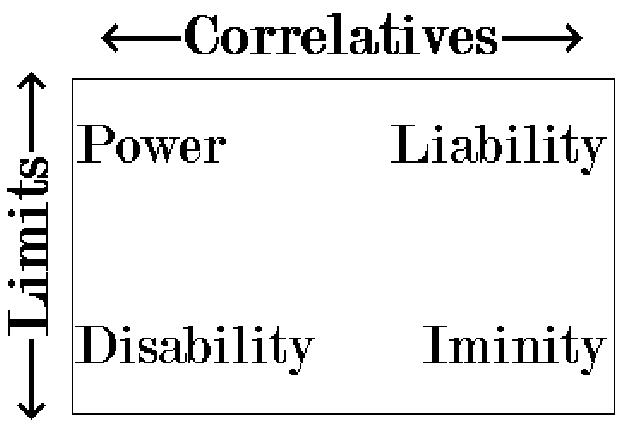


Figure 1.2: The Authoritative Relationship (adapted from Commons, 1924 p.97)

An individual with a certain power has a correlative liability in which he is responsible for its act and is limited by its potential disabilities. To the contrary, the limit of a liability is a situation of immunity where nobody can challenge the position of power of an individual or a group of individuals. In that respect the expression of power is in line with a Weberian definition of power which is the "probability that one actor within a social relationship will be in position to carry out his own will despite resistance regardless on which this probability rests" (Weber, 1947 p.152). Such a resistance can be equivalently considered as a liability which gives the possibility of contestation upon the exerted power or, more specifically, the inability of exclusion the others by the individual in position of power (Calabresi and Melamed, 1972). In other words, while the power gives the possibility of exclusion upon specific decision, the liability allows the contestation of such exclusion.

Similar to the correlative duty of a right, the power imposes a correlative liability to others of not interfering with the action of the individual in position of power. However, if the latter reaches the limits of his power, he will not be able anymore to coerce further the others from interfering with his activity and will find himself disable to secure his use of a resource (Ostrom and Ostrom, 1972). In that sense, property rights may be perceived as the ability to take control of a resource and exclude others from using it not only through law but in reality (Alchian, 1965 p.817 and Allen, 2000 p.897). Thus, the authoritative relationship may be perceived as the "authoritative allocation of value" (Easton, 1953 p.146). Yet, the often-circuitous interactional situations in which an individual may be involved induces generally the latter to be disable in exercising his power. In such cases, the development and the intervention of a larger group as a third party with a bigger coercive power can provide sufficient support for the individual to get the necessary ability to enforce a set of given rights. Classic example of such a large group can be found in the constitution of a State that have sufficient ability to impose rights and duties to its citizens through a monopoly of coercion. In other words, States may have the required power to produce and impose institutionalized rules which induce rights and duties to individuals in different interactional situations (Ostrom and Ostrom, 1972 p.5).

In this view, the support of the right by a legal authority is an important aspect of property rights. Bromley (1991 p.2) defines property rights as "a claim to a benefit stream that the state will agree to protect through the assignment of duty to others who may covet, or somehow interfere with, the benefit stream". Thus, the support of some higher authority for specific rights gives *de jure* rights of use recognized by the legislative authorities and thus enforced if these rights are challenged in court. To the contrary, *de facto* rights of use correspond to a system designed by the resource users themselves but are not recognized by any higher authorities (Schlager and Ostrom, 1992). This last distinction sheds light on a third aspect of property rights: the inalienable entitlement in which a party is not allowed to interfere with an action undertaken by another party if this later does not go beyond its property rule (Bromley, 1991 pp.42-45). While a *de jure* system is protected by a State legislation, a *de facto* system may not be inalienable as a third party can challenge it in court and therefore is less secure until it is recognized by legal authorities as a *de jure* right (Schlager and Ostrom, 1992 p.254). However, this is not to say that *de facto* property rights are less suited to manage a common resource. Institutionalized rules emerging from users in a bottom-up fashion can outperform the State's laws if such rules are better fitted into the local context in which these *de facto* rules are applied (Ostrom, 2005). But neither the governmental, nor the individual arrangements can guarantee the rise of an efficient equilibrium of rights and duties (North, 1990 p.59 and Furubotn and Richter, 2000 p.119). This point is particularly important since it implies that no equilibrium is a priori efficient and therefore externalities may subsist even when an equilibrium can be reached (Sugden, 1989 p.95).

In that respect, Demsetz (1967) narrowed the concept of externality by considering an externality only the kind of interdependence too costly to be handled in a different manner. Thus, an interaction within the large scope of general interdependencies should be termed externality if and only if the situation can be improved but "the cost of bringing the effect to bear on the decisions of one or more of the interacting persons is too high to make it worthwhile" (Demsetz, 1967 p.348). In other words, there is a change in power relationship (or similarly property rights) when the benefits of such a change become sufficiently higher than the costs of the status quo. An example often given to explain the relationship between property rights and externality is the conflict between cattle owners and crop farmers in the USA at the end of the nineteenth century (Hornbeck, 2010). Farmers could not fully use the land appropriated by them due to the important risk of damages from livestock and cattle from other farmers that could freely pass through the agricultural lands and destroy the growing plants. The solution came from a simple invention in 1874 by Joseph Glidden: the barbed wire. It allowed to effectively delineate and enforce at a cheap cost the property rights and reduced the externalities from cattle owners imposed to crop farmers. The same reasoning can be applied to water resources. Indeed, due to its fluid property, the delineation of right of use is particularly difficult which often requires a judicial system to resolve conflicts. These are ex-post methods in the sense that it is the recognition of a specific harmful effect that will bring a specific and costly solution. Jandoc, Howitt, Roumasset et al. (2015) pointed out the modern use of satellite imagery to estimate the real consumption of water by each agricultural user and then delineate properly the multiple needs to enforce property rights. Such examples point out the important aspect of property rights (and more specifically the private ones) in resolving externalities issues which is to develop an exclusion mechanism to separate the different activities and adequately allocate control over side effects (Anderson and Hill, 1975). The existence of easy mechanisms to delineate the different responsibilities between individuals upon specific actions (through the formalization of adequate rules) allows to derive enforceable rights with their correlative duties upon these very same actions. Consequently, individuals in such situations can be well aware of their opportunities and markets may naturally arise to exploit these opportunities (Demsetz, 1967).

However, the theory of property rights developed by Demsetz is often criticized and can be viewed as "optimistic" (Furubotn and Richter, 2000 p.120). Indeed, the main aspect of this theory is that market forces will open opportunities through a redistribution of power which should lead to an efficient equilibrium. The underlying mechanism is that a higher value of a specific resource subject to ill-defined property rights will push the individuals to undertake the necessary effort in delineating rights and duties with a greater ability in exclusion through the formulation of adequate rules (Demsetz, 1967). This view has also been shared by Libecap (1989a), who considered the “design of institutions or governance structures as maximizing decisions to economize on transaction costs and to facilitate new economic activities. Market forces are argued to erode property rights institutions that are poorly suited for responding to new economic opportunities. If the existing rights structure limits or blocks reactions to changes in relative prices or technology, the existence of unexploited potential gains will lead individuals to mobilize for the adoption of more accommodating property rights” (p.6-7). The Demsetz’s argumentation has been however termed as a “naïve theory of property rights” by Eggertsson (1990 p.275) who argued that property rights arrangements following market opportunities may also fail in insuring a sustainable path of extraction of a natural resource. The main issue arises as an insufficient or inadequate distribution of power among individuals involved in the interactional situation that leads to a mutual disability and inability of defining adequate rules (Akbulut and Soylu, 2012 see also Copeland and Taylor, 2009). Along with the high disability of organizing the interplays, exclusion costs increase and property rights in their private form weaken. In other words, the lack of authoritative abilities by either individuals or governments induces an important limitation of power and thus an insufficient level of authorized relationships through ill-defined rights and duties.

Excludability is what distinguishes the private good from common pool resources (Ostrom, 1990). The former being easily excludable and transferrable through market at low costs, while the latter often embeds circuitous interdependencies with important risks of side effects from the use of the resource. Classical problems of common pool resources are the rent dissipation that arise as a side effect from the overuse of a common resource and the tragedy may emerge when the costs of fully excluding some users to improve the benefit of some others are very high and out of reach for most individuals and for governments as well (Hardin, 1968). In other words, it may not be possible to possess enough power to formulate and enforce private property rights toward the conception of a private good (Ostrom, 1990). In such cases, a system of more comprehensive rules must be formulated to provide the required authorized relationship that will adequately handle the external effects. As pointed out by Eggertsson (1990 p.257), “[t]he dissipation of rent from shared resources can be reduced by collective action, but such measures are costly and give rise to internal governance costs, costs that are justified if the limits on overutilization increase net output.” Governance costs are different from the exclusion costs in being not intended to develop private property but rather common property rights (Field, 1986 and Eggertsson, 1990). However, the distinction between these two types of property rights is fuzzy since they both rely upon institutionalized rules to prescribe the adequate behaviors, the sole difference being that private property defines more precise delineation of rights and thus more strict exclusion mechanisms between individuals than the common property does (Papandreou, 1994 pp.207-208).

1.3.5. From the General Equilibrium Approach to an Institutional Perspective of Externalities

The limitation of coordination among individuals implies a separation between the multiple decision makers which cannot account for all effect of their actions. This interdependence can be either general in which any types of interactions are potentially an externality, including market (institutional approach) or specifically outside a market which excludes *de facto* the market interactions from the definition of externality (general equilibrium approach). Thus, the choice between these two approaches depends upon the extent of the economic area under survey. “If people outside the chosen area are, on balance, made worse off when those inside the area are on balance made better off this fact is of no concern to the insiders” (Mishan, 1965 p.9). This argument can be used to discern between the Pigou’s analysis which is only in partial equilibrium (and thus excludes any other markets) and the general equilibrium (which consider all markets). But it can be used also to differentiate between the general equilibrium analysis which excludes all market interactions from the concept of externality and the institutional approach in which no kind of interactions can be *a priori* discarded (Papandreou, 1994). For the latter, competitive market advocated by the former approach can be perceived as the idealistic result of perfectly and effortlessly predictable behaviors which would insure to the interacting individuals that expected outcomes will be fulfilled. Yet, such predictability is neither perfect nor costless which drive to the conclusion that “no market is simply there” (Furubotn and Richter, 2000 p.300) but is more often the result of a system of rules (formal or informal) that provides sufficient predictability and reliable expectations upon the future outcome of an interplay with other individuals.

In that respect, markets are specific institutions, and like any other institutions, they are based upon their constituent rules, either formal or informal, which describe or prescribe the relationship between individuals upon the use of a resource (Bromley, 1989a p.202). Such prescriptions induce a sufficiently accurate predictability of other’s behaviors in a social situation which triggers voluntary exchanges and facilitates the constitution of a relatively dense network of social interactions (Weber, 1968 and Williamson, 1975). In other words, “[i]n absence of trust, it would become very costly to arrange for alternative sanctions and guarantees, and many opportunities for mutually beneficial cooperation would have to be forgone” (Arrow, 1971 p.20). Whether it is trust directly upon its partner or indirectly through the respect of the institutionalized rules, market transactions require the individuals to be sufficiently informed upon an interactional situation to formulate accurate expectations upon the future outcome of an interplay (Simon, 1991). The core problem of water resource management is the difficulty to create a more flexible system of reallocation to cope with the climate and structural changes of many regions around the world (Saleth and Dinar 2004). The growing imbalance between demand and supply that led to the multiplication of water crises these past years induced policy makers to reconsider their strategies of water management through institutional changes (Saleth and Dinar, 2004). A key measure of these changes has been the development of water markets to provide sufficient flexibility in water allocation and to cope with increasing scarcity (Garrick, 2015 and Knutson, 2013). But, the great level of intricacy in establishing well-functioning water markets, induces a predominant role for the institutionalized rules with an emphasis upon the governance structure of the resource held in common rather than a crude exclusion which often causes conflictual situations from external effects not adequately handled or simply not accepted by the exclusion procedure (Smith, 2008). Therefore, assuming externalities as the sole absence of markets for the interdependencies where such markets are neither impossible nor acceptable cannot lead to effective policy prescriptions. In that respect, the study of externalities arising from water markets may be better approached with the institutional perspective rather than the general equilibrium one.

In summary, externalities can be described as interdependencies inadequately handled by the institutionalized rules which induces the individuals to misbehave by not accounting for all the side effects that their actions may have upon others. Transaction costs, defined as the resources required to produce, use and maintain such rules have an essential impact since they limit the ability of individuals involved in an intricate interactional situation to develop better institutionalized rules and craft adequate property rights to handle all side effects. More specifically, the ignorance at the source of these costs induces imperfect mechanisms of exclusion and higher risk of unintended external effects. Thus, because it is not always possible to fully devise exclusion mechanisms, other types of governance structures have been created to economize on transaction costs of excluding individuals and to provide instead institutionalized rules to promote the adequate behaviors without delegating the full control of a resource to individuals like the private property rights do. As pointed out by Baumol and Oates (1988 p.15), "[u]ltimately, definitions are a matter of taste and convenience". The purpose of a definition for such a complex concept is not to grasp all its implications and refinements within the wide variety of situation it may occur but rather to insert the concept into a specific context. The main point is to consider the importance of rules that create property rights in the process of exchanges, bearing in mind that such rules are the result of the efforts to improve the predictability of any interplay by increasing the regularity of individual behaviors responding to societal, biological or physical phenomena. An externality can thus be defined as the result of a bundle of rules (formal or informal) that guide the relationship between two or more individuals but, due to the transaction costs cannot capture all the relevant consequences upon individuals' opportunities of the actions required, permitted, or forbidden by all or part of these very same rules. In other words, and as stated above, it is an inadequately ruled interaction that creates such inefficiencies (Griffin, 1991). In that definition, two fundamental components of the concept of externality is being lied down. The first component is the notion of interdependency which ties individuals together and act as a channel for side effects to arise and become external if not handled by a specific rule. The second component is the notion of incompleteness of such rules due to the existence of transaction costs which implies a potential inefficiency of the institutional structure. The persistence of such inadequacies calls for an adaptation of rules and organizational restructuration of the interactional situations through an institutional change intended to economize on the transaction costs and thus to provide the ability to rule the unregulated interaction (North, 1990).

1.4. Institutional Change to Cope with Inadequate Institutionalized Rules

While the above inadequacies may exist from the initial formulation of rules (Griffin, 1991), they often grow larger and emerge as detrimental externalities following some exogenous alterations of the interactional situations they are supposed to rule. Demsetz (1967) coined this process when he stated that: "[c]hange in knowledge result in change in production functions, market values and aspirations. New techniques, new ways of doing the same things, and doing new things – all invoked harmful and beneficial effects to which society has not been accustomed" (p.34). In other words, the new context induces a certain incertitude and a difficulty to predict the others' behavior within the unascertained interactional situation which leads to increase the transaction costs from attempting to decipher all the effects of the interplays. Institutional change through an adaptation of the rules are occurring in response to these rise of transaction costs in an attempt of reducing them (Bromley, 1989a p.14). Then, because rules are changing, a modification of property rights will mechanically follow toward a better delineation (Anderson and Hill, 1975; Demsetz, 1967 and Libecap, 1989). Consequently, "[p]roperty rights develop to internalize externalities when the gains of internalization become larger than the cost of internalization" (Demsetz, 1967 p.34).

However, this logic fails to explain the persistence of inadequate institutionalized rules and thus, the subsistence of externalities. As pointed out by Eggertsson (1994 p.11), "in the naïve model control issues do not present a dilemma, property rights will adjust to maximize the joint value of resources – and economists need not be concerned with political processes". The theory of property rights developed by Demsetz (1967) have been characterized as "naïve" because it mostly overlooks the political effort required in the formulation of new rules to overcome the old ones (Eggertsson, 1990). In a similar way, Sened (1997) expressed that "[a]nalysts should not expect private property rights to come into existence just because they increase efficiency" (p.176). More specifically, such models disregard the complexity through which a process of institutional change must go and thus, the substantial transaction costs that may arise from deciphering such complexity. Consequently, the existence of such transaction costs in the political process of institutional change will bias the decisions toward the status quo in which past reforms will influence the determination of new ones in a path dependency process (North, 1990 p.115-117). Pioneers of the Institutional Economics have already recognized the importance of "cumulative causation" (Veblen, 1919 p.70) in institutional developments. Veblen (1899) pointed out that "[t]he situation of to-day shapes the institution of to-morrow through a selective, coercive process, by acting upon men's view of things and so altering or fortifying a point of view or a mental attitude handed down from the past. The institutions under the guidance of which men live are in this way received from an earlier time; from the past. Institutions are products of the past process, are the adapted past circumstances, and are therefore never in full accord with the requirements of the present" (p.118). Because individuals have a certain way of thinking or a certain power of acting from the past institutionalized rules (Granovetter, 1985 and March and Simon, 1989), it is often difficult to amend or reverse such process and thus requires a supplemental effort (North, 1990).

Such institutional linkage through time has been reasserted by North (1990) who developed a theoretical framework based upon a distinction between institutional and economic features within a process of institutional change.

1.4.1. Transaction Costs from Institutional Linkages through Time: Path Dependency

North (1990) went further than the simple cost-benefit analysis formulated by Demsetz (1967), to provide a more politically based framework of institutional changes as depicted in figure 1.3 in a simplified manner. The main aspect is to clearly distinguish the economic from the political spheres with the individuals in each of these spheres as the source of change within a continuous process (North, 1990 p.5).

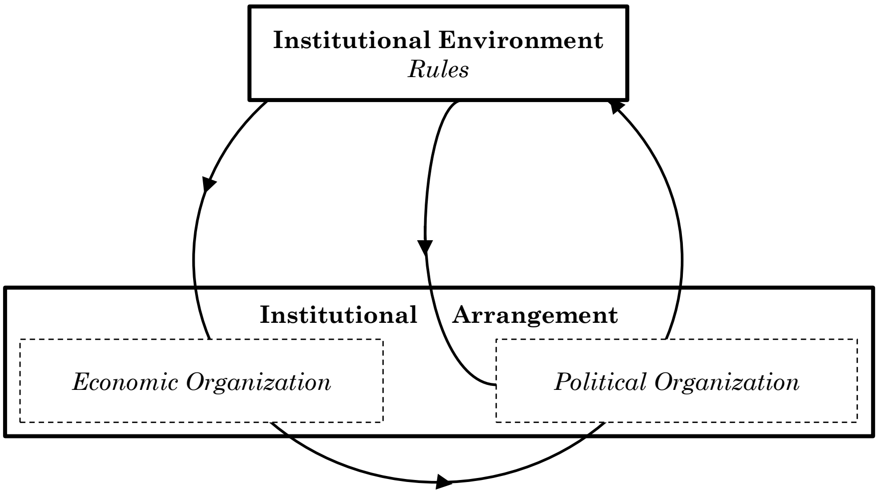


Figure 1.3: A depiction of the institutional change as a continual process

In this simplistic depiction, adapted from Challen (2000 p.49), we specify the two centerpieces of the institutional configuration: the institutional environment and the institutional arrangement (Davis and North, 1970 p.131). The latter corresponds to the different interactional situations in which individuals are involved, the former provides the basic institutionalized rules for such situations, itself shaped by the political actions of the individuals embedded into the institutional arrangement (Saleth and Dinar, 2004 p.25). Thus, institutional environment comprises all rules of interaction which have to be applied into the institutional arrangement which can be decomposed again into two separate but intimately linked structures: the political and economic organizations. The economic organizations encompass the set of productive structures which cooperate or compete with each other and have the sole objective of maximizing their economic outcome subject to a set of natural, technological and in some extent, institutional constraints (which are view as exogenous if no lobbying activities are engaged). Influencing the institutional environment can be done only indirectly through the political organizations which have their actions solely directed toward the institutional environment and will undertake effort to modify or hold unchanged the rules (North, 1990). The main point from such a distinction is that, while economic organizations may substitute political organizations to determine "who gets what, when, and how" through efforts to participate in markets, the question "who decides who gets what, when, and how" can only be answered in the political organizations through efforts to produce rules in the institutional environment. (Blomquist, 2012 p.370). In other words, the agents in the political organizations hold the authoritative position to formulate the institutionalized rules (Challen, 2000 p.112).

While economic organizations generally consider the institutional environment as exogenous, it can be endogenized through efforts and investment in lobbying activity. In the economic organizations, agents combine their different technical and institutional constraints to formulate their expectations through costs-benefit analysis. They can either undertake efforts in market transactions to buy, sell, produce, consume and invest, or get engaged into an effort toward institutional change by altering the perceived cost and benefit of agents in the political organizations (Challen, 2000 p.50). Through that way, they may be influenced by the agents in the economic organizations to undertake the necessary effort in changing the institutionalized rules toward a new system that will benefit the agents in the economic organizations. Such effort may also be viewed as rent seeking behaviors as they are intended to drive the political decision to get an economic rent from the institutionalized rules (Nicholson, 1995 p.846). Transactions between economic and political organizations will arise to reduce transaction costs and improve the stability of exchanges within the economic organization through the formulation of institutionalized rules and the restructuration of rights and duties to handle in another way the side effects of the economic activities. However, since the transactions between economic and political organizations are also subject to similar incompleteness of institutionalized rules as the transactions within economic organizations, transaction costs will also arise in the interplays between economic and political agents. "The process of institutional change is thus modeled as many transactions between economic and political agents with associated transaction costs" (Challen, 2000 p.51). A key insight from this model is the process of institutional change that will arise from the interactions or the transactions between agents in the economic organizations and agents in the political organizations (Challen, 2000 p.110).

The dual view of the institutional arrangement between political and economic organizations is more a conceptual simplification rather than a reality as frontiers between both types of actions are generally fuzzy and this is more particularly the case at a small scale of analysis such as individual level (Saleth and Dinar, 2004 p.25). Indeed, the latter will be alternatively distributed in the political or economic organizations depending on the objective they are pursuing. However, this distinction has the advantage of clearly depicting the endogenous nature of institutions and the indirect link between the source of change and the change itself: from production maximization in economic organizations through the political organizations which will regulate the production maximization processes. The institutional rules are thus subjective construct which evolves from the effort of the individuals embedded into the same institutional configuration (Saleth and Dinar, 2004 p.26). In other words, the cost-benefit analysis which will foster the political organizations to act toward the change of the institutions will be determined by the prior actions of these very same political organizations (Challen, 2000 p.50). "[w]e know that that prevailing customs and, in general, history matter for the success or failure of institutional change and that there are limits to institutional engineering. The path dependency of institutional change and the ideological and emotional predispositions of the public always have to be taken into account" (Furubotn and Richter, 2000 p.34).

This way, an economic system may experience path dependency which is basically the effect of past reforms upon present decisions and will determine the level of political costs in transacting between the economic and the political organizations to overcome these past reforms. These political costs of transacting represent the costs of undertaking specific efforts in creating, maintaining or changing a system of institutionalized rules to create, maintain or change the political organizations (Furubotn and Richter, 2000 p.56). More specifically, they are composed by "the costs of measuring, monitoring, creating and enforcing compliance" (Levi, 1988 p.12). The point of such efforts is to develop the authoritative relationship dedicated to provide sufficient power and coercive abilities to create, maintain or change the institutionalized rules. In general, the State represents the most powerful organization as it possesses the monopoly of coercion (Levi, 1988). In that case, efforts are directed toward the laws to get support from the power of the State in undertaking actions within the institutional arrangements. However, such processes are also occurring at lower level since the institutionalized rules provided by the State are not controlling all the interactions but left some of these transactions to the discretion of lower levels of organizational structures (Ostrom, 1990).

1.4.2. Transaction Costs from Institutional Linkages Between Organizations: Polycentricity

Since the State alone cannot effectively regulate any interactions, the principle of subsidiarity in which power is being decentralized for some of the authoritative relationships allows the creation of a somewhat spontaneous order through an increase of ability for political organizations to craft local institutionalized rules in accordance with the local context, such as counties, cities or special districts (McGinnis, 1999). In other words, economic organizations willing to create or change some of the institutionalized rules that are applied to them, will still need to go through some of the political organization to do so, but are no longer required to undertake effort in creating or changing such institutionalized rules at a State level, but rather at a smaller scope. Therefore, the costs of transacting with other political organizations may be drastically reduced since the scale of change is shrinking. Since some of the institutionalized rules are defined at the local level, it follows that property rights are, at least in part defined for the local context. Indeed, property rights "are significantly more likely to address the interests and needs of local people when they are not imposed from the outside but rather are based on existing rights and reflect local values and norms" (Knox and Meinzen-Dick, 2001 p.22). Smaller entities are often better to cope with local problems that the higher levels of the hierarchy will not see or acknowledge (Ostrom, 1990, 2005). Thus, several benefits from a local organization are drawn in Ostrom (2005 pp.281-282) which include a better adaptability through local knowledge, resilience and inclusive organization as well as a lower enforcement costs or a lower probability of failure through multiple parallel organizations (Garrick, 2015). This underlies the basic reason for adopting a system of polycentric governance where multiple organizations are competing or cooperating at multiple scales in a nested system (Ostrom, Tiebout and Warren, 1961; Ostrom, 1999 and Polanyi, 1951).

1.4.2.1. The Concept of Polycentric System

As Garrick mentioned in the context of water management, "…a middle ground has emerged between the extremes of abject failure and unmitigated success in the form of polycentric governance arrangement" (Garrick, 2015 p.12). Originally envisioned by Polyani (1951) in its book, *The Logic of Liberty*, the concept of *polycentricity* is intended to depict the multiplicity of localized decision centers having a certain degree of autonomy. This concept has been diffused in multiple law and social studies (Chayes, 1976; Horowitz, 1977 and Fuller, 1978) but gains in popularity with the various works of Vincent and Eleonore Ostrom in the field of governance (V.Ostrom, Tiebout, and Warren 1961; E.Ostrom, 1990, 2005 and 2010) in which they defined a coherent framework to analyze such polycentric system. In this framework, each action situation is embedded into a broader system of hierarchical level. While the higher levels fixe the global rules (property and liability), the lower levels define the operational rules from the global rules aforementioned.

A polycentric system, defined by Ostrom, Tiebout and Warren (1961) as having "many centers of decision making that are formally independent of each other" (p.831), allows a certain degree of institutional separation among the population into specific organizations. The goal of such organizations is to bring a substantial discretion in crafting their bundle of institutionalized rules not only to fit this latter more adequately with the complexity of a local situation (Polanyi, 1951 and Ostrom, 1972), but also to provide sufficient rights to some economic organizations to the detriment of others toward the maximization of some objective function (Arrow, 1971). Indeed, since the actions of some agents may be overturned by the actions of others, some action within some organizations may be favored to the detriment of others. Put differently, an organization is "a group of individuals seeking to maximize an objective function" (Arrow, 1971 p.224) in which control is given by a set of rules providing the individuals the ways and the motivation to act in accordance with these rules (Arrow, 1971 p.225). The polycentric governance is thus based on multiple centers and is, to some extent, close to the notion of "polyarchy" where representative agents are elected or nominated to rule certain situations in the name of the population they are representing (Dahl, 1973). In its most extreme form, polyarchy may be viewed as multiple individuals acting separately and having extensive allowance in participation and contestation. Yet, such an allowance is not equally divided into a number of individual actors but is rather clustered in multiple groups (or organizations) with a relative autonomy and obligations toward the other groups (rights and duties) (Dahl, 1973). In an organization, interaction among cooperative individuals is more likely and can limit the needed effort to gather the information, replacing it by trust which can be a self-reinforcing process through frequent interaction (E.Ostrom, 2005 and Camerer, 2003 p.117).

It points out the importance of coordinating the action of the multiple centers (either through competition or cooperation) as a fine line between order and chaos (Garrick, 2015). Although the multiplicity of governance units can become particularly complex, it is not always synonymous of a chaotic fragmentation. As pointed out by Ostrom (1972 p.20), "Patterns and regularities which occur under an illusion of chaos may involve an order of complexity that is counterintuitive". Indeed, when the provision of a public good is intended to serve heterogeneous needs, a wide range of specific entities is thus necessary to correspond to these multiple demands. These highly specialized entities can be coordinated in an integrated mechanism of management (Oakerson and Parks, 2011). An effective integration of the different organizational units can be viewed as a good combination between the subsidiarity and the complementarity principle. In this way,governance tasks are assigned to the lowest level possible of organizational entities while the task of coordinating these multiple organizations is bestowed to higher levels when a complementarity of actions (due to externalities or economies of scale) is necessary between the multiple organizations (Marshal, 2005 cited by Garrick, 2015 p.12). In that case the mechanism for deepening the integration between the multiple local organizations is a necessity to improve coordination. Feiock (2013) differentiates this mechanism between two major characteristics: the authority and the scope. The former varies from informal networks to formal agreements though contracts. The later determines the extent of the problem that goes into a deepening of integration (one or multiple rules to be changes for two or more organizations). The more important is the risk of defection from the higher level, the less the relation would stay informal (Feiock, 2013). Therefore, rules that define the inclination toward a particular system of institutionalized rules and thus for a specific type of property rights regime are the consequence of a series of adaptations at each level and becomes more specific to the locality as we go into lower levels. In that respect, the design of more appropriate rules through polycentric systems to share the knowledge and to coordinate individuals' behaviors will help in managing the water resources at the local level but will nevertheless not provide complete or fully defined private property rights and may cause some deterrence in handling larger problem such as water scarcity at the State level (Garrick, 2015 p.43).

While such organizational structuration makes the deciphering of intricate situations easier by providing more adequate institutionalized rules to rule the local interactional situations, it also induces a substantial limitation in modifying institutionalized rules at a higher level (Ostrom, 2005 pp.281-282). Furthermore, the interdependence of multiple organizations only shifts the problem of externalities from the individual level to the organizational level but is not necessarily reducing such conflicts and may even enhance them (Ostrom, 2005 p.286). Combined with the notion of path dependency previously defined, we can more clearly see the problem of adapting an institution in a polycentric system to some exogenous and larger changes than the scope of the aforementioned organizations.

1.4.2.2. The Problem of Path Dependency in a Polycentric System: The Adaptive Efficiency

Adaptive efficiency refers to "trajectories of economic performance in the face of pervasive uncertainties, systemic risks and shocks, feedbacks and tradeoffs across multiple scales" (Garrick, 2015 p.224). In the context of path dependency and non-zero transaction costs, such adaptive efficiency involves sequential innovation of the institutions to lower the transaction costs (Carey and Sunding, 2001 p.291). Since the decentralization of power will imply a greater ability to act for local political organization and thus will provide an easy access of local economic organization to change the institutionalized rules, the latter will be adapted to the local context at the time they are defined. It is not unreasonable to expect that such adequacy of institutionalized rules will make the economic organizations to grow sufficiently larger to foster a certain specialization of the political organization (decision to change the rules are mostly initiated by the economic demand). Such process of self-reinforcement may continue until the political organization has no longer the ability to produce institutionalized rules in accordance with the demand of the economic organization. Yet, the power vested to local organizations may be sufficient to promote an important specialization of the economic organization under its authority which will limit the willingness to change from economic agents. This will be more specifically the case if the required changes may harm some of the productive agents to the profit of some others, the latter being in minority since the institutionalized rules established by political organizations have promoted other types of productions. The problem lies in the external effects that different economic activities may have upon one another.

The rights granted to the political organizations are generally accompanied with the power to enforce these rights and thus to establish and enforce property rights for all the activities in economic organizations. If some of these activities have negative effects upon some others, the latter being favored at a certain time by a substantial part of economic and political agents, duties upon the former will be created to not affect the latter, which will cause the decrease of some activities subject to these duties and the expand of some others granted with the correlative rights upon the side effects. The inadequacy of the institutionalized rules will arise if some changes occur in the future that make the constrained activities more beneficial if rights were vested to them. Since the required costs of transacting with political organizations to change the institutionalized rules can be very high (more specifically if the opposite interests are well established among the political organizations), attempts to foster institutional changes may simply not worth the efforts necessary to promote such changes. Multiple causes to such increase of transaction costs can be listed but one of the most prominent is the difficulty to scale up the governance structure when issues lies outside the authorized and authoritative boundary of the political organizations (Ostrom, 2005 and Garrick, 2015). The limit in accessing sufficient information when this task is under the authority of other political organizations, the potential conflicts from economic agents in different organizations or the problem of dealing with large scale problems which are potentially creating side effects not only between individuals but also between organization, all increase the transaction costs of changing the institutionalized rules by limiting the ability to act of political organizations (Ostrom, 2005 p.282).

Overall, path dependencies are arising as a corollary of the Coase theorem which states that in the absence of transaction costs, the initial allocation of resources is irrelevant to get an efficient system of production (Coase, 1992 p.717). However, in presence of non-zero transaction costs, the initial allocation of resources, provided by past reforms and established institutions affects the end-result of a system based upon the decentralized exchange of the resources and create inertia in the reallocation of these latter when changes are required (Griffin, 1991).

In the context of water institutions, climate and structural changes in many arid regions around the world, without any proper institutional adaptation of property rights have induced, these past decades, more frequent water crises (Saleth and Dinar, 2004). While such conflictual situations are often triggered by an increasing scarcity of water which magnify the external effects that some activities may have upon others and thus, institutions are at the heart of such conflicts (Saleth and Dinar, 2004). Indeed, the insufficient quantity of water to meet the growing demand requires to make choices in enhancing the rights to fulfill some needs to the detriment of some others which will experience expanding duties. Thus, change of water institutions will be needed to fit more adequately the context in which this resource is being used (Libecap, 2011, 2012). Flexibility of behaviors from institutionalized rules is more specifically needed in a situation of increasing versatility of water supplies (Saleth and Dinar, 2004). The benefits from such institutional changes is however not without costs since supplemental efforts will be required not only to devise new institutionalized rules but also to cope with the previous ones (Libecap, 2011 and North, 1990). Path dependencies and lock-in effects are fostering political conflicts to redefines rights and duties among water users and is adding up to the already significant technical challenges of disentangling the different external effects from the varied water uses (Challen, 2000 and Garrick, 2015).

1.4.3. Physical and Institutional Challenges for Water Markets to Arise

As previously defined, an externality can be viewed as an inadequately ruled interaction which induces the property rights to not account for all negative (or positive) effects they may cause, and transaction costs are the resources lost in the process of changing these property rights through the creation, the maintenance or the change toward more adequately fitted institutionalized rules. Due to the tradition of water institutions heavily centralized and mostly based upon supply enhancement strategies rather than demand management, the rise of water markets where decision processes must be decentralized implies an important modification of the institutionalized rules that are currently applied (Challen, 2000; Easter, Rosegrant and Dinar, 1998; Garrick, 2015: Griffin, Peck and Maestru, 2013; Libecap, 2012; Rosegrant, Ringler and Zhu, 2014 and Saleth and Dinar, 2004). The magnitude of change will thus require a substantial amount of time and financial resources not only to decipher the technical challenges due to the physical and complex nature of water resources but also to overcome the current institutions, often well fitted for past conditions but source of inadequacies and potential conflicts in the present (Libecap, 2011 and Saleth and Dinar, 2004).

Recent work of McCann and Garrick (2014) pointed out the different challenges for water markets to arise. They draw a classification between physical and institutional factors that may deter the changes of the water institutions toward an effective system of water markets. While they depict multiple issues arising from physical factors such as the geographic scale of the potential external effects from transacting water and the available technology to measure, monitor and also improve the water use, their main focus is upon the institutional elements and more specifically, the property rights: "[p]roperty rights, and conflict over property rights, which results in high costs of enactment, are revealed as fundamental determinants of transaction costs" (McCann and Garrick, 2014 p.29). The point is that physical factors will provide a wide variety of limitations and opportunities for water institutions in general and water markets in particular to be developed, but its rests upon the authoritative entities to take advantage of these opportunities and to cope with these limitations by drawing adequate institutionalized rules. This implies that water markets cannot be simply the result of a spontaneous behaviors toward order, but are instead the outcome of a designed set of rules purposely defined to facilitate the decentralized exchanges of a complex resource (Challen, 2000; Garrick, 2015 and McCann and Garrick, 2014). Such rules may attempt to define allocation mechanisms of the available water resources either through a strong excludability principle which will provide perfect or close to perfect private property rights for individuals, or alternatively through a weaker version of this excludability where delineation is being drawn at a community level rather than at the individual one and thus provide common property rights (Smith, 2008). Decision between the two poles of the spectrum will ultimately depend upon the intricateness of the hydrological interconnections and thus the easiness of delineating the rights and duties between users. Therefore, the choice over the more common or private property rights regime is the result of a tradeoff between the costly information needed to improve the property rights regime and the costly effects of inadequate property rights regimes (Smith, 2008).

In summary, one of the main issues arising from the establishment of water markets and the possibility of transacting water outside of the basin of origin is the question of the external effects that such transfer may cause. An adequate set of institutionalized rules need to be settled to foster and sustain a certain predictability of actions undertaken by water users (including the act of trading water). Yet, defining such institutionalized rules requires to gather a substantial amount of information upon the circuitous hydrological cycle and the multiple interconnections with the societal and the environmental systems. Due to its fluid characteristic, which induces the resource to be difficult to measure (Libecap, 2012 p.400) and the permanence of its molecule which induces it to be reusable (Griffin, Peck and Maestru, 2013 p.5), water resources cannot be easily divisible and thus cannot be partitioned into well-defined shares upon which individuals could have complete control. In light of such difficulties to decipher the complex nature of hydrological cycles and the circuitous interactions with the societal and biological phenomena, property rights for water will likely never be complete nor traded like a private good can be (Garrick, 2015 p.43).

1.4.4. The Challenging Task of Defining Property Rights for Water

1.4.4.1. The Different Types of Property Rights from Different Institutionalized Rules

The physical and socio-economical context in which the property rights are settled has a major impact on the effectiveness of the institutionalized rules established by the very same property rights (Ostrom, 2005). Drawing upon Bromley (1989 p. pp.204-206), we can define four broad categories of property rights that can be used to manage the water resources:

1. The open access property rights regime (or non-property regime) is the case of a resource without any specific rule to define the adequate behavior for extractors. This implies that the resource is owned by everyone and as everyone can extract the quantity they want, the available stock collapse under the pressure of the multiple uses and lead to the well-known tragedy of the commons (Hardin, 1968). The excludability is close to zero in this extreme property regime and the divisibility might be possible but is not effective as anyone can extract the quantity desired. However, even in such regime of property rights, the resource

stock is not necessarily doomed. The limit in extraction capability due to weak technological improvement or similarly a moderate demand can avoid the tragic ending.

2. The common property rights regime has often been confounded with the open access regime due to the illusion sometimes that no rules are in effect within some communities but this impression is often given by the fact that many rules are informal and not well written in State's law (Griffin, 2016). Indeed, the major difference with open access regimes is that common properties embeds boundary rules which determines who can have access to the resource and who cannot. Thus, the community have the right or the ability to exclude an individual or a group from the extraction activity and can subdivide the stock following allocation rules devised by the community itself (Ostrom, 1990).

3. The State property regime rights refers to a situation where the resource is explicitly owned by the State and will establish the property rules and liability rules that the citizens must follow. Any change from the initial use by an individual have to be review and accepted by the State authority through an administrative process. However, it is generally the case that the State owns the property of the resource but the individual owns the right use the resource (have the *usus* and *fructus* but not the *abusus*).

4. The private property rights regime is a system in which the resource is parceled up between individual such that no interference arises from the use of the property rule by a party to the other parties. There is full excludability and divisibility of the resource and thus transferability through a private decision making. While the common property manages the resource through collective choice rules, the private property rights, in its complete form allows the sole individual to undertake the decision without the acceptance from other individuals. Griffin (2016) states that the evolution from an open access regime to a private property regime can be the fruit of an historical process through incremental refinement of the property and liability rules and progressively moves from an open access to a common then to a State and finally to a fully private property regime.

While this categorization is somewhat arbitrary (recall that the range of property rights regime is better described as a continuum of multiple rules), it is useful to begin by this simple classification before going into the more complex reality. Indeed, multiple property rights regimes can coexist depending on the physical and socio-economical context in which these regimes are settled as well as the level of analysis (Ostrom, 2005). The categorization of property rights regimes is thus less evident than presented above and might be better depicted as a hierarchical combination of multiple property rights regimes (Ostrom, 1990). In general, the State set up basic property and liability rules which are appropriated and adapted by the community to finally end up driving the individual behaviors within or between the communities. At each level, the rules are refined to correspond to the local opportunities and constraints and constitutes a complex system of nested institutions within a polycentric structuration of the organizational space (Ostrom, 1990 pp.50-54). Such system of institutionalized rules that provides the foundation of property rights will be defined from the mechanisms used to provide entitlements to individuals.

1.4.4.2. The Difficulty in Defining Institutionalized Rules for Water Resources

Challen (2000 pp.26-27) distinguished three levels or steps of institutional decision over the specific task of resource allocation. The first step is the establishment of an entitlement system which will subdivide the water resource into appropriable shares to be used by the individuals. This system of delineation will provide exclusion mechanisms through the formulation of institutionalized rules and will define the nature of property rights such that the authority will be able to enforce the initial allocation determined in the second step and its adjustment in the third step. This second step corresponds to a mechanism for supplying an initial allocation of the entitlements delineated in the first step. While this initial allocation would be unimportant in a world of zero transaction costs, this is not the case when gathering the relevant information and disentangling the circuitous interplays of water uses are costly and induces a substantial inertia in the third step which is a mechanism for adjusting the initial allocation. In this later step, rights defined in the first step are being confronted with the allocation provided in the second step and solutions are being found to solve some potential inadequacies. These solutions may be through market interactions, equilibrating the demand and supply of water rights by means of a price mechanism. It may also be through community regulation where some members of a local community are in position to reallocate the water resource. Finally, it can be through governmental authority where reallocation is defined by bureaucratic decisions. The important point is that, the adequacy of the reallocation's mechanisms in the third step will be determined by the decisions undertaken in the two first steps. The first step principally depends upon the measurability and the observability of the effects that an activity may have on others because the delineation and enforcement of rights requires to be able to disentangle the different effects from one use to another to adequately divide the resource. It will define the tools that may be used to exclude some users from extracting the resource and will provide the process for granting specific rights for claims of use. This entitlement system is more specifically important since it will formulate the basic institutionalized rules that will be used to extract the resource and thus will define the property rights that individuals may have (Challen, 2000 p.26).

The type of entitlement system can be defined as quotas either on an input- or on an output-based depending on the level of information that a regulator may have (Stevenson, 1991 pp.63-67). The output-quota is defined as a limit on the total amount of the resource that can be extracted by one or more individuals (if it is a limit for one agent, the property rights regime tends toward a private system while if it is a limit for multiple agents the property rights regime tends more toward the common). Such system requires that the use of the resource can be directly observable to enforce and monitor the extraction at a relatively low cost. Whenever this is not the case the sole alternative is a system of input-quota. Indeed, the input quota does not attempt to directly measure the resource used but rather fixes the amount of a chosen input for a specific use. The goal is to attempt to create a system based upon the exclusion principle by using a proxy of the resource demand as exclusion tool. In that case, whether the costs of enforcing and monitoring the resource is high or low, the input-quota simply bypasses the potential issues by focusing upon a good complementary of the resource and easy to monitor. However, such a system requires the proxy to be well correlated with the extraction of the resource to have an effective system of allocation. Finally, if the resource is neither easy to monitor, nor has a stable proxy to limit for potential overuse, no system of entitlement can be said to be better than the other since none of these allocation mechanisms will produce effective exclusion tools and management will more tends to governance principles where individuals have only part of the control upon the resource (Smith, 2008). Table1.2 shows the different possibilities and is adapted from Challen (2000 p.37):

		Monitoring Costs	
		Low	**High**
Complexity or Instability	**Low**	Input or Output quotas	Input Quotas
	High	Output Quotas	None

Table 1.2: Information and allocation mechanism, adapted from Challen (2000 p.37)

In the context of water resources, the important difficulty to monitor and enforce the extraction of water from streams or from the aquifers (fluid characteristic) allows to use the output-quota system of entitlement only in specific conditions, when water is being stored and conveyed using human infrastructures for example (Challen, 2000 p.36). Yet the input-quota cannot be considered as the panacea either. The problem generally arises from the stability of the water molecule which allows downstream individuals to reuse this resource already used by upstream users (Griffin, 2016 p.268).

In agricultural irrigation for example, there is a substantial difference between the quantity of water diverted from a stream and the actual quantity of water consumed by the crops, the latter being higher than the former and the difference can be reused by other irrigators (quality concerns left apart). This often causes the water uses to overlap one upon another which can be view as typical reciprocal externalities (Blomquist, 2012 p.376). Thus, by adapting the formalization of Scitovsky (1954 p.145) previously defined, the production function of an irrigator can be $x_i = F_i\left(l_i, w_i, (1-c)\sum_j w_j\right)$ where j corresponds to all upstream irrigators using a quantity w_j of water for which only the share $c < 1$ is consumed by the crop and the share $1 - c$ is made available for the irrigator i to produce his output. If the input l_i is easily measurable and correlate with the extraction of water such that it can represent the land used for irrigation, and if c is sufficiently close to unity so that there are no significant externalities, the land could be used as an input quota to control for the extraction of water at low cost. Yet, if the value of consumption c is relatively low, the correlation between land and water extracted is not anymore so perfect and the production function of a downstream user will now depend upon the production of an upstream user. The problem becomes even more complicated and the production function more difficult to estimate when the agent i is not an irrigator, but a city using the return flows for domestic use x_i, or environmental needs with a non-valuated outcome x_i. Such interconnectedness has led Freyfogle (1989 p.1530) to define water property rights as a "complex web of mutual dependencies".

One of the main issues with defining adequate property rights for water lies in the wide variety of uses and values of this resource which induces an important specificity of the hydrological asset (Garrick, 2015). Blomquist (2012 p.374) has at least counted 11 different values attached to the use of water with different degree of rival interconnections between each of them (Garrick, 2015). The table 1.3 is summarizing these different values of water use with their rivalry with other types of use principally determined from the requirement of subtracting water from its original place[11].

Subtractibility	Type of Use
Non-Subtracting	*Transportation/Navigation* *Hydropower*

[11] The basic classification presented here solely focuses on quantitative aspects of the rivalry nature of water resources as some of the used presented may not be compatible over other aspects (hydropower and ecological or transportation and aesthetic, for example). Yet, at some level, any type of activity will have some side effects upon at least one another activity which would make any attempts of classification useless.

	Recreation *Waste Disposal* *Aesthetic* *Spiritual* *Ecological*
Subtracting	*Domestic Use* *Irrigation* *Industry* *Public Safety*

Table 1.3: The multifunctionality of water resources, adapted from Blomquist (2012 p.375)

Thus, adding to the technical difficulties of delineating adequately the rights of use, the political controversies upon which uses should have the priority over others increases the challenges of establishing a somewhat harmonious system of property rights. More specifically, subjective values for water can be an important component of the total value attached by a community to the resource. In the water context, the subjective value of this resource in some communities goes beyond the market value such as security, opportunity, and self-determination (Draper, 2005 and Shiva, 2002) or symbolizes life, power and status (Haan, 1997). It has also intrinsic features not even valuable in money units such as the non-anthropocentric values of environmental needs (Dellapenna, 2013). The key point is that neither a State nor a community and even less an individual can truly apprehend the extent of the water values for all other individuals. Thus, from these subjective values, added to the important heterogeneity of complex phenomena faced by the agents, property rights upon water cannot be simply a dichotomous situation between private (full exclusion through perfect institutionalized rules) and open access property rights (complete absence of institutionalized rules). Indeed, as have pointed out Blomquist (2011 p.376) "in the world we are trying to understand and explain, there is not a unique resource being used for a particular purpose by one set of users with one bundle of property rights. There are various resources with multiple valued uses, there are multiple and overlapping groups of users, and different users have different types of rights to different aspects of the valued uses of those resources". Thus, the monotonic change toward a more refined property rights regime in a "Demsetzian" fashion is not occurring in many arid regions around the world, including the West America (Brewer, Glennon, Ker and Libecap, 2007).

Due to its characteristic of public good (pervasive and indispensable use of water for number of societal and environmental needs as depicted in table 1.3), the water institutions have been developed more in line with a governance strategy rather than based upon strict and clear exclusion principles (Smith, 2008). As a result, common property rights are being developed to provide institutionalized rules adapted for the local situation of the water use. In such regime, the collective choice that issues rights of management, exclusion and alienation are being mostly defined within the community, but embedded into a broader set of rules defined at a higher level of authority. Thus, the community has the right or the ability to exclude an individual or a group from the extraction activity and can subdivide the stock following allocation rules devised by the community itself (Ostrom, 1990). The community will thus be constituted toward a formal or informal organization to manage the water resource through mutually agreed rules that define the different rights and their correlative duties of individuals upon the use of water resources. For example, the Water User Organizations (WUA) are specific local entities (often public or semi-public) intended to manage the hydrological resource at a local scale through institutionalized rules can be view as such units of governance (Schlager and Blomquist, 2008).

It can be said that when information upon the complexity of a resource is measurable and enforceable at a low cost, exclusion principles can be easily defined and the regime of property rights will tend toward the private one. This fosters the possibility of trading the resource since rights are well defined. However, when the resource has intricate complexities with multiple external effects for which information is costly to obtain, it can be under State or common property regimes (Smith, 2008). From its greater coercive power, the State or other governmental agencies can impose a specific way of acting, advocating or restricting the transfer of the resource through markets, but is often dependent upon the acceptance of such power by the local community (Ostrom, 1990). The mechanisms to allocate the initial endowment and to provide adjustment to exogenous shocks will follow the path of the institutionalized rules defined in the system of entitlement.

The categorization of property rights regimes is thus less evident than the one developed by Bromley (1989) and it might be better to depict such broad systems as hierarchical combinations of multiple institutionalized rules at multiple levels (Schlager and Ostrom, 1992). Each of these rules enacted at a higher level will be adapted and interpreted at the lower level to fit with the local set of opportunities and constraints. Given the heterogeneity of these opportunities and constraints when looking at a territory sufficiently large (at the State level for example), local groups or entities will emerge from a certain intra-group homogeneity which leads to similar rules but thus creates an inter-group heterogeneity. While, such a patchwork of localized entities may resemble to a complete disorganized set of local organizations, this diversity is often necessary to manage a complex resource such as water (Ostrom, 1972 p.20). However, a major issue arises when it comes to coordinate these multiple entities and adjust their use of water for larger scale problems that go beyond the authoritative and authorize relationship of these entities (Garrick, 2015 p.178).

1.4.4.3. The Challenging Task of Adjusting the Institutionalized Rules

For water markets to arise, substantial benefit must be expected from the private decision making of transferring the resource (Saleth and Dinar, 2004). As previously shown the intricacy of water use often causes the transaction costs to rise dramatically such that most of willingness to trade water vanishes (Archibald and Renwick, 1998; Colby, 1990 and Easter, Dinar and Rosegrant, 1998). In that case, individuals or local organizations will prefer to rely solely upon the existing institutionalized rules which may not provide a sufficiently stable and predictable authorized relationship to participate into water markets. This is more specifically the case in certain types of common property regime where alienation rights are not well defined because divisibility and excludability are being drawn for a certain type of use within the community that does not necessarily match the specific use induced by transferring water (Smith, 2008). For example, an accurate measure of return flows is not required when water is used in the region of origin since the reuse is still possible. It is thus not cost effective for the individuals or the local organization to define and enforce a precise exclusion tool for such external effect since no conflict will arise. However, if some users are intended to transfer the whole or part of their water entitlement outside the region of origin such that the return flows from this amount of water is from now on not available for other users, conflicts will arise inducing important transaction costs if institutionalized rules did not accurately specify the rights and duties of each individuals or local organizations upon these return flows (Griffin, 2016 and Smith, 2008).

While such institutionalized rules may provide in theory the exclusion tool which allows a sufficient predictability of behaviors and thus will facilitate the transfers since individuals do not bear the risk anymore of misbehaving, defining a sufficiently accurate exclusion tool for all use and potential external effects is generally too costly and too conflictual to be handled by the sole individuals or local organizations. Such issues are generally best managed case by case with the support of a higher authority such as governmental agencies (Smith, 2008 and Garrick, 2015). In other words, the exclusion tools will provide modularity of property rights in the sense that it will allow individuals to undertake action without being concerned by the actions of others as long as he stays within the limits of his rights (Smith, 2008 p.465). But such modularity goes along with an important investment in institutional infrastructures to draw the exclusion tools that will handle any types of external effects prior to the interactional situations. To the contrary, a governance system based upon weaker exclusion tools induces a less modular structure for decentralized decision making to transfer the water resources since they cause supplemental interaction to occur and thus an increase in transaction costs for determining rights and duties in each case. However, by providing an interface of discussion, such a system limits the risks of unintended external effects to arise from inadequate exclusion tools, but often requires the support of higher level of authority to foster the coordination between individuals or local organizations (Garrick, 2015). Indeed, in an organization, interaction among cooperative individuals is more likely and can limit the needed effort to gather the information, replacing it by trust which can be a self-reinforcing process through frequent interaction (E.Ostrom, 2005 and Camerer, 2003 p.117). The importance of regrouping individuals in organizations is thus to decrease such costs for any exchange within the organization and facilitate the coordination among members of the aforementioned organization (V.Ostrom, 1997). Smaller entities are often better to cope with local problems that the higher levels of the hierarchy will not see or acknowledge. Thus, several benefits from a local organization are described in Ostrom (2005 pp.281-282) which include a better adaptability through local knowledge, resilience and inclusive organization as well as a lower enforcement costs or a lower probability of failure through multiple parallel organizations (Garrick, 2015). In that respect, adjusting the institutionalized rules to accommodate for the potential effects of water markets require a supplemental effort at multiple level of the authorized relationship and represent a scaling-up challenge for policy makers (Garrick, 2015 p.178).

Feiock (2013) depicts such a challenge as an "institutional collective action dilemma" where each local organization may prefer to pursuit their own goals rather than participating into an interactional action with other organizations in deciphering the necessary institutionalized rules to manage water markets. Because these local organizations were often not created specifically to handle the effect of water markets but rather to manage water at the local level, they may not be willing to participate in such endeavor when they are expecting to lose from the arrangement made and may block as well the possibility of coordination in a large scale (Libecap, 2011). Effort from governmental agencies to foster the development of an effective polycentric system and the coordination of the multiple organizations is often a requirement but cannot substitute the advantages provided by the local management (Ostrom, 2005 and Garrick, 2015). It points out the importance of coordinating the action of the multiple centers (either through competition or cooperation) as a fine line between order and chaos (Garrick, 2015). Although the multiplicity of governance units can become particularly complex, it is not always synonymous of a chaotic fragmentation. Indeed, when the provision of a public good is intended to serve heterogeneous needs, a wide range of specific units is thus necessary to correspond to these multiple demands. These highly specialized units can be coordinated in an integrated mechanism of management (Oakerson and Parks, 2011). An effective integration of the different organizational units can be viewed as a good combination between the subsidiarity and the complementarity principle (Garrick, 2015). In this way, the assignment of governance tasks is granted to the lower level possible of organizational entities while the task of coordinating these multiple organizations are bestowed to higher levels when a complementarity of actions (due to externalities or economies of scale) is necessary between the multiple organizations (Marshal, 2005 cited by Garrick, 2015 p.12). In that case the mechanism for deepening the integration between the multiple local organization is a necessity to improve coordination. Feiock (2013) differentiate this mechanism between two major characteristics: the authority and the scope. The former vary from informal networks to formal agreements though contracts. The later determines the extent of the problem that goes into a deepening of integration (one or multiple rules to be changes for two or more organizations). The more is the risk of defection from the higher level, the less the relation would stay informal (Feiock, 2013). Therefore, rules that define the inclination toward a particular type of property rights regime is the consequence of a series of adaptations at each level and becomes more specific to the locality as we go into lower levels.

1.5. Conclusion

The determination of an adequate system of property rights for water resources has been an important and challenging problem for scholars and policy makers (Libecap, 2012; Saleth and Dinar, 2004 and Smith, 2008). The difficulty arises from the circuitous interactions between this resource and societies that induces transaction costs to emerge as impediment for any establishment or maintenance of an effective allocational mechanism (Schlager and Ostrom, 1992). Consequently, large efforts are required to provide adequate property rights that will fit the local complexity of the interplay between water resources and human needs. Indeed, water is a complex resource with multiple physical and socio-economic interdependencies between the different agents and the biological system (Smith, 2008). Having a complete understanding of such complexity is a difficult task and is generally out of reach for most (if not all) individuals. In that respect, the design of appropriate rules to share the knowledges and to coordinate individuals' behaviors will help in managing the water resources but will nevertheless not provide complete property rights (Garrick, 2015). The important point from this is that, as have pointed out Garrick (2015 p.183), "[t]he need to set up and periodically modify the institutional arrangements governing water markets contradicts the proposition that water markets are a self-maintaining allocation mechanism". It is rather the result of multiple interactional situation to draw institutional rules that handle the different external effects that such water markets may have. Depending upon the authoritative relationship vested from past institutions, the institutionalized rules will either foster the development of water markets or to the contrary will deter its progress.

Chapter 2: Scaling-up the California Water Management through Water Markets

"A discussion of California water policy cannot be fully appreciated without some sense of the complexity and expanse of the California water resources system, including its physical and institutional characteristics" (Israel and Lund, 1995 p.1). Indeed, history has shaped the water institutions in California to cope with contemporary crisis from the aridity of its climate and the recurrent water shortages. Through that way, history has also molded the future evolution of water institutions from the delineation of rights to lower the transaction costs for some water uses which have caused the increase of the transaction costs for some other uses, locking the whole system into a path dependency (Libecap, 2011 p.76).

During the nineteenth century, California took advantage of its geographical features to develop its economy, mostly based upon agricultural production in relatively small units, scattered in the State's territory. Such small units were a very effective way to manage the scarce water resources at the local level. The institutional infrastructure gave them the security of their water use and the ability to reallocate water among their members to optimize the utilization of this resource within the unit's boundaries. But with the growth of the State and the expansion of its economy accompanied by the increase of its population, the small units of water management were not anymore sufficiently well fitted to cope with the larger problem they had to deal with. Increasing demand in many new places required to reallocate water not only among the unit's members, but also between the units themselves. In that respect, scaling-up the water institutions in California was a necessary condition to continue its economic expansion.

In that context, scaling-up means to build the adequate institutional and physical infrastructure to connect agents that were initially separated. The objective is to account for some interdependencies that were initially not formally recognized (Garrick, 2015 p.178). In California, the unintended interdependencies were the fact that the small units created initially to manage water within their boundaries would be affected upon each other by appropriating part of the water resources, reducing at each extraction the total quantity of water available. Without appropriate institutionalized rules to manage the whole system, some units may be in excess of water while some others may experience water shortages. Thus, the history of water in California can be simply summarized as a continual attempt to meet the supply with the demand of water through frequent reforms and institutional changes.

However, an institutional change being dependent of the previous ones, the path of institutional restructuration is, from the beginning biased toward the initial allocation of water and can only be altered at the cost of substantial efforts from the political organizations. Minimizing these costs by establishing low changes in water institutions would cause the costs of deciphering the multiple interactional situations to rise for the economic organization.

In this chapter, we attempt to review the most important events in the water history of California to understand the path of its water institutions and get some insights of the current issues within the developing water markets.

2.1. A Glance at the Californian Economy and its Hydrologic Condition

As have pointed out Howitt (1998 p.120), "[w]ater is essential for all sectors of California's vibrant economy. It is no exaggeration to state that the eight largest economy in the world literally run on water." In this small section, we quickly review the main social and economic features of California to put it in perspective with its hydrological condition and some aspects of the water institutions with its growing economy.

2.1.1. Economic and Institutional Conditions of California

In approximatively 150 years, the State of California has arisen as one of the most powerful State in the US and a leading economy worldwide. The following presentation will provide basic information upon the State of California that will be useful for understanding the evolution of its water institutions

2.1.1.1. Populations

The Gold Rush of 1848 provided California with a spectacular burst of prosperity and engaged this State into the rapid track of economic development with a non-native population multiplied by ten in only one year and a jump-start of its economy from agricultural to the extensive exploitation of the mineral resources. However, the rapid exhaustion of the precious metal drove the miners to reallocate their work force to sectors more productive such as agriculture at the dawn of the twentieth century and finance and service related sectors fifty years later.

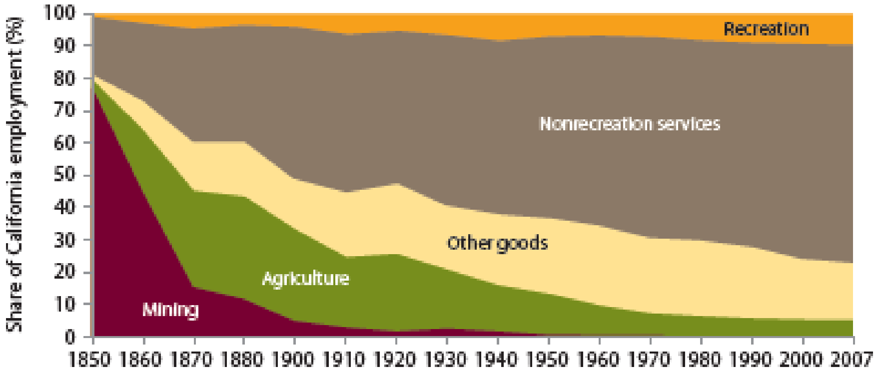


Figure 2.1: Employment in California, 1850-2000 (Source: Hanak, Lund, Dinar, et al., 2011 p.54)

The history of the California's economy can thus be divided in four stage which will lead to the multiple State's reforms in water policy. The first is the pre-gold rush with a population predominantly native and specialized in agricultural production. The real breakthrough was the John Marshall's discovery at the Sutter's Mill in 1848 that led to the famously named "Gold Rush" and attracted a massive immigration from various countries. The lion share of the labor force was then dedicated to the mining activity, but quickly diminished with the rarefaction of the precious metal. Agricultural production and service related activities took the baton in a third stage. For example, the massive reallocation of workers led to the decrease of mining activity and the number of farms was multiplied by more than twenty in ten years (from 872 in 1850 to 18716 in 1860). But the service sector quickly overcame agriculture in terms of employment to become the major source of employment in California by the year 2000. This caused the cities to expand at the detriment to the rural population which shrunk from half of the State population in 1900 to less than one percent in 2000.

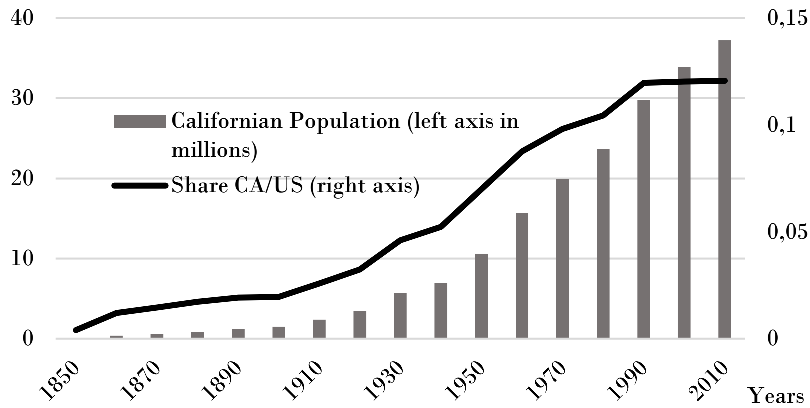


Figure 2.2: Population in California and share of the USA (Source: US Census)

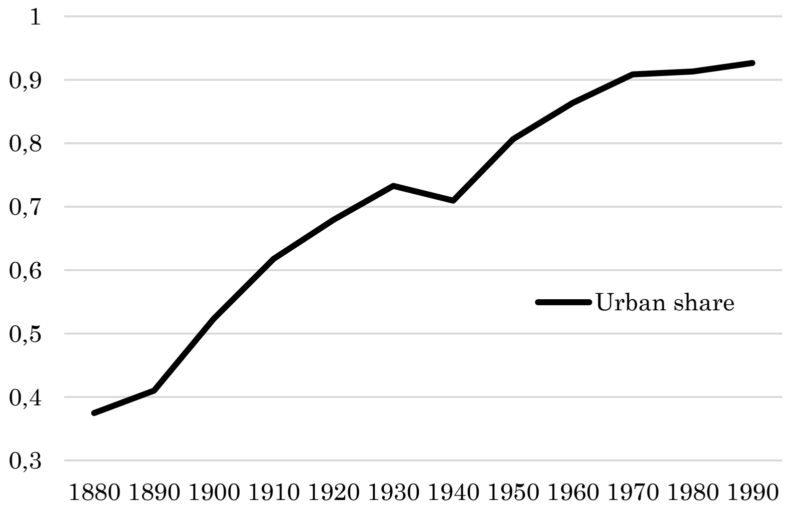


Figure 2.3: Share of the urban population in California (Source: US Census)

Today, California is the most populated State in the US, with close to forty million inhabitants (around 12% of the US population) and major cities such as the megalopolis of Los Angeles (13.3 million of residents), San Francisco (4.6 million of residents) or San Diego (3.3 million of residents). Such burst of population in the twentieth century has been an important challenge for water institutions to meet the growing demand of water (Hundley, 2001).

2.1.1.2. Administration

Administratively, the State of California is divided into 58 counties with varying size (larger counties being in the North and South while smaller counties are located in the Center of the State).

While county's authorities have relatively little authorized action upon the management of water resources, they have a certain power in facilitating or deterring attempts in building the required local institutional infrastructures for managing water resources. Furthermore, they can use their police power to protect public welfare in areas not regulated by the State as a mean of water management (Hanak, 2003 p.30). While this is a crude protection against potential external effect from water markets, it allows a very basic and somewhat effective emergency protection of some counties particularly weaken by the water markets (Hanak and Dyckman, 2003).

Figure 2.4: County Name in California

2.1.1.3. Economy

The Californian economy is commensurate with its population, contributing to more than ten percent of the country's Gross Domestic Production (GDP) and being among the most dynamic region in the world with a GDP evaluated to 2 200 billion dollars in 2014. The structure of the production in this State is relatively close to the one of the country with a large contribution from services, financial and manufacturing sectors (however, the latter is significantly less contributing in California than in the US). The extractive industries such as mining and agricultural sectors have only a marginal contribution to the State's as well as to the country's GDP. Agriculture is however not outdone in California and is also one of the most productive despite its dwarf share in the Californian GDP (around 1-2%). Compared with the US, California contributes to more than ten percent of the country's agricultural production and is specialized on high value added crops such as fruits and vegetables. More specifically, the county of Imperial in the south east of the State and the Central Valley which encompass approximatively 19 counties in the center of the State are important agricultural hubs. The important agricultural production, combined with the large cities impose an enormous pressure on water resources and is particularly pronounced in the south of the State, particularly arid.

2.1.2. Hydrologic Condition of California

With its Mediterranean climate, the State of California is perceived as an arid region despite substantial precipitations and natural storages in the North and in the Center-East of the State (inside the Sierra Nevada Mountains). This is in sharp contrast with the South of the State where precipitations are close to zero and individuals as much as wildlife heavily rely upon rivers and groundwater to meet their demand of water.

Figure 2.5: The California Water Features

The Sacramento Rivers from the North connects the South with the San Joaquin River at the Center of the State in what is called the Sacramento-San Joaquin Delta (or simply the Delta). This place is even more strategic that multiple smaller rivers are flowing from the Sierra Nevada to supply the Delta. Furthermore, two important natural storages in the North are worth the mention: the first is the Shasta Lake which maintain the flow of the Sacramento Rivers and the Oroville Lake which supplies the Delta through the Feather River. In the East, the two major lakes are the Mono Lake and the Owens Lake which were at the center of an intense conflict during the first half of the twentieth century between the City of Los Angeles and the farmers of the Owens Valley (Hanak, 2003 and Libecap, 2008). Finally, an essential source of supply for the South of the State is the Colorado River that serves as a border between California and Arizona and supply water primarily for the county of Imperial and Riverside.[12]

2.1.3. The Growing Crisis of Water in California

Water crisis has been an inherent part of the Californian history, and will be probably be a part of its future as well. The main issue has been to cope with the growing imbalance of water between the places of water use (South and Center) and the places of water supply (North).

[12] The South-Coast of California also get a substantial share of water from the Colorado River but is conveyed through physical infrastructures.

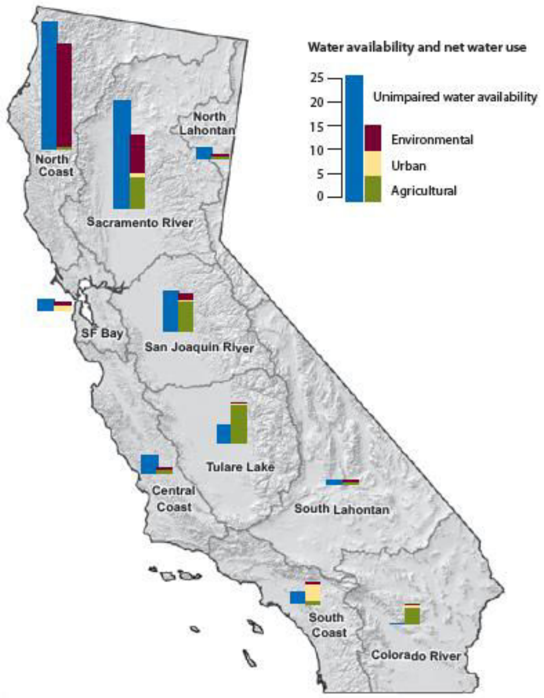


Figure 2.6: Map of the water demand and supply in California (Source: Hanak, Lund, Dinar et al., 2011 p.75)

Indeed, almost half of the population is located in the south-coast (concentrated in the Los Angeles and San Diego area) which has to compete over limited water resources with the agricultural hubs of the Palo Verde Irrigation District (PVID) and the Imperial Irrigation District (IID) in the south-east of the State. The local water resources cannot sustain such a developed economy and water use goes far beyond the local capacity such that water has to be imported from the northern part of the State. Basically, the same schema is reproduced in the center of California where the two major cities (San Francisco and Sacramento) have to compete with the agricultural hub of the Central Valley. While the situation in the center of California is less extreme than the one in the south, the pressure on local water resources is still concerning and the environment has suffered from this situation (principally the Sacramento-San Joaquin Delta). This economy is also heavily dependent from the northern export of water. Finally, the north of California is largely rural with a better balance between water use and available resources but all excess of water supply is shipped to the center and the south through one of the most complex system of canals and aqueducts in the world. Thus, along the past until present days, innovative solutions through legal reform or physical infrastructures have been established to cope with such imbalance within the State and to address the multiple conflicts that arose from recurrent water shortages. Three eras can be drawn in this timeline depending upon the scope of transfers (figure 2.7).

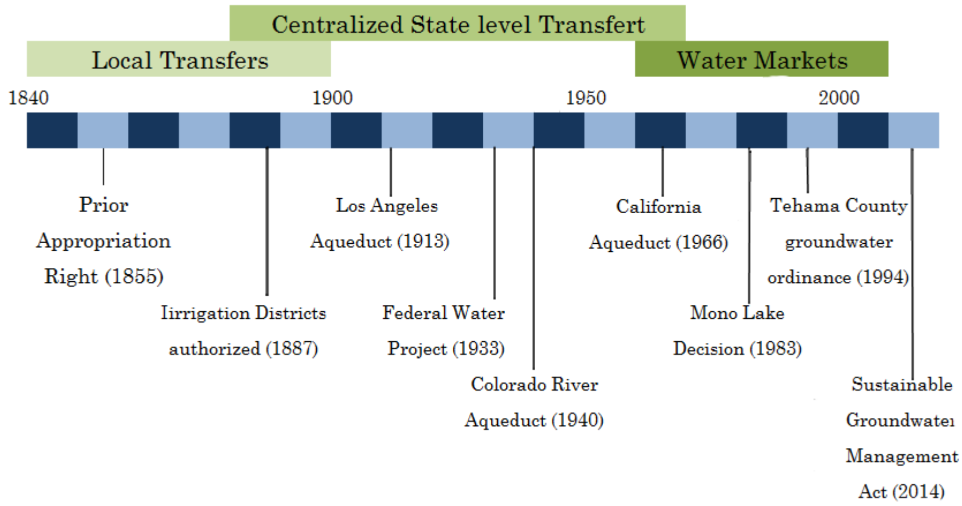


Figure 2.7: Timeline of the water events in California 1848-2014

The first era (during the second half of the nineteen century) is related to local transfers initiated by private decision makers. It is often referred to an era of laissez-faire because the initiative has often been undertaken by individual agents, the higher-level authorities being generally weakly involved in the transfer process. However, from the 1880's, States and federal authorities began their active role in water management by authorizing the creation of irrigation districts to transfer water at local scale which have been expanded to encompass not only the irrigation but many water-related activities (the broader term for other purpose than irrigation is water districts). But with the expansion of Californian economy larger scale transfers were needed and this led to the second era: State level transfers trough centralized management. During this period (from the 1900's to the 1970's), the increasing imbalance between the North and the South of the State called for large scale transfers of water and institutions previously established were often unable to undertake such investment. Only the bigger organizations such as the one in Los Angeles, San Francisco or the Imperial Irrigation District and the Glenn-Colusa Irrigation District could afford such large infrastructures. Thus, State's and federal authorities developed a series of infrastructures to convey water from North to South and to provide water for smaller organizations. Finally, the third era is the one of State level transfers but through decentralized process of decision making (otherwise named the water markets) in order to cope with increasing risk of water shortage and structural change of the Californian economy. In the following section, we review more in depth the two first eras of the evolution of water institutions in California. This will allow to get a better understanding of the opportunities and constraints encountered in the third era which will be reviewed in the last section.

2.2. The Path of Water Institutions in California

The figure 2.8 is a depiction of the human changes of the Californian hydrography with the major canals to transfer water from the source of supply to the multiple places of demand.

Figure 2.8: Map of the humanly devised hydrography of California

While the growth of California can be attributed to many factors, the ability to transfer water toward the places of use has been a predominant one and is still today a key to the future of this State. Over more than one century, California has gone through multiple reforms to facilitate the transfer and reduce the associated transaction costs to promote the use of its water resources by the most productive sectors of its economy. For the most part of the twentieth century, such reforms were mostly dedicated to develop the physical infrastructures to provide sufficient water to the place of use and durably shaped the geography of the State.

We review in this section, the most salient events in the Californian water history which are indispensable to understand the limits and opportunities for water policies. Indeed, it is well recognized that water institutions (like other institutions) are subject to path dependencies (Libecap 2011).

2.2.1. Local Water Transfers and Management Through Decentralized Authorities

The capability of transferring or diverting water from its source origin is not only dependent upon the technological advancement but also upon the law which gives the right or not to displace the water. The water right system in California as in other States is a *usufructory* right and not an ownership attached to the *corpus* of the flowing water flow (Hutchins, water right law in the nineteen western states p151). In other words, the water resources are fundamentally managed under a State property rights regime in trust for its citizens who have solely a usufruct right (Gould, 1995; Simms, 1995 and Libecap, 2010). In that sense, the water laws can be traced back to the Roman laws who considered the water and the air to belong to everyone and therefore could not be privatized. Thus, rather than an absolute ownership, a use right regime is best described as a set of rules embedded into a broader physical and socio-economical system to regulate individual behavior with regard to a valued object or resource (Alchian, 1988; Bromley, 1989 and Griffin, 2016).

Fundamental institutions for water resources gave to California the system of rights sufficiently developed to allocate effectively water among users and allowed the coordination of these same users into water organizations intended to manage the resource at a local level. We present in the following sections, a brief overview of the evolvement of water law. We subdivide this era into two distinct periods: the period of laissez-faire and the period of local organizations. In the first period, settlers from the Mexico and eastern US developed the right system and create the formal institutional environment to rule the water use. In the second period, authorities are concerned with the applicability of the environmental institutions and create the environmental arrangement through water user organizations.

2.2.1.1. From a Common to a Private-like Rights of Use

The second half of the nineteenth century has been a period of important changes for California and for its water resources. The rules to use water have been enacted and modified to address unintended consequences but served as an indispensable backbone for the development of California during the twentieth century. Their original purpose was predominantly to treat the hydric resources as a common property but they rapidly moved toward a more private-like system of water rights to address the conflicts arising from the well-known Common Property Problem (Ostrom, 2011).

2.2.1.1.1. The Spanish Origin

Until the year 1850 which mark the formal annexation of California to the United-States, the water right system was based on the Spanish law through Mexican colonization which was the so-called pueblo water right (Hundley, 2001). These rules can be summarized by "the paramount right of an American city as successor of a Spanish or Mexican pueblo to the use of water naturally occurring within the old pueblo limits for the use of the inhabitants of the city" (Hutchins, 2009 p.145). This can be considered as a common property rights regime with the cities having the power to distribute water among inhabitants and irrigation uses (Hutchins, 2009). While the missions and cities had specific priorities to use water in their regions, the many ranches that were created during that time did not had these privileges. Thus, the farmers had to expand their grazing area to sustain the cattle and create a pattern of large agricultural landownership specific of the current California (Hundley, 2001). This system of rights gave a relative security to the urban areas by providing sufficient water resource to sustain their development. For example, the pueblo right gave to the nascent city of Los Angeles a priority of use for all native water of the Los Angeles River and its groundwater resources (Hanak, Lund, Dinar, et al., 2011). The reason behind this differentiation is to promote the development of urban areas and to attract new settlers into California and is strongly reaffirmed in the later law case of *Los Angeles v. Pomeroy* in 1899 (Los Angeles v. Pomeroy, 124 Cal. 597, 649, 57 Pac. 585 (1899)). This system of water rights has been recognized into the Treaty of Guadalupe Hidalgo in 1848 which preserve the property rights established under the Mexican law (Hanak, Lund, Dinar, et al., 2011).

2.2.1.1.2. Adoption of the Riparian Doctrine

However, with the incorporation into the United States, the Riparian doctrine which is based on the English Common Law and serves as the basis for property law in the rest of America has been formally adopted by California in 1850 (Walston, 2008). Under this doctrine, a user can be granted the right to extract water only from watercourses adjacent to or passing through their land properties and can utilize the water as long as other users are not harmed (Getches 1997 p.33). In a case of water shortage, all users are required to reduce their extraction in proportion of their initial right (Libecap, 2010). Like the Pueblo rights, the Riparian doctrine is mostly a common property regime as water is proportionally shared among users. However, the major difference is on the "boundary rules" (Ostrom, 2005) which determine who can access water and who cannot. In the Pueblo rights system, the full authority over water is given to cities in such a way as to define a fair repartition between the multiple users (inhabitants or irrigators), while in the Riparian doctrine, the access is given by the location of the land and is tied to it. This means that if a land owner wants to transfer water to another agent, the first owner has to sell the land with the water to the second and water can only be used within the watershed of the watercourse (Hanak, Lund, Dinar, et al., 2011).

The establishment of the Public Trust doctrine also followed the annexation of California by the United States. This doctrine originally in the English Common Law and in effect in all eastern States defined the water courses as public property on which no private landowner can restrict the navigation. In other words, the State holds the water course and water beds in trust for the public use in navigation, commerce and fishing. With such rules, the water law explicitly expresses the State ownership of water and has been amended to not only account for navigable rights but also for environmental concerns (Marks v. Whitney (1971)[13]). A famous case is the *National Audubon Society v. Superior Court* (1983) in which the Court had revoked the right of the Los Angeles city to divert more water from the Mono Valley in the Sierra Nevada granted eighty year before and justified it by the Public Trust Doctrine. While not used in the next decades, the Public Trust Doctrine is a powerful set of rules to control some misbehaviors. However, prior to this case, the Public Trust doctrine has never been used and as a general observation, the State authorities did not interact with the water sector in the first decades of the nineteenth century. One exception however has been to change the system of water rights to a more suitable set of rules.

2.2.1.2. The Change toward a More Suitable Water Doctrine

The Riparian doctrine is predominant in the eastern States of America due to the colonial past and is relatively well adapted to the specific hydrological condition of the East. Indeed, the important density of watercourses makes easy for a landowner to get access to water resources. But the hydrologic condition in the West is very different from the East America (figure 2.9). The former has a more scarce and variable water resources than the later which cause many lands to be inhabitable due to the lack of close rivers (Getches, 1997; Kanazawa, 1998 and Libecap, 2011). As pointed out by the Legislative Irrigation Committee of the State Irrigation Convention (1885 p.3 cited by Hundley, 2001 p.93), "We submit to your good judgment that the common law of England [Riparian doctrine], as expounded by the Courts, [is] repugnant to and inconsistent with the climate, topography and physical condition of the State and the necessities of the people". Indeed, information problem with regard to the climate is important in those regions because large investment in water diversion and storage is necessary to irrigate many lands. Thus, the induced uncertainty of the Riparian

[13] In that case, the Court stated that the Public Trust doctrine protects also "the preservation of those lands [covered by the trust] in their natural state, so that they may serve as ecological units for scientific study, as open space, and as environments which provide food and habitat for birds and marine life, and which favorably affect the scenery and climate of the area." (cited by Hanak et al., 2011 p.29).

doctrine combined with the high variability of the climate implies an important risk for investors (Libecap, 2011). Furthermore, the push of agricultural production and the need to irrigate arable lands not in close contact with any watercourse made necessary to separate the land and the water use (Kanazawa, 1998). This inadequacy induced a quick move by all western States toward another doctrine more appropriate to the aridity of the region: the Prior Appropriative doctrine.

2.2.1.2.1. The Improvement with the Prior Appropriation Doctrine

Under this doctrine, the place of use of a water claim is not anymore tied to the land and can be conveyed through ditches and canals to new locations (Johnson et al., 1981). This gives access to an important portion of arable land. The first claimant for a specific amount of water has a priority to receive the demanded amount before the second claimant, who has priority over the third, and so on. The water user having the highest priority are generally called seniors, while those with the lowest priority are called juniors. This system has been adapted from other natural resources property regime such as land and is often named first-in-time-first-in-right (Kanazawa, 2015 and Libecap et al., 2011). It has multiple advantages in the western climatic context and the predominant one is the reliability of water supply for the first settlers (Leaonard and Libecap, 2016).

Consider N individuals who need to use a quantity $\overline{w}$ in complement of a fixed factor of production x such that $\overline{w} \geq \alpha x$ (where $\alpha > 0$ is the amount of water required per unit of factor x). The total available water resources for the N individuals are W. Under the Riparian doctrine, an agent $i \in N$ possessing a share $l_i < 1$ of the total land L adjacent to the water resources, can expect to get the right of use upon a quantity of water $w_i = l_i W$. If individuals are identical in their land possession such that $l_i \equiv l = L/N$, the available amount of water per individual are $w_i \equiv w = W/N$. In that case, all that matters to get water from a shared resource is to possess some riparian lands, but the final use αx_i of this water is irrelevant to obtain the right. To the contrary, under the Prior Appropriation doctrine, this same agent $i \in N$ can claim a quantity w_i of water bounded to his needs αx_i and to the resource left by the individuals $j \in N$ with a higher priority of use such that $w_i \leq \alpha x_i$ and $w_i \leq W - \sum_j \alpha x_j$. From this simplistic formalization (a more complete formalization can be found in Burness and Quirk, 1979), it is straightforward to see that water right under the Prior Appropriation doctrine is independent from the later arrivals, while the available water under the Riparian doctrine is sensitive to the total number of riparian users. Thus, it is more likely to create a tragedy of the commons under the Riparian than under the Prior Appropriation doctrine because a shortage of water will only impact the later arrivals but not the first settlers (unless the drought is very important and make $W < \alpha x_j \ \forall j \in N$). This secured the claim for first settlers from new arrivals and such protection is an important aspect of the water sector as it requires (and more particularly in arid regions) heavy investment in infrastructure development and the construction of dams, canals and ditches. The clarity of the Prior Appropriation doctrine gave such security with the system of priority. Later in 1922, the US Supreme Court stated that this doctrine of Prior Appropriation could also be applied to solve inter-State conflict over shared water resources. However, not all western States abandoned the Riparian doctrine which would cause important conflicts and only the driest places fully replaced the Riparian doctrine by the Appropriative doctrine (Getches, 1997). The other western States, including California adopted a mix between Appropriative and Riparian doctrine (less costly to establish but more complicated to handle over time as the different doctrines can contradict each other).

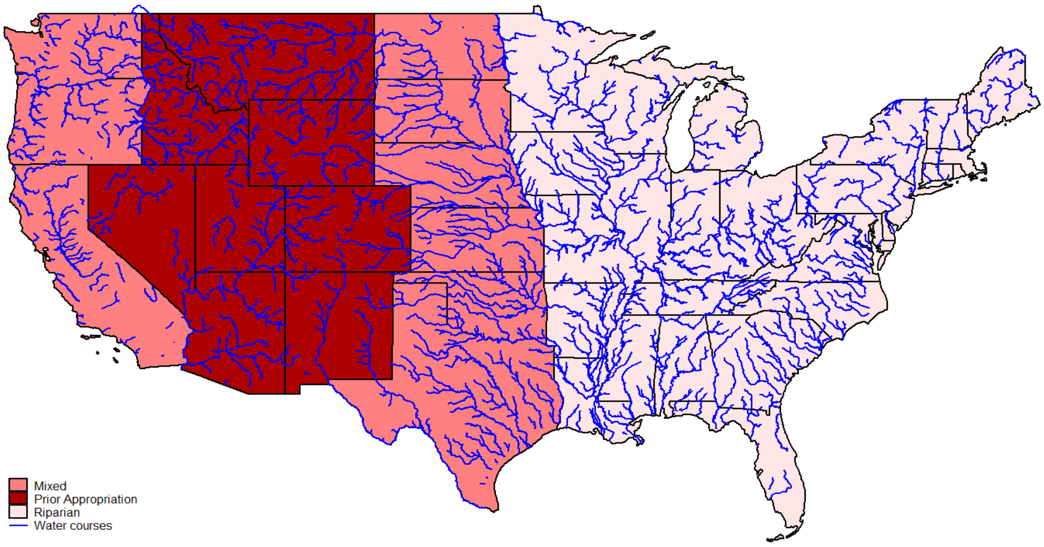


Figure 2.9: Map of the United States hydrology and water doctrine established

In California, the change toward the Prior Appropriation doctrine occurred only five years after the establishment of the Riparian doctrine. This rapid move has been the consequence of the Gold Rush. While the first migrants undertook a somewhat artisanal gold search by a simple panning of gold carried downstream rivers, the rarefaction of the precious metal implied a more industrial search with an increasing need for water (Hundley, 2001). However, the gold lodes were not in a close proximity of rivers and miners had to divert a sufficient amount of water for their activities which was not legally possible under the Riparian doctrine. Indeed, miners diverting water often violated the Riparian doctrine in two ways: first, the deposits from the extractive activity were not located on the Riparian land and second, they did not own the Riparian land (Hundley, 2001). But despite the interdiction of moving water, the miners diverted important amounts from the rivers and instituted the custom practice of first-in-time-first-in-right which would later become the Prior Appropriation doctrine (Hanak, Lund, Dinar, et al., 2011). In this custom, the size and number of claims that a miner could demand were limited and an effective use of the claims were imposed through a minimum work requirement. Each claim had to be publicly notify to be recognized as such (Kanazawa, 2010). The important step in formally recognizing this custom has been the case *Irwin v. Phillips* (1855) in which the California Supreme Court had to judge between the Riparian and the Prior Appropriation doctrine. Although the Court acknowledged the effectiveness of the miners' custom and officially recognized the first-in-time-first-in-right principle as a doctrine in the Water Code, the Prior Appropriation did not displace the Riparian doctrine which led to multiple conflicts between riparian and appropriator users (Hanak, Lund, Dinar, et al., 2011). These would escalate until the law case of *Lux v. Haggin* (1886) in which powerful riparian landowners were opposed to equally powerful appropriator landowners. The Court reassessed the superiority of Riparian over Prior Appropriation and stated that if a water shortage occurred, the Riparian users have first claim on water native watercourse, the appropriator users are following to fulfil their demands (Hanak, Lund, Dinar, et al., 2011). But the *Lux v. Haggin* law case did not dent the Prior Appropriation doctrine and such system of property rights became the backbone of the Californian water development. Indeed, the possibility to divert and use water in places far away from watercourses opened the path for an important agricultural development and the number as well as the size of the farms increased from 1850 to 1900.

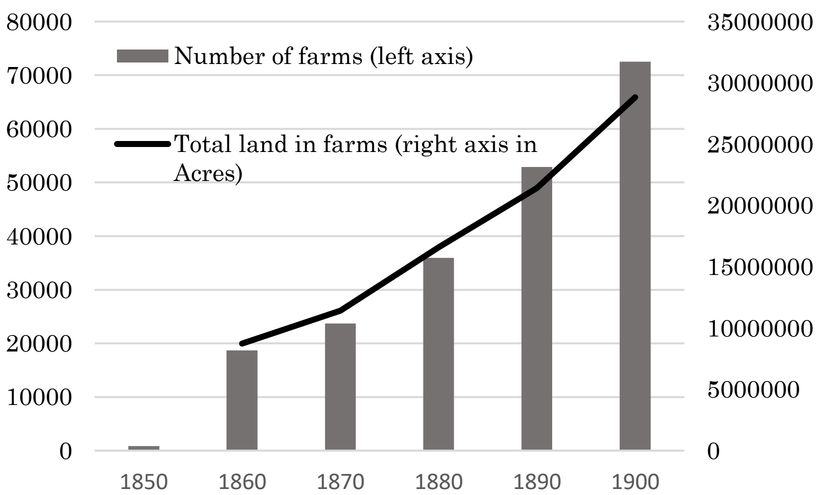


Figure 2.10: The increased number of farms and farm's land from 1850 to 1900

Neither the Prior Appropriation, nor the Riparian doctrines give directly the right to extract a quantity of water (Smith, 2008). Water rights are defined in terms of use and more specifically with the doctrine of the reasonable use (Libecap, 2010). This rule states that the users have to share the resource in a manner that does not cause waste and should be efficient under currentl conditions (Hanak, Lund, Dinar, et al., 2011). It is thus close to a common property right regime in which the property rules are defined from the "test of non-wastefulness" and one party may be challenged by other parties if it is proven that the former uses its water entitlement unreasonably and in a harmful way for the latter (Tarlock, 1991 cited by Griffin, 2016 p.170). This corresponds to Alchian's definition of property rights that a property rule depends on the ability of a party to use its property rule and not only on its legal right (Alchian, 1965). In the important case, *Town of Antioch v. Williams Irrigation District* (1922), the court gave the right to use water to junior appropriator without respect to the priority because it has been estimated that allocating water to senior appropriators would cause to much damage to the juniors without creating a commensurate benefit for the senior appropriator (Hanak, Lund, Dinar, et al., 2011). Thus, the notion of reasonable use can override the system of property rights in place and shows the growing concern from the authorities to maximize the benefits that can be obtained from water. While this notion of reasonable use is important because it allows to diminish potential wastes and inefficiencies, it lacks clarity when it comes to describing what may constitute the "reasonability" behind each use (Griffin, 2016). This notion will become an important rule for the water management in California and will be modernized in 1928 to solve problems between Riparian and prior appropriator users (Hanak, Lund, Dinar, et al., 2011).

2.2.1.2.2. The Prior Appropriation Doctrine Still Incomplete

It is often advocated that the Prior Appropriation doctrine leads the water institutions to lean more toward private rather than common property rights (Anderson and Hill, 1975 and Lueck, 1995). While it is true that such doctrine, based upon a priority principle gives more delineation features than the Riparian doctrine and thus, spares the water users the tedious task of continually collecting the information upon the quantity appropriated by others to determine the quantity available for their own use, it does not however give the same extent of control than a private property rights regime does (Smith, 2008 p.449).

The underlying reason is that Prior Appropriation doctrine give the right to use a certain quantity of water for a defined purpose but not the right to possess this quantity of water, which implies a restricted discretion over the type of use and a limited control over the resource appropriated in this way (Smith, 2008 p.468). More concretely, if an individual claimed to use a certain quantity of water for agricultural purpose, he cannot unilaterally decide to shift the use toward hydropower or to change the place of use by transferring the water to another user. Therefore, the decrease of transaction costs induced by the fact that senior users do not need to know about the actions undertaken and the risk borne by junior users (reciprocally, the latter are aware in advance of the quantity that can be appropriated by the former and can act in consequence) (Smith, 2008 p.468), can only hold true when uses are not being changed since no quantitative divisibility of the resource has been settled and as a result, external effects have not been handled. Otherwise, transaction costs are likely increasing to produce such divisibility and decipher the interdependences caused by the previous use which will possibly no longer occur, and the interdependences that will potentially arise from the new use (Smith, 2008). Thus, the use-based of such doctrine importantly limits the excludability principle previously devised, because no mechanisms for a quantitative divisibility of the resource is being envisioned prior to the change of use. In the context of water markets, the return flows which can go up to 50% of the total water consumption (Young, 1986) are generally emerging as the main issue of changing the use of the water resources appropriated through the Prior Appropriation doctrine (Libecap, 2011 and Williams, 1972). On one hand, the transferability of water use rights is largely increasing by unlocking the latter from land possession and thus providing basis for better divisibility and excludability (Trelease, 1957 and Libecap, 2010), but on the other hand, such transferability is also reducing because of attaching the right to a specific use (Smith, 2008). Although it is true that the Prior Appropriation doctrine may provide better exclusion tools for relatively stable uses than the Riparian doctrine does, it is also important to recognize that such doctrine does not provide as such refinement in the excludability and divisibility than the private property regime does and as a result, is still a system of common property rights similar to the Riparian doctrine (Smith, 2008 p.449).

The use-based principle of the Prior Appropriation doctrine implies that the quantity of water not consumed cannot be considered as used by the appropriator and is thus made available for other appropriators like the junior users (Gould, 1998 p.8). The latter, having in general access to less water than senior appropriators are dependent from these return flows and endorse the higher share of risks in comparison to senior appropriators (Burness and Quirk, 1979 and 1980). Thus, the interdependency increases with the Prior Appropriation doctrine when water is transferred outside of the water basin but such transfer does not cause trouble when exchange of water is occurring in the local area. Indeed, the return flows is generally still appropriated by junior farmers. Such effect is magnified by the right of use for a specified amount of water and not a share of available resources (Pisani, 1992). At that time the problem was not to facilitate the marketing of water but to maximize the use of land by providing water in arid places (Libecap, 2011). Another perverse effect of the use-based system of the Prior Appropriation doctrine is that water saved through investment in irrigation technology cannot be claimed by the appropriator since this amount of saved water is not anymore used (Johnson, 2007).

In that respect, it cannot be said that the Prior Appropriation doctrine can provide sufficiently well-defined private property rights but is rather intended to mimic the private property regimes by ascertaining a certain pattern of use for appropriators inducing sufficiently accurate expectations in the availability of water for all users in specific condition. Thus, State and other governmental agencies are still required to settle issues regarding any change of use or exogenous modification of the context of use.

2.2.1.3. The State Gets Involved: Modernization of the Water Code

During the first decades of the second half of the nineteenth century, State and federal authorities did not had a forceful role in the water law development. The original adoption of the Riparian doctrine has been the normal process of California joining the Union and the choice of the Prior Appropriation doctrine five years later has been more a recognition of an effective custom rather than an active decision. However, as the West grows (including California), the competition for water increases and limited financial resources (Hanemann, 2014) as well as a low coordination among individual users (Ostrom, 2011) call for a more active role from the higher authorities. The *Report on the Arid Lands of North America* from John Wesley Powell stressed this point and promoted a change in water and settlement policies in order to sustain the nascent economy of the western part of the one hundred meridian. A series of Act, passed by the congress has followed the Powell's report in order to facilitate the organization of water users (principally directed toward the irrigators who are the major users).

Until the first decade of the twentieth century, getting rights on water was relatively easy. As Hundley (2001 p.237) wrote: "*individuals could do as little as post a claim on a river for any volume that struck their fancy, file a copy with a local recorder, and then try to resolve disputes with other claimants in court if not with weapons*." But face to the increasing number of disputes over water rights, the Governor Hiram Johnson ordered to gather data on most of the natural resource use in the State, including water to reform the law (Hundley, 2001). The key aspect of the subsequent reforms has been the Water Commission Act (passed in 1913) and the creation of the State Water Resources Control Board (hereafter named the Board or SWRCB) with power to issue rights for water use (Hanak et al. 2011). However, the Board was still limited over the type of resource it could regulate. Indeed, the water ruled by the Riparian doctrine, Pueblo rights, groundwater and any other rights issued prior to 1914 was not subject to review by the Board. Until today, there is still a distinction between rights issued after December 1914 and the so-called pre-1914 rights, the later having not the requirement to go through the review process by the Board for any transfers. These pre-1914 rights represent approximatively half of the water actually used by agriculture and cities in California (Hanak, 2011 p.38). Furthermore, in the beginning of its setting up, the Board was only intended to verify that a water course had unappropriated water before issuing a permit (Gray, 1989). However, due to the increasing pressures, power has been gradually granted to the Board to protect the public interest[14] (Archibald, 1977). The Board has first to verify that sufficient water is available for the right to be issued, then has to define term and condition for water use to comply with the public interest. Importantly, it has the power to amend or suppress the right when more information on the real impacts of the granted rights are known and has played an important role in the *National Audubon Society v. Superior Court* (1983) aforementioned (Gray, 1989). Thus, through the Public Trust doctrine, the Board can have some power over riparian and pre-1914 rights (Gray, 1989).

2.2.1.4. The Groundwater Still Unregulated

Groundwater in California has been a conflicting resource and generally free from any kind of regulation which has led to the well-known problem of the open access resources. Changes have only occurred in the recent decades under the growing pressure on underground water resources (Ostrom, 1990 and Hanak, Lund, Dinar, et al., 2011).

While the surface water has been handled by the State under the Common Law and rules have been adapted through conflicts over time, the groundwater has never been under the State control or property and this has led to overuse in some places (Thompson, 1993). In this situation, the externalities imposed by users to others can take several forms (Ostrom, 1990). The first type is the increase of environmental degradation which affects the whole ecosystem in adjacent streams (Hanak, Lund, Dinar, et al., 2011). The second type is the increase of pumping costs to access the falling water level due to over-extraction which is closely related to the strategic behavior of pumping more today in order to prevent the withdrawal by rivals in the future (Negri, 1989). One reason is that during the second half of the ninetieth century, when major surface water laws was enacted, the groundwater was not considered as a major source of supply due to the difficulties to access it. Indeed, the technological limits on pumping capacity made the underground resources relatively safe for several decades and no real competition (and thus no case to rule the use) occurred to access this resource (Tellman, 2011). However, farmers and cities began to rely more heavily on groundwater resources when pumping technology has improved through the spread of powerful electricity and gasoline engines in the early twentieth century which led to growing tensions and conflicts over the century (Hundley, 2001). The problem lies in the strict distinction made by the law between surface and groundwater which makes

---

[14] The public interest means that the benefit from the issued right has to be compared with other types of use, the domestic use having the highest interest followed by the irrigation, municipal, industrial, the preservation of fish and wildlife, power generation, mining and all other requirement to protect the quality of water subject to specific plan. (California Water Code, section 1257).

little sense according to Thompson (1993 p.685) as both resources are hydrologically linked one another (Weatherford, Malcolm and Andrews, 1982). In that sense, while the law considers the surface water as a common good with the State property in trust of the people, the regulation for groundwater use is mainly inspired from the Blackstonian notion that land ownership can be extended from the earth's center to the space (Hundley, 2001 p.528).

As pointed out by Weatherford, Malcolm and Andrews (1982 p.1033), *"[t]here is no coherent or comprehensive groundwater law, polity or policy in California. Rather there are scattered strands of precedent and experience awaiting judicial and political splicing and braiding. The major regulator of groundwater in the [S]tate is the dollar – the economic cost of pumping and deepening wells*". During the whole history of California, very few rules have been passed to manage this resource and they were often not enforced. Among them, one of the predominant one has been the case *Katz v. Walkinshaw* (1903) in which the Court stated that landowner had correlative rights to available resources of the aquifer that replaced the strict application of Riparian doctrine for groundwater (Ostrom, 1990 p.107). The Correlative doctrine is a mix between absolute ownership and the Prior Appropriation doctrine with the notion of reasonable use (Griffin, 2016 p.170). In that system, overlying agents (Riparian) have priority over the non-overlying agents (appropriator) (Weatherford, Malcolm and Andrews, 1982). The multiple owners overlying an aquifer have each the right to pump a reasonable amount of water until the safe yield is reached. The remaining water is appropriated by others through the doctrine of Prior Appropriation (Hundley, 2001). In that sense the Correlative rights are relatively close to the common property regime as the use of one agent is correlated to the need of others (Goldfarn, 1984 p.25). However, the definition of reasonability is vague (Griffin, 2016 p170) and even if a clarification has been made in 1921 with the case *San Bernardino v. Riverside* (1921) which states that water can only be put to beneficial use[15] (Ostrom, 1990 p.107), depletion has arisen from the fuzzy definition of adequate property rights and a difficulty to coordinate between pumpers (Hanak et al., 2011). The problems lied in the fact that only local authorities had power to enforce the rules which led to a patchwork of groundwater managements throughout the State and incredible difficulties to coordinate all the organizations. In 1949, an attempt has been made to reorganize the

[15] This principle of beneficial use has been reasserted in the Water Code modernization of 1928 (Article 10, section 2): "*It is hereby declared that because of the conditions prevailing in this State the general welfare requires that the water resources of the State be put to beneficial use to the fullest extent of which they are capable, and that the waste or unreasonable use or unreasonable method of use of water be prevented, and that the conservation of such waters is to be exercised with a view to the reasonable and beneficial use thereof in the interest of the people and for the public welfare.*"

regulation over groundwater use through the creation of the Mutual doctrine. This law defined prescriptive rights to user in case of an overdraft occurs. The prescribed amount determined through a calculation of the five highest pumping years was established and then reduced in proportion to comply with the safe yield of the aquifer (Hundley, 2001). However, this had the perverse effect of increasing overdraft in many groundwater basins already in difficult situation. All users engaged in a race to pump more and then to increase their prescriptive rights through an increase of the average five years of highest use (Hundley, 2001). In that respect the Mutual doctrine worsened the strategic externality exposed by Negri (1989). The race to appropriate the maximum amount of the resource was not solely dependent on an uncertain future that others would extract the remaining resource but rather was contingent on the immediate risk that others could assert larger rights from a higher average pumping. But the problem is more pervasive than that. The lack of well-defined property rights gives no basis for a property rules to exist prior to any legal resolution (Blomquist, 1988). Thus, the delineation of property rights can only occur through a liability rule in which users have to demonstrate their needs for extracting a certain amount of water through a continuous withdrawal (obviously, the larger as possible) (Krieger, 1955). However, complete depletion did not occur in the southern part of the State (the most seriously threat by exhaustion) due to coordination between the multiple agencies and local authorities. Ostrom (1990 pp.111-142) provides a good summary of the effort in coordination to provide a comprehensive groundwater management in this region. In this resolution, a complex system of polycentric governance has been the key point in which multiple local agencies coordinate within the jurisdiction of a *watermaster* with coercive and important monitoring power appointed by the Court (Ostrom, 1990 p.136). The flow of information facilitated the coordination and the incremental change toward a more sustainable management. In other places, the management is still largely uncoordinated (Garner and Willis, 2005). When sufficient surface water is available, the solution to limit groundwater depletion has been to setup a price of surface water lower than the cost of extracting groundwater (Vaux, 1986 and Jenkins, 1992). Other solutions have been found in a diverse type of monitoring networks (Thomas, 2001 and Hanak, 2003).

The California Court acknowledged the chaotic management of groundwater in a footnote, carrying no legal weight in the law case Barstow v. Mojave Water Agency (2000): "*If the Californians expect to harmonize water shortages with a fair allocation of future use, the courts should have some discretion to limit the future of groundwater use of an overlying owner… and reduce to a reasonable level the amount the overlying user takes from an over-drafted basin.*"[16] The point made in this case is the lack of State

[16] Cal. Stats., chap. 1361 (1951); chap. 1690 (1953) Barstow v. Mojave Water Agency (Aug. 21, 2000, SO [Slip Opinion] 71728, Cal. 4th [Typed opinion, p.25, note 13])

power to regulate the groundwater use which limits the available option for local groundwater authorities (Null, Lund and Hanak. 2011). Indeed, no real attempt has been made through the twentieth century to have a have an adequate property regime in California and by the 2000s, this State (along with the State of Texas) was the last of the western States not to have a comprehensive groundwater management (Garner and Willis 2005). However, the recent legislation that followed the most intense drought in the Californian history might bring the State power back into groundwater management. The Sustainable Groundwater Management Act of 2014 allows the State (through the Department of Water Resources) to override local managements if the latter cannot limit the overdraft of a groundwater (Culp, Glennon and Libecap, 2014).

2.2.2. The Organization of Water Users

As previously stated, the establishment of the Prior Appropriation doctrine allowed irrigation to expand far away into the land but the disconnection with watercourses also imposed to develop the infrastructures to convey and store water. This capital-intensive activity quickly raised the issue of the size of farms as the needed investment were often beyond the financial resources of many landowners (Allen and Lueck, 2002; Anderson and Hill, 2004; Bretsen and Hill, 2006 and Rosen and Sexton, 1993). In other words, the required size to invest in water infrastructure were largely superior to the optimal size for agricultural production. Thus, farmers had to organize in a collective action in order to invest in water infrastructure but they faced important transaction costs. We do not review here all the laws enacted during this period, we prefer to focus on one of the most successful reform which was the Wright Act passed in 1887 (Ostrom, 2011; Libecap, 2011 and Hanemann, 2014). This reform allowed the organization of farmers in official districts and improved the financial capabilities of these new organizations (Hanemann, 2014) and increased the trust between members (Ostrom, 2011).

2.2.2.1. The Transaction Costs of Organizing Water Users

Such issue arose in water organization as the upfront cost to provide a well-functioning irrigation network is in most cases very high and can discourage any attempt to develop such infrastructures. Furthermore, the solution which could be proposed of vertical integration where farms grow sufficiently large to provide their own infrastructure is often unrealistic. Indeed, the optimal size of a farm is generally much smaller than the minimum size required to undertake such investment. Therefore, growing bigger to support the cost of irrigation investments is only possible at the cost of a reduced productivity of the farming activity and would cause in most of the cases the bankruptcy of the farm. The real solution can be found through collective action which allows to reduce the transaction costs for building the needed infrastructure and provide an effective transfer of water from the source of origin to the place of use. However, such organization is often prompt to fail due to asset specificity, opportunism, holdout and free-rider problems (Bretsen and Hill, 2006). Indeed, the agricultural production through an irrigation network creates an important specificity of the water infrastructures because it can only be used to deliver water in a specific area. If farmers try to contract with an investor, this latter through its monopoly power or the formers through their monopsony power can strategically behave in order to appropriate the rent induced by the specificity of water infrastructures. These opportunistic behaviors are magnified by the fact that farmers have a need for water in specific time (Anderson and Hill, 2004). Similarly, in a community-based organization, the free-riding temptation is generally the cause of collective action failures (Ostrom, 2011).

A well designed contractual arrangement is thus needed to expand further the agricultural production and multiple attempts have been made along the second half of the nineteenth century to achieve this goal (Bretsen and Hill, 2006). We review and compare in the next section three specific organizational arrangements that were experimented in California: the commercial irrigation companies, the mutual irrigation companies and the irrigations districts.

2.2.2.2. Different Experiences of Water Organizations and the Rise of Water Districts

The early commercial irrigation companies have been established to coordinate the individual farmers and invest in water infrastructures. But these companies were profit organizations and mutual distrusts followed by frequent conflicts soon arose between the company's board and the farmers. Gardner (1983) estimated that the price elasticity of irrigators in California was approximatively -0.65 (and -0.35 for the whole Western US). From this relatively inelastic demand, water suppliers can benefit from an important market power (Rosen and Sexton, 1993 p.40). As Ganoe stated in 1936: "*When a company built a reclamation project, the usual procedure was to complete it as quickly and cheaply as possible. The weirs were often constructed in cheap wooden framing. The result was that the cost of maintenance soon forced the company into bankruptcy*" (Ganoe, 1936 p.266). On the other side, a company had the power to break the farmers' production by overcharging the water at a critical moment (Teele, 1904 p.165). In its well-known article in the first issue of the *American Economic Review*, Coman (1911) observed that this strategy was detrimental in the long run: "*Such promoters soon discovered that they had killed the goose that laid the golden egg, for without water-users there could be no revenue*" (Coman, 1911 p.5). The major issue in the commercial irrigation companies was the inability for farmers to get a control over the decisions made by the company and symmetrically, the struggle for companies to be reimbursed by the farmers (Hanemann, 2014).

Mutual irrigation companies were more effective than commercial irrigation companies mostly because the formerwere not for profit companies and were producer-owned institutions (Bretsen and Hill, 2006). Indeed, when a mutual was created, the shares of the company were distributed among its members but contrary to commercial companies who redistributed the profit as dividends, the mutual companies were generally developed to secure water provision at a lower cost with active participation in the management decision by the members. This particular type of organization has been often the solution for farmers to take control of an irrigation infrastructure from a commercial or private water company (Hutchins et al., 1953 Irrigation Enterprise organization). It was essentially a community-based organization created by the farmers for the farmers and had in this respect more success than the commercial companies. However, the lack of financial capabilities restricted the ability of these institutions to expand further their irrigation facilities and the free-riding problem became an important issue as few members would contribute to the operating of the mutual (Bretsen and Hill, 2006). Indeed, farmers at the head of the canal had very weak incentives to contribute in maintaining a well-functioning canal and farmers at the tail often suffered from this situation (Bretsen and Hill, 2006).

The Wright Act, enacted in 1887 was intended to cope with these issues by authorizing the creation of irrigation districts. These districts are political subdivisions and have thus the power to issue bonds and to tax the property within the district's boundaries. In this respect the legal permission to tax individuals solved one of the multiple problems encountered by the mutual and the commercial companies which is to limit the risk of free riders and could be formed by two-third voting rule within the area (Pisani, 1984). But despite these advantages, irrigation districts had a tumultuous commencement as they were perceived by many farmers as a "communism and confiscation under the guise of law" (Benson, 1982 p.377) while others created districts without a proper cost-benefit analysis (Hanemann, 2011) or that were simply illegal (Pisani, 1984 for a compilation of such problems) and went into bankruptcy at the early stage of their creation (Teele, 1927). However, the district as an institution to manage water became the predominant water purveyor along the time (Libecap, 2011) and this specific institutional setting has been expanded to encompass not only irrigation but other type of water-related purposes such as conservancy or flood control (Hanemann, 2011).

The reasons underlying the success of irrigation districts are the democratic features of these types of organizations. The district generally holds the right of water use and distribute it among its members in collectively based decision rule which help to avoid the problem from one member exercising any kind of power on other members. Furthermore, the right to tax gives the district a supplementary power of coercion that mutual or commercial companies do not have the and thus avoids the temptation of free-ride. From the original statement of the Wright Act, only landowners within the district's boundaries are allowed to vote and constitute the governing board (Libecap, 2011). But California (as two other States, Idaho and Kansas) went further by providing the right to vote and to be eligible to all registered voters. This implies to give the right to take part in the local water management for a wide range of decision makers (including non-farmers) and account for heterogeneous interests. The board is composed of five elected directors representing different geographical section of the board (Pisani, 1984) which have the duty to supervise and distribute the water among members. The formation of such organization is done through a vote in which a qualified majority of two-third of voters within the district's boundaries have to vote for it. This is in contrast with the mutual companies where an implicit rule of unanimity is needed to create the organization. The two-third rule implies that even if a minority (less than or equal to one-third) of voters is against the creation of a district, this later can "force" the contribution of the unwilling individuals. This allows such organizations to avoid the problem faced by mutual companies of holdouts from the multiple heterogeneous individuals, preventing any organization to amass sufficient capital for the water infrastructures (Bretsen and Hill, 2006). This is more specifically true for irrigators at the head of the canal who do not have great incentive to voluntarily contribute to the collective investment. It is also reasserted in the Wright Act that the State has no control over the decision made by the board of the district (as long as it respect the general State's law). This is particularly attractive for small areas who saw this as a way to get more independence from the State. The attractiveness of irrigation districts grew larger when they became exclusive partner to receive federal water (water from federal projects) and subsidies in the 1920's (Bretsen and Hill, 2006).

The creation of water districts had an important impact on the future evolution of the water sector as it provided an adapted arrangement to allocate and reallocate (if necessary) the water resources among its members. The intra-district transfers of water were thus greatly facilitated through the reduction of transaction costs (Bretsen and Hill, 2006 and Libecap, 2011).

2.2.3. State Level Water Transfers Through a Centralized Authority

At the dawn of the twentieth century, the expansion of irrigation (a total agricultural land of close to 30 million acres), the growth of population (now estimated at approximately 1.2 million inhabitants) and the increasing reliance of exhaustible groundwater resources called for a management of water at a State level. Indeed, the scope of the water districts was too small to achieve the necessary transfer of water from the source of supply (the North, the Sierra Nevada and the Colorado River) to the major places of use (the South and the Central Valley). Bigger projects such as storages and conveyances needed to be developed in order to meet the growing demand (Hanak, Lund, Dinar, et al., 2011). While the two cities of Los Angeles and San Francisco had sufficient financial resource to undertake such investment, most of agricultural districts and smaller cities were unable to support such upfront costs. Thus, the State and the federal authorities had to endeavor to develop the infrastructure at a State level and not anymore at a local level. Furthermore, the increase of conflicts among water users induced the authorities (State and federal) to modernize the rules of water allocation and use. This involvement has been also the consequence of the painful and very conflictual first large scale transfers started by the cities of Los Angeles and San Francisco in the beginning of the twentieth century. We first review the different projects and their impact on the local communities then we discuss the new laws passed in this era.

2.2.3.1. The Hydrologic Era: Large Scale Water Infrastructures

As previously stated, California needed bigger infrastructures to provide water to the most productive place and thus sustain its growing economy. The important growth of population in the first decades of the twentieth century (cf. figure 2.2) and the expansion of agricultural production led to the development of large conveyance and storage infrastructures. While these projects brought the expected benefits for the recipients of the displaced water, the costs incurred by the communities in the area of origin increased the tensions between the source of supply (North and East of the State) to the place of use (South and Center of the State). The first initiative came from the private sector with the Los Angeles aqueduct (to serve the city of Los Angeles) and the Hetch Hetchy aqueduct (to serve the city of San Francisco). We first review these two examples of water transfers because they were the first real attempts at a voluntary exchange and still have consequences today (even eighty years later). We then go on to review the other projects in the 1930's supported by federal authorities who got the right to manage a significant share of water resources in the West through the Reclamation Act of 1902. This reform authorized the federal government to operate water projects in the western States through the creation of the US Bureau of Reclamation (hereafter named the Bureau or USBR) within the US Department of the Interior (Walston, 2008). While section 8 of the Reclamation Act stipulates that the Secretary of the Interior must "proceed in conformity with the state legislation" and therefore cannot override the State authority, the decision of Supreme Court in the case *Ivanhoe Irrigation District v. McCracken* (1957) casted some doubts about how to interpret this law. The judgement claimed that State's authorities cannot regulate federal water use because the State possesses only the property and not the right of use over water resources. Thus, as long as the Bureau respects the property law of the State, this latter cannot intervene in the regulatory law over water (Walston, 2008 p.12). Almost thirty years later, the Supreme Court reverse the 1951's decision through the case *California v. United States* (1978) in which it has been reasserted that the Bureau has to comply with both property and regulatory laws of the State (Walston, 2008 pp.12-13). However, this applies only when State's law is not inconsistent with clear congressional directives (Walston, 2008 p.13). This is more than an anecdotal event as the US Bureau of Reclamation will have the right over a massive amount of water in California through the Central Valley Project (CVP) in the 1930's and the multiplication of dams on the Colorado river. The uncertainty over rules to allocate the federal water reserves have led State's officials to develop a State owned water infrastructure, the so-called State Water Project (SWP) in the 1950's to equilibrate the power of decision between the State and the Bureau (Hundley, 2001 and Hanak, Lund, Dinar, et al., 2011).

2.2.3.1.1. Los Angeles and the Owens Valley: Water for the South and the California Water War

While the Spanish Pueblo water right allowed the city of Los Angeles to appropriate a large portion of the water resources in its hydrologic region, the rapid expansion of the city created a dangerous disequilibrium between the available supply and the growing demand. Kahrl (1982 p.26) stated that "When William E. Smythe, first executive secretary of the National Irrigation Congress [...], surveyed the prospects for economic development in California in 1900, he saw no future for the Los Angeles and the other communities of the South Coast." However, at the same time William E. Smythe wrote its prediction, the mayor of the city, Fred Eaton and the chief engineer of the Los Angeles Department of Water and Power, William Mulholland casted envious glance at the water resources available in the Sierra Nevada and more specifically in the Owens Valley which straddles two counties, Inyo and Mono. This rural region with relatively good soil for agriculture had 41 026 acres of irrigated crops, mostly alfalfa, grains and orchards (apple and pears) and accounted a population of more than 7 000 inhabitants. A quick (and superficial) statistical analysis of the two counties of Inyo and Mono shows that agriculture was relatively well developed. Farms were relatively larger in these two counties (and more particularly in the Mono county) than in the rest of the State (figure 2.11 and 2.12). However, the farm value per acre in Inyo and Mono counties (respectively $11.23/Acre and $13.73/Acre) was less than for the rest of the State ($21.87/Acre)[17]. This difference was more particularly pronounced in the Mono county where the value of the crop production per acre was almost six times less than the value of the entire State (Inyo county had a value per acre very similar to the rest of the State). The cause of such a low income is more the consequence of prohibitive freight costs to import and export any good from or toward the east of the Sierra Nevada (Kahrl, 1982 p.38). However, at the dawn of the twentieth century, the valley seemed to wake up as economic activity arose (largely supported the mining and the discovery in 1900 of silver mines). Furthermore, transportation companies (The Southern Pacific Company and The Randsburg Railway) began to be interested in building infrastructures to link the Owens Valley to the rest of the State

[17] Data calculated by the author from the US Census.

(Kahrl, 1982 p.39). The question on how wealthy would the valley be if the transfers had not occurred is still an ongoing debate and trying to answer this question here would only be pure speculation. There is however no doubt that this first private transfer marked the mind of all subsequent water managers and local authorities (Hanak, 2003 and Hanak et al., 2011).

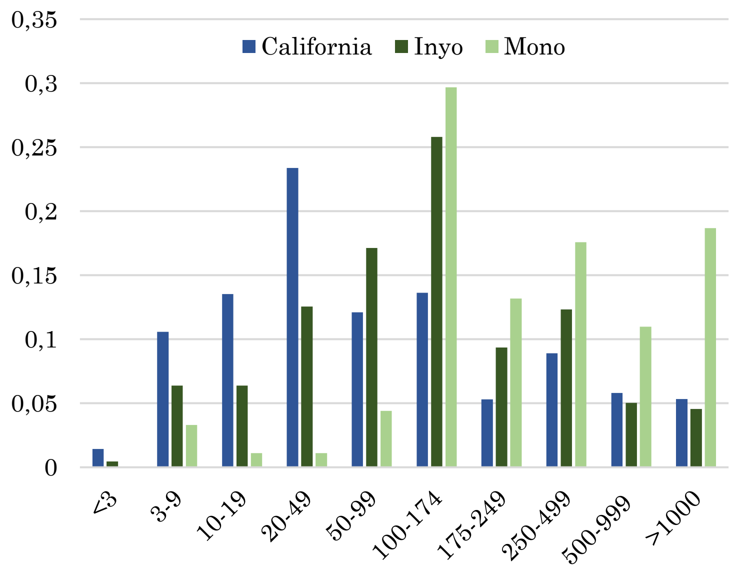
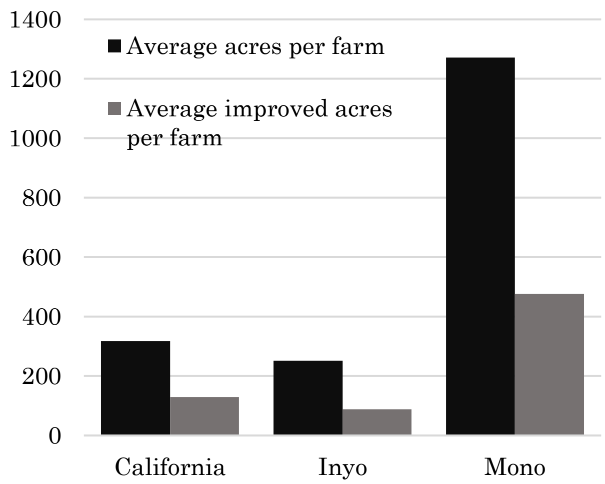


Figure 2.11: Number of farms per acre size in 1910

(a)



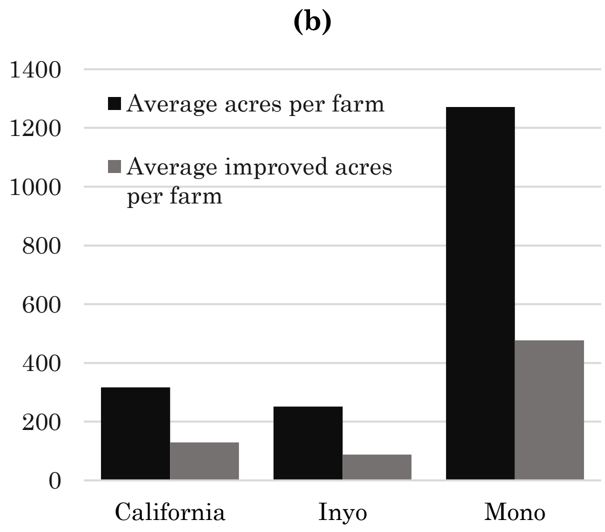


Figure 2.12: Average size (a) and average value (b) of farms in 1910

In 1905, negotiation began between the city of Los Angeles and the farmers in the Owens Valley. The goal of Eaton and Mulholland was to build a 400 miles long canal that would link the Mono lake to the city of Los Angeles (cf. figure 2.8). But to secure the water, land had to be purchased first because most of water rights were under the Riparian doctrine (Libecap, 2008). Thus, during the time Mulholland designed the future project for water conveyance, Eaton was buying the farm's land on its own. While some negotiations have been smooth and ended up to a quick agreement, others have led to an acrimonious bargaining for a 5 to 10 years' duration (Libecap, 2008 p.313). The first phase of the acquisition was to buy lands in the south and driest part of the Owens Valley which did not cause controversies as agriculture production was marginal and unorganized. The price for acquisition was thus low ($15.4/Acre) when compared with the prices paid for later acquisition which approximated $113.72/Acre (Libecap, 2007 p.46). The difference is due obviously to different value of land between the North and the South of the valley but also to a difference in timing of acquisition. Indeed, the first sales have been enacted without the farmers really knowing the large project that were in preparation and by 1922, the city had bought most of the water it had initially planned. However, from the launch of the project in 1905 till its end in 1922 (the Owens Valley Aqueduct being built from 1908 to 1913), the city of Los Angeles had grown to 500 000 inhabitants and would reach 1.2 million one decade later (Hundley, 2001 p.138). Faced with this important increase in water demand, the city of Los Angeles had to come back to the Owens Valley to buy more water (Hanak et al., 2011). But the farmers were now much more hostile to the city's plan due to the progressive drying out of the Valley (Hanak et al., 2011). In 1922, farmers from eleven ditch companies formed a unique entity through the creation of the Owens Valley

Irrigation District in order to strengthen their power into the negotiation with the Los Angeles City. This district grouped 323 farms with a total of 54 000 acres of land and a total water claim of 180 000 acre-feet (Libecap, 2008). This accounted for approximately three-fourth of all the agricultural water claimed in the entire valley (Hoffman, 1981 pp.176-179 and Kahrl, 1982 p.277). Recognizing the potential threat of a single and unified bargainer for the whole valley, the city of Los Angeles hastened to purchase the properties at a premium price in the two major ditches of the valley in the years 1923-1924, the McNally and the Big Pine ditches (Kahrl, 1982 p.279). This action broke the cartel into three distinct pools controlling together approximately 17% of the valley's water claim: the Keough pool (23 members), the Watterson pool (20 members) and the Cashbaugh pool (43 members) (Libecap, 2008). The concentration of farm's size in these three pools was the highest in the Keough and the lowest in Cashbaught[18]. This gave important bargaining power of the Keough's members who sold their lands in 1931 at a price of $466/acre (almost twice the first offer from the Los Angeles city) (Libecap, 2008). The other two pools however sold their properties for a price slightly higher than the first offer from the Los Angeles city and sooner than the Keough pool due to the lack of bargaining power and stability of the cartel (Libecap, 2008). The total gain for the Inyo county is estimated at more than $11 million which is 40 times less than the lower estimate of the gains for the city of Los Angeles ($407,051 million) (Libecap, 2008 p.336).

Libecap (2008) argues that the dark legacy of the transfer from the Owens Valley to the Los Angeles city is specifically due to the important difference in the respective gain. The inequity of the rent sharing has left a bitter taste toward the farmers and even more for the others members of the community without any land to sold. For these later, the result has been a net loss due to the diminishing of the agricultural production (Hundley, 2001). Many of them became outraged and violent leading to number of dynamiting of the aqueduct during the 1920's (Ostrom, 1953 pp.121-127; Wood, 1973 pp.30-37 and Hundley, 2001). In this first attempt at a large scale water transfer, the transaction costs paid by Los Angeles has been particularly important principally due to the long process of bargaining. But more than these static transaction costs, the consequences on future transfers has been significant through the increase in a lock-in cost. Reluctances and restrictions toward modern transfers of water often found its roots into the Owens Valley's experience (Hanak, 2003). On the other hand, this aqueduct gave the city of Los Angeles the indispensable water supply to continue its development and gave a push into the hydraulic era

In other words, and from the distinction provided by Viner (1931), the problem developed here is not the one of technological externalities where side effects arise

[18] Libecap (2008 p.323) calculated the Herfindahl index of farm's size and found a value of 1538 for the Keough, 1163 for the Watterson and 410 for the Cashbaught.

outside of a market mechanism which could theoretically handle these effects, but rather an issue of pecuniary externalities (Hanak, 2003 and Libecap, 2015). This points out the distributional concern market-based instrument in reallocating water and, despite the total effect of such transfers that may be positive, non-consideration of the fairness is likely to drive more intensely the conflict between the sellers and the buyers (Haddad, 2000 p.xv). Through that historical event, it can be shown that the concept of externality should not be just seen as an "absence of market" since such market, through inadequate institutionalized rules can cause as much damages as technological externalities not only for the region of origin, but also for the market itself. It would be pure speculation to imagine what would look like the water markets in California if this so-called California Water War never happened, but it can be ascertained that such event has profoundly marked the people and durably shaped the decision of policy makers in the matter of water institutions. Even approximatively 90 years later, The Economist wrote: "…farmers remain suspicious of the 'Owens valley syndrome'… The 'theft' of its water…in the early 20th century has become the most notorious grab by any city anywhere…the whole experience has poisoned subsequent attempts to persuade farmers to trade their water to thirsty cities" (The Economist, July 19, 2003 p.15 cited by Libecap, 2015 p.327). This event has also sent a strong signal to policy makers to account for the fairness characteristic of a water exchange and not solely on its global efficiency, but future development of large-scaled projects without proper recognition of pecuniary externalities upon local population have proven a certain deafness (Dellapenna, 2013).

2.2.3.1.2. San Francisco and the Hetch Hetchy Valley: Tapping the Reserves in the Sierra Nevada

At the same time, Los Angeles envisioned its aqueduct from the Owens Valley, the city of San Francisco also sought new sources of water in the Sierra Nevada. The city chief's engineer, Michael Maurice O'Shaughnessy proposed to convey water from the Hetch Hetchy Valley in the Tuolumne county. While the Hetch Hetchy aqueduct (started in 1913 and finalized in 1934) was less contentious than the Los Angeles aqueduct, the problem faced by the San Francisco city's engineers was that the Hetch Hetchy Valley was part of the Yosemite National Park since 1890 (Hundley, 2001). The frequent disputes with the federal authorities to dam the valley and get access to the water combined with financial difficulties made the project particularly unpopular and struggling for the city of San Francisco (Hundley, 2001). Furthermore, the ongoing struggle of the city of Los Angeles to get water from the Owens Valley, just on the other side of the Sierra Nevada, discouraged many to undertake such endeavor and reasserted some other to fight back against this project. However, Congress passed the Racker Act in 1913 that authorized the city to launch the construction of a dam into the Hetch Hetchy Valley.

The legacy of Hetch Hetchy aqueduct has been less damaging than the Los Angeles aqueduct because it did not affect in a negative way the economy of the Tuolumne county. However, the impact of this project has been more significant in the long run through the growing of the environmental concerns that characterized the second half of the twentieth century (Hanak et al., 2011).

Building on the experience from the Los Angeles and the San Francisco aqueducts, federal and local governments planned multiple interregional water transfers through different projects (Hanak, 2011). Two major regions are involved in those schemes. The South with the growing urban and agricultural area respectively in the coast and along the Colorado river and the Center of the State with important agricultural production.

2.2.3.1.3. The Boulder Canyon Project: More Water for Southern California

The federal authorities envisioned a large-scale plan to dam the Colorado river and share the resource among the seven States (California, Arizona, New Mexico, Utah, Colorado and Wyoming). However, the fear that California could grab a large portion of the Colorado river and the ongoing sharp negotiation with the Owens Valley led the six other States and Mexico to protest against this project. Indeed, following the US Supreme Court decision of 1922 on applying the Prior Appropriation doctrine to inter-State apportionment of water, California had the right to claim the lion's share of the Colorado river resources[19] (Hanak et al., 2011). As Hundley (2001 p.212) wrote: "*For many westerners California was not only a lurid and morally corrupt society… it was also a behemoth, the largest and fastest-growing State in the basin, and one supremely arrogant*". Thus, the rapid expansion of California's economy was scrutinized with a lot of suspicion by other States' officials who saw their water resources for their own potential growth being grasped by this *arrogant* State. To resolve the growing conflict, the Colorado River Compact was passed in 1922 which equally divided the water resource between the upper (Colorado, Utah Wyoming and New-Mexico) and lower basin (California, Arizona and Nevada). Therefore, each would receive 7.5 million acre-feet of water annually (the Colorado River Compact, 1922). Six years later, the Boulder Canyon Project Act defined the allocation of water apportionment for each States within the lower Colorado basin such that California receives more than 50% (4.4 million acre-feet) of the total water allocation and Arizona and Nevada are entitled respectively with 2.8 and 0.3 million acre-feet (the Boulder Canyon Project Act, 1928).

[19] California being on the path of a rapid growth could easily justify the appropriation of a large share of the Colorado river through the reasonable use doctrine, contrary to the other States.

Soon after the completion of the Los Angeles aqueduct, two new projects with federal support were setup to appropriate the water of the Colorado river by the city of Los Angeles (Colorado river aqueduct) and the farmers in the Imperial county (All-American canal), at the corner of the Mexican border and the aforementioned river. These latter are located in an arid but fertile area of 600 thousand acres and had access to the Colorado water only through the Alamo canal shared with the Mexican farmers. This canal, built in 1902 takes its source in the US but quickly crosses the border to supply the Mexican farmers first and then crosses a second time the frontier to end up in the US territory. Conflicts between American and Mexican arose soon after the completion of the canal and farmers North to the border envisioned to build their own canal but lacked financial resources to do so (Hundley, 2001). Thus, they promptly jumped at the opportunity to finance their so-called All-American canal when federal authorities stated their intentions to develop large water facilities on the Colorado river. The Imperial Irrigation District (IID) was created in 1911 to negotiate with the US Bureau of Reclamation and has been the cornerstone of the water appropriation by IID's farmers (Hundley, 2001 p.208). Important support came from the city of Los Angeles and the newly created Coachella Valley Water District (CVWD) in the hope to see their own canal also authorized and financed along the All-American canal (Hundley, 2001). At the end of the year 1922, the IID had absorbed all water companies in the area which covered approximately more than 448 thousand acres of land (Dowd, [1956]2012 p.67) and through important lobbying activities get the authorization to build the Imperial dam (49 miles North of the Mexican border) and the All-American canal completely in US territory in 1928 (Hanak et al. 2011). The construction of both facilities (dam and canal) were completed at the end of the 1930's and 1940 mark the first delivery of water to Imperial Valley's farmers (Stene, 1995). Nine years later, the Coachella canal which takes its source in the All-American canal was completed (Stene, 1995). Simultaneously to the All-American canal, another dam was built 143 miles upstream to the Imperial dam to divert water from the Colorado watercourse to the Colorado River aqueduct. This aqueduct conveys water across California from east to west and serves the newly created Metropolitan Water District of Southern California (MWDSC). Despite the Los Angeles aqueduct which gave excess supply to the city of Los Angeles, the surrounding areas were often in water shortage (Zetland, 2008). It is thus nine different water agencies delivering water to thirteen cities that organized into one district in 1928 to collectively finance the construction of the Colorado River aqueduct (Zetland, 2008). The US Bureau of Reclamation accepted the project and construction of the Parker dam on the Colorado river began in 1934 to end in 1938 and in June 1941 is the first delivery of water through the Colorado River aqueduct (Hundley, 2001 p.230). Since then, 17 other agencies joined the MWDSC from its creation in 1928 to 1971.

Two other dams have been built on the Californian border: the Palo Verde dam to serve the Palo Verde Irrigation District (PVID) since 1957 and the Laguna dam originally designed to serve the Yuma Project in Arizona but water has been diverted into the Imperial dam since 1948[20].

2.2.3.1.4. The Central Valley Project: Bringing Water to the Center of California

From the Gold Rush to the mid twentieth century, the central valley has experienced important growth in agricultural production and more specifically in the south of the valley (Tulare county). The increasing pressure on local water resources in this region while important source of supply existed in the Sierra Nevada and in the North of the State dramatically augmented the water imbalance and called for a reorganization of the Californian hydrography. Furthermore, the recurrent overdraft of groundwater in the South needed to be corrected through larger import of surface water to the detriment of alternative and more comprehensive groundwater management. However, local organization (irrigation districts and other local agencies) did not have sufficient finances or power to develop the large scale infrastructures to transfer water (Hanak, 2011). Thus, under the lobbying of western farmers who suffered two decades of very frequent droughts, federal authorities got involved in the water management.

In 1919, R.B. Marshall, a member of the US Geological Survey proposed a bold plan to dam the Sacramento river and supply water in the Central Valley, in the Bay cities and to limit salt intrusion in the Sacramento-San Joaquin Delta. While the estimated investment for such project was significant ($800 million from Marshall's estimates), revenues from water sold and power generation was predicted to cover the costs (Hundley, 2001 p.243). However, this plan failed for two main reasons (Hundley, 2001 p.244). First, the private companies of power production feared the competition with a State power generation and denounced the plan as "sovietization". Second, the growing concerns from northern farmers that water would be entirely diverted toward the south increased the unpopularity of such large scale projects (moreover that the city of Los Angeles was already intensely engaged in the acrimonious negotiations with the Owens Valley's farmers).

In 1931, the State engineer Edward Hyatt developed a new plan based on the ashes of the Marshall's plan with the largest dam on the Shasta lake to control the flow of the Sacramento river, a smaller dam on the San Joaquin river to divert water to the southern part of the valley (the counties of Madera, Kings, Fresno, Tulare and Kern). Then other facilities have been added to the preliminary plan: several dams on the American river, on the Stanislaus river and on the Trinity river to divert water from the North Coast to the Sacramento river. The goal was threefold: first it would provide

[20] From the US Bureau of reclamation website (accessed the 26, august 2016): http://www.usbr.gov/projects/FacilitiesByState.jsp

water to the South of the valley relatively drier than the North, second it would replenish the groundwater in those regions, often in overdraft and third it would restore the environmental equilibrium in the Sacramento-San Joaquin Delta afflicted by the development of agricultural production in this area (Hanak, Lund, Dinar, et al, 2011). While the plan primarily envisioned an aqueduct in southern part of the State, the main interested parties asked not to be included in this project as they already have been engaged in the Boulder Canyon Project and feared to weaken their positions in the latter project with a new commitment into the State Plan. Thus, this latter became focused on the Central Valley only and was renamed the Central Valley Project (CVP) (Hundley, 2001 p.246-247). The Project was initially intended to be funded by State's bonds and in 1933, the State legislature accepted the proposal (Hanak, Lund, Dinar, et al, 2011). However, despite a cost reduction of about $200 to $300 million from the initial Marshall's Plan and an acute drought, the Great Depression that stroke the whole US (including California) in the 1930's abruptly halted the project and it became clear that the necessary funds could only be raised at the federal level. Through the *New Deal* policy developed under the Roosevelt presidency, the US Bureau of Reclamation accepted to fund the totality of the Central Valley Project in 1935 and a project initially developed by the State of California ended up as a federal takeover (Hundley, 2001 p.252-257). The construction began in 1937 with the raising of the Shasta dam in northern California to end in 1951 with the first delivery of water through the Delta Mendota canal. Other facilities have then been added with the Tehama-Colusa canal along the Sacramento river in the northern part of the Central valley and two canals (Madera and Friant-Kern canals) that provide water from the Friant dam to the southern part of the Central valley (Hanak, Lund, Dinar, et al, 2011).

Through the CVP, the federal authorities have the control over an important share of California's water resources. However, the 7 million acre-feet of water produced annually would meet the growing demand only during one decade (Hanak et al., 2011).

2.2.3.1.5. The State Water Project: Even More Water for Southern California

While the CVP was still under construction, a new idea came to the State's officials to complete the federal project with a State owned project for two main reasons. Firstly, the quasi-monopole of federal authorities on a large amount of water raised some concerns by farmers and officials on future development of water related activities. Moreover section 8 of the Reclamation Act casted some doubts on who had the power of decision over the water resources under federal authorities (Hundley, 2001 p.276). Such anxiety would increase even more when the Bureau declared to prepare a large reorganization of water use in the West. The federal authorities planned larger deliveries of water from Oregon to the Center and South of California through the Klamath river in exchange of diverting the American river to Nevada. The plan also envisioned to take off more water from the Owens valley toward the Mojave

Desert (Hundley, 2001 p.279). Secondly, population growth in the State had exploded during the World War II and the subsequent decades (from 5.6 million in 1940 to 15.7 million in 1960)[21]. Thus, economic prosperity that propelled California as the leading States in the US goes hand in hand with a higher pressure on hydrological resources and a growing demand of water. Predicting these issues as soon as 1945, the State Water Resource Act has been enacted to establish the Water Resource Board and to study more in depth the question of further infrastructures in water storages and diversions. In 1951, a report was delivered to the State governor establishing that approximately 40% of available water was flowing unused to the Pacific Ocean through the Sacramento and the San Joaquin river (CDWR, 1951 p.70). The same year, the State's engineer A. Edmonston proposed an ambitious plan composed of multiple reservoirs and aqueducts throughout the State to optimize the use of water resources (Hundley, 2001 p.279). The capstone of this plan was the construction of the Oroville reservoir on the Father river (northern California) to store excess of water and convey it through the Sacramento River to the Delta. Then the water would be pumped from the Delta to be conveyed to Lake Perris (South of Los Angeles) through the California Aqueduct (CDWR, 1963 p.9). Largely supported by Governor Pat Brown and the Southern California water districts, the project was regarded with a lot of suspicion by the northern part of the State who feared to repeat the Owens Valley experience (Hundley, 2011 p.281). Despite the strong opposition, the bill to raise the $2.5 billion necessary to finance the State Water Project was passed in 1960 and construction began in 1961 to end in 1971.

The State Water Project marked the end of the hydraulic era in which large scale water infrastructures are designed to supply more water to the ever-growing demand. Underlying reason stems from the rise of environmental concerns and potential external effects that such transfers may have upon the regions of origin (Hanak, Lund, Dinar, et al., 2011 p.54 and Hundley, 2001 p.308). During the 1960's and 1970's, it becomes clear that the adopted strategy of supply enhancement through the development of large physical infrastructures without developing the necessary institutional system to cope with detrimental effects that such projects cause cannot be sustain over the long term (Haddad, 2000). However, the environmental crisis that triggered the recognition of an institutional change was the tip of the iceberg. With increasing demand from the cities, the stability of agricultural demand and the limited possibilities in building supplemental infrastructures, growing awareness that the supply enhancement strategies used so far to content antagonists' needs could not provide anymore the expected benefits has been acknowledge (Howitt, 1998 p.120).

[21] Data from the US Census, see figure 2.2 for more details

2.2.3.2. The Rise of Conflicts and the Need for Institutional Change

While the large physical infrastructures built in the first half of the twentieth century provided to the State of California the mean to develop and to become the wealthier State of the US that we know today, such investments also imposed important costs to some of the regions from which water is being pumped. Indeed, the transfers of large quantity of water over long distances have caused numerous external effects inadequately handled by the institutionalized rules upon the users in the regions of origins. Added to the pecuniary externalities previously presented, the Owens and Mono lakes have particularly suffered from the transfers to the city of Los Angeles through technological externalities, the former has been nearly dried out, while the ecosystem in the latter has been broken from the lack of freshwater inflows (Hanak, Lund, Dinar, et al., 2011 p.54). The "ghost of Owens Valley" is now haunting any policy makers advocated for water transfers (Haddad, 2000 p.xv). Another icon of the environmental failure from the large-scaled project stands in the Central Valley, further West from the Owens Valley. The Sacramento-San Joaquin Delta (or simply called the Delta), is a large region drained by the two most important rivers of California: the Sacramento River from the North and the San Joaquin River from the South and represents a hub for conveying water from North to South through either the CVP or the SWP as much as provides water for irrigated land south of the Delta (Godhue, Sayre and Simon, 2012 p.286). Yet, the regular activity of pumping rapidly caused the water quality and quantity to decline inducing major issues for the wildlife of the Delta (Moyle and Bennet, 2008; Lund, Hanak, Fleenor, et al. 2007 and Lund, Hanak, Fleenor, et al. 2010). The growing resentment from local populations and the more general tendency of the nationwide population to lean in favor of increasing environmental protection, led the State's officials to develop an institutional infrastructure more in line with the new challenges of large-scaled transfers of water. Indeed, previous conflicts were generally settled by a water supply enhancement investment which simply provided more water to content almost everyone, the communities being affected in a negative way were perceived as necessary losses for a greater end. But, the limits in developing water courses by the wider recognition of the environment calls for a reallocation of water rights of use that triggered the latent conflicts between efficiency and equity in the distribution of water resources (Libecap, 2012 p.400).

2.2.3.2.1. Conflictual Emergency Policies to Mitigate Environmental Damages

Whether initiated by the Congress or by the State's officials, a series of reforms to account and control for potential detrimental effects of water transfers has been enacted in the late 1960's-early 1970's. Through these changes, attempt has been made to mitigate the environmental damages by amending of the institutionalized rules which serve as a guideline for establishing rights of use.

At the federal level, the National Environmental Policy Act (NEPA) requires the assessment by federal agencies of any actions likely to have a major impact upon the environment have been passed in 1969. The State of California followed one year later with the California Environmental Quality Act (CEQA). Similar to the NEPA, the CEQA requires that each project management be precede by an environmental assessment and potential alternatives or offset mechanisms for unavoidable environmental damages. Furthermore, restrictions in building physical infrastructures within water courses have been established through the National Wild and Scenic Rivers Act and the California Wild and Scenic Rivers Act respectively in 1968 and 1972 (Hanak, Lund, Dinar, et al., 2011 p.56). Finally, the Clean Water Act initially passed as the California's Porter-Cologne Act in 1969 and revised in 1972 gives substantial power to the SWRCB in defining water quality standards for the different uses settled and enforced by the State (Walston, 2008 p.793).

In 1971, the California Supreme Court also amends the Public Trust Doctrine to include the protection of ecological services in addition to the traditional protected use of navigation, fishing and recreational use (Hanak, Lund, Dinar, et al., 2011 p.59). This has been used to settle the case of *National Audubon Society v. Superior Court* (1983) in the Owens Valley in which the city of Los Angeles has been required to limit its transfers and reduce the environmental impacts. More significantly for the future development of water institutions, the California Supreme Court ascertained the continuous responsibility of the State to protect the environment and that, whenever the past allocations have been. It implies that in matter of reallocating water, the decisions of the State are no longer tied to the past decisions when the environment is being under threats. This has important implication in the possibility of institutional change because as it has been previously explained in chapter 1, the reallocation of a resource following an exogenous change is always subject to substantial transaction costs arising from the political conflict of the multiple interactional situations with between economic and political organization. Yet, with the expansion of the Public Trust Doctrine, such transactions are no longer needed to reallocate a water previously entitled to a detrimental use for the environment, navigation, fishing and recreational use (and only for these uses since such power cannot be used by the State to account for other types of external effects upon other users). However, some argued that such overthrown of private rights by the State may have deterring effects upon the decision to trade water since any action can now be potentially overturned by governmental agencies if environment is under serious threats (Huffman, 2012). The underlying reason can be found in the legal analysis of Commons (1934) that granting a right mechanically implies to impose a duty. Thus, providing more rights to the environment through by increasing instream flows induces to foist duties for others to respect these new rights by decreasing their uses.

Another iconic struggle from these large-scaled water projects has been the forty-years-long conflict over the Sacramento-San Joaquin Delta (Hanak, Lund, Dinar, et al., 2011; Moyle and Bennet, 2008; Lund, Hanak, Fleenor, et al. 2007 and Lund, Hanak, Fleenor, et al. 2010). During the late 1970's, it became evident that the ecosystem and native fish species in the Delta would quickly vanished if nothing was done to remedy the external effects from the increasing pumping of the both projects, diverting approximatively 5.5 million Acre-Feet per year in the late1960's (Godhue, Sayre and Simon, 2012 p.286). The first solution advanced by the SWRCB in 1989 has been primarily to cap the water exports from the Delta at their level in 1986 and secondly to assigned the burden of the Delta conservation on the Southern water importers which have caused a strong political resistance and protests, ending up to the rejection of the ambitious SWRCB's plan (Hanak, Lund, Dinar, et al., 2011 p.61). After multiple other unsuccessful attempts undertaken by the SWRCB to redefine a plan that could be agreed for all stakeholders, the federal authority get involved through the Environmental Protection Agency (EPA) and promulgated several water quality and quantity standards for the Delta in 1994. This also laid down the ground for more ambitious environmental project in the 1990's to coordinate and redefine the agreement between the multiple stakeholders of the environmental crisis in the Delta. Representing the State of California, the Water Policy Council would allow the multiple water agencies to speak with a single voice face to the representatives of the federal agencies, the Federal Ecosystem Directorate. Together, they led to the formation of group known as CALFED (Hundley, 2001 p.407). The project however fall short after its constitution due to the lack of political and financial support (Hanak, Lund, Dinar, et al., 2011 p.63). Finally, a federal court judge ruled in 2007 that current operation in the Delta was not in accordance with the federal laws in term of environmental protection and required that water exports from the Delta should be reduced by a third the next year (Godhue, Sayre and Simon, 2012 p.288). This decision caused an estimated total loss of 500 million of dollars annually in the short-run, and 140 million of dollars annually in the long-run for the agricultural and municipal importers of this water (Sunding, Ajami, Hatchet, et al., 2008 p.4).

All these attempts have been made to cope with actual or potential environmental externalities through the reallocation of rights of use from human activities (principally urban and agricultural uses) to the environment. Yet, the perceived inflexibility of the law added to the absence of any kind of compensatory mechanisms for the loss of these rights have increased the political tensions that was already existing between agents (Hanak, Lund, Dinar, et al., 2011). As a result, the lack of political or financial support from a substantial part of the stakeholders have often led the reforms to fail in their objective, which in turn called for more inflexible change through the intervention of the federal level. The problem is not only a difficulty in deciphering the multiple interdependencies between water users and the ecosystem that caused the action of some agents to damage the environment, but more broadly from a path dependency which arose at the initial stages of allocation of rights of water use. Therefore, such dependency to past institutionalized rules causes not only the rise of technological externalities through the problem of return flows, but also the increasing concerns from pecuniary externalities to local communities (Libecap, 2011).

2.2.3.2.2. Path Dependency as a Source of Conflict

Path dependency of water institutions in California, can be understood as a water use patterns that become fixed in historic locations, such as agricultural in what is now rural areas, which have been chosen in the early twentieth century for regional development, but not for economic efficiency (Libecap, 2011). These inheritances from the past water allocations promote predictability of behaviors and thus increase certainty, but also may be transformed into rigidity that impede necessary adaptation with the exogenous changes of water conditions (Garrick, 2015 p.81). The first source of such rigidity is the physical infrastructure to store and convey water from the place of extraction to the place of use. Such facilities are capital intensive with a lifespan of several decades (Hanemann, 2006 p.74) and hooks the water use in a specific place and often for a specific use which becomes difficult to change due to the prior investment and the new one required to modify the place and type of use of the water (Bruns and Meinzen-Dick, 2001 p.2). However, while the physical infrastructures make the potential changes more difficult, it is not the most challenging task for modifying the institutionalized rules of water sectors. A second source of rigidity probably more constraining than the first one, is the expansion and the strengthening of certain communities that largely benefited from these initial allocations and are now taking advantage of the Status quo (Garrick, 2015 p.83).

In the early stages of its development, California was looking for expanding its agricultural production as a way for developing its economy and thus, has established the institutional and physical infrastructures to promote irrigation and to adapt the farming production to the arid and uncertain climate of this State (Hundley, 2001). As pointed out by Bretsen and Hill (2009 p.732), "…there was almost no thought that the water would ever be more valuable for uses other than raising crops by the farmers". The Prior Appropriation doctrine combined with the creation of Irrigation Districts have fostered the necessary stability in the interdependencies between irrigators to induce sufficient predictability of behaviors and thus, to promote private and local investments in agricultural production (Bretsen and Hill, 2006). While particularly effective at the dawn of the twentieth century, this system has also concentrated a certain amount of power in the hands of few. Indeed, being vested of the rights of water use by the State (who retains the property upon the physical water through the Public Trust Doctrine), the Irrigation Districts have extensive power from these rights and more specifically the one to coerce their members (as previously discussed, it was often a required condition to foster coordination within the district). More specifically, the management, exclusion and alienation rights which give the position to adequately setup the institutionalized rules to transfer water inside or outside the district are generally not granted to the individuals but to the district which would require the approval of the district's board to modify the place of use (Thompson, 1993 p.726). the Irrigation Districts are semi-public organizations, members of the district's boards are elected either from land owner or more often in California from all the registered voters within the district's boarder (Bretsen and Hill, 2006 p.321, 2009 p.737). Consequently, any changes from the traditional use of water will implicitly require a substantial support of the community and raise the transaction costs of interacting with other members which may have different perspectives upon the value of this use (Libecap, 2011 p.74).

In summary, the partial decentralization of the authoritative relationship in the past has been done to maximize the effectiveness of specific use of water (predominantly the agricultural one) and small-scaled transfers (mostly intra-districts transactions). Through that way, water resources have been "locked" into rural areas, mostly for agricultural purposes due to the fundamental principle of the Prior Appropriation doctrine which gives first priority to the first claimants of use (i.e. agricultural producers) and basic mechanisms of water organizations which are biased toward keeping the use within the organization (Howitt, 1998 p.120 and Libecap, 2011 p.76). When the South-Coast of California and the Central Valley have grown larger than their respective local water resources could sustain and have thus been required to seek new sources of supply for their expanding needs of water, the inadequacy of institutionalized rules within local communities to deal with larger issues of large-scaled transfers has become clear. However, since a substantial part of the power to change the institutionalized rules has been vested to these local communities, higher levels of the authoritative relationship get the hands tied up to reallocate the water more adequately with the new needs. While the change of the Public Trust doctrine in 1971 may be view as a successful empowerment of the State to avoid the most harmful technological externalities upon the environment, the multiple unsuccessful attempts of reconciliation to protect the Delta has shown the limit of such process. Challen (2000) noted that "the devolution of property rights down the hierarchy may reduce the flexibility of the institutional structure with respect to future reforms" (p.150). Consequently, institutional changes of water sector and its adaptability to large-scaled problems in California heavily rely upon the important coordination of the existing patchwork of water organizations that were not intended to be so coordinated at their creation (Libecap, 2011).

2.3. The Water Markets as Scaling-Up Instruments to Manage Water

In the case of California, like other Western States, the Prior Appropriation doctrine have led the water resources to be locked into places of use not necessarily providing the highest return since it solely depended upon the earliest claimant and not the highest value of use (Libecap, 2011). Through that way, water uses have been parceled out allowing the users to grow independently of each other which have been beneficial to develop the different regions but have also increased the heterogeneity of water value between regions. Through water markets, water resources should flow to the most valuated uses toward the maximization of economic welfare and the reduction of the imbalances in the pattern of water values. In that respect, water markets are perceived as a tool to scaling-up the water management by connecting the different places of use and by providing an interactional interface to equilibrate divergent demands with the equally heterogenous supply of water (Garrick, 2015 p.181). From this interactional interface, potential buyers and sellers can agree upon an acceptable compensation for both protagonists of the exchange through direct negotiation rather than by the intermediate of the State or other type of governmental agencies (Colby, 1998 p.87). In theory, each party will engage in a Coasian bargaining to define institutionalized rules of the exchange and thus to delineate the rights and their correlative duties within the broader scope of the preexisting institutionalized rules defined by the State (Burness and Quirck, 1979). Through that way, water should be unlocked from low-valued uses to high-valued uses (Carey and Sunding, 2001) without causing uncompensated harm to other and, not only the market for water may address and manage the conflict between users, but may also delay or avoid the costs of developing expansive and new physical infrastructures (Garrick, 2015 p.8).

Yet, water is a challenging resource to adequately delineate for trading purposes and institutionalized rules are often as complex as the circuitous hydrological interdependencies are, such that transaction costs to apply and to enforce them rise quickly, limiting the interest and the hypothesized efficiency of water markets (Howitt, 1994 and Smith, 2008). Thus, while water markets can provide the necessary flexibility and security in the arid regions such as California, it requires also sufficient security of property rights which can only be achieved with a "delicate" structuration of institutions (Easter, Rosegrant, and Dinar, 1998; Howe and Goemans, 2003 and Livingston, 1995). This notion of transaction costs from institutional inadequacy being always more at the core of the problem of water markets, Carey and Sunding (2001) performed a comparative analysis of water markets between the Central Valley in California and the Colorado-Big Thompson in Colorado and pointed out the institutional differences between these two regions assessing it as the cause of the diversity of water markets performance in the Western States (path dependency). They ended their article by stating that: "Given the high costs of achieving consensus among heterogeneous users and affected parties, the trigger event for change may be a crisis event such as drought or a threat to endangered species that increases the cost of maintaining the status quo to the point where the benefits of change outweigh the costs" (p328). Livingston (1998) promoted institutional change to improve efficiency in water markets when supply investment is not possible (or too expensive). But, the costs of such restructuration of the institutions are often very high, such that Howitt (2002) stated about the lack of institutional changes, even facing recurrent water shortage that "this interminable cycle of short run panic and long run inertia has been termed the "hydro-illogical cycle" by members of the National Drought Mitigation Center" (p.14). Furthermore, the variability of water supply induces more uncertainty about institutional investment making the latter less attractive. Howitt (1995) implemented the stochasticity of water resources in a model of institutional change and shows that investment in property right definition might take more time than expected due to the uncertainty that surround marginal product of water value and the return of such change. In that respect, "[w]ell-functioning water markets with common agreement on the nature of the rights being exchanged are the exception, not the norm, in the American West" (Colby, 1998 p.88).

In this section, we review the third era of water management in California, when its officials acknowledged at the end of the twentieth century that the relative certainty of its water supply in which they have been used for more than a century will come to an end, and thus attempted to develop the water markets. We first provide a non-exhaustive literature review of water markets with its two phases: first, an expectation that water markets could bring efficiency, and second, the realization that such efficiency can only be obtained at the costs of changing the actual institutions. We then analyze the evolution of water markets in California and more specifically, we classify and explain the different barriers to trade barriers.

2.3.1. From the Expectations of Perfect Competition to the Recognitions of Institutional Imperfections

As have pointed out by Griffin and Boadu (1992), water markets are not always the panacea to the water problem but can be beneficial for surface and groundwater if they are appropriately regulated. Thompson (1993) asserted the important role of institution in water markets and identified the district's organization and more specifically the fuzziness of the rules for market profit redistribution among members as one major impediment to trade. But conflicts over potential externalities and exercise of a market power by sellers are also important issues in such institutional setting.

2.3.1.1. The Assumption of Efficient Markets for Water

Harding (1936) stated in a seemingly expression of faith[22] that "economic pressure will eventually result in the available water supplies' being used where the greatest return will be secured" (p. 46). As previously depicted, the underlying argumentation is a classical economic mechanism of marginal productivity equalization under perfect competition and is an implicit call for expanding the water markets institution (Garrick, 2015 p.40). When water is used to irrigate a poor-quality land, the free transferable water right allows to reallocate this resource to higher quality land or other high-valued uses and thus, increase the marginal value of water (Griffin, 2016 p.256). From this basic reasoning, several authors have conjectured the superiority of market-based instrument over the non-market institutions to manage efficiently the water resources either through rhetoric argumentation (Flack, 1967; Harding, 1936; Hutchins, 1942; Milliman, 1959 and Trealease, 1957), empirical studies (Anderson, 1961 or Gardner and Fullerton, 1968), simulations model (Hartman and Seaston, 1970 and Walker and Skogerboe, 1975) or theoretical model (Burness and Quirk, 1979). Among the firsts, lies Harding (1936) and Hutchins (1942) who considered the potential gains of efficiency through free transferable water rights which are allowed within the Prior Appropriation doctrine. They postulated that, since water rights of use are not anymore tied with land ownership, it is possible to sell the former without having to abandon the possession of the latter, and thus, water transfer can be developed such that the price of water would be equalized to its marginal productivity, in a relative independency from the land value (contingent upon the functional form of the production function). They were also among the firsts to raise the potential issues from a fuzzy definition of the rights which is most likely the case in the water sector because water rights have never been defined and develop for trading them. But, regardless of these potential legal issues, Anderson, (1961, 1967), Flack (1967), Hirshleifer, De Haven and Milliman (1960), Milliman (1959) and Trealease (1957), argued that marketing water is an effective alternative to improve efficiency in the water sector. Most of these authors justified the need for water markets to increase social welfare through a higher Production Possibility Frontier, but not to cope with possible water shortage which was seen as unlikely in the next future: Milliman (1959) saw "little likelihood of actual physical shortage of water" (p. 41). However, the conditions and the structure of the economies at the end of the 1960's has been heavily modified through the rise of urban areas. A future water scarcity turned to be much more likely than in the 1950's and the need to find a standardized system of water reallocation became more urgent. In that respect, Flack (1967) was among the firsts to urge for expanding water markets to adapt the economy to the more frequent scarcity induced by the population and economic growth. The article of Burness and Quirk (1979) have been

[22] From Gaffney (1961 p.33)

an important contribution in the formalization of the argumentation provided by the aforementioned authors as they demonstrated with a simple theoretical model the inefficiency of the prior appropriation doctrine without a competitive market for water. More specifically, since senior appropriators are facing less uncertainty upon the available water resources that can be used, they will have the tendency to increase their capability in catching and claiming more water resources than the junior users while the former having less necessity of this water than the latter. Consequently, a Coasian bargaining between junior and senior appropriators may allow the system to come to an efficient level[23].

Yet, the assumption that water markets will work relatively close to the idealized competitive market was a critical point of the argumentation developed by the aforementioned authors, and the latter were eager to validate this point. While, the empirical studies have been scarce in the 1960's and 1970's to prove such assertion, the work of Anderson R.L. (1961) gave them some reasons to believe so, as it provided a case study of a successful water market development in the South Platte Basin (Colorado) between agricultural users. The data showed that water is actually moving from low to high valued crops creating opportunities for expending water markets as expected by Harding in 1936. Then, Gardner and Fullerton (1968) hypothesized that allowing transfer of irrigation water could increase the marginal value of product of

---

[23] A problem with the reasoning developed by Burness and Quirk (1979, 1980) is that they supposed sufficiently large water markets to provide the necessary competitive mechanisms to get the efficient equilibriums. With thin markets, rules of bargaining become much more important in the determination of the efficiency since they will determine the market power that may get the interacting agents. Indeed, as have demonstrated Saleth, Braden and Eheart (1991), under multiple bargaining environment and rules, the size of the markets has a great influence upon the outcome of the bargaining. More specifically they provided theoretical evidences of the superiority of the water appropriation doctrine based upon a priority system (Prior Appropriation doctrine) in comparison to the one based upon an equal sharing (Riparian doctrine). This is in contradiction with the conclusion of the second article of Burness and Quirk (1980), but is nevertheless coherent with the previous work of Balleau (1988) who considered the Prior Appropriation doctrine as being superior to other systems for water transfers and calls for extending this right system to groundwater resources. Similarly, Clyde (1989) supported the prior appropriation system for its flexibility and its adaptability to changes of the water value. He insisted on the fact that such system is not an obstacle for change but recognized that time is needed to correspond to the rapidly changing societal values (see also Johnson and DuMars, 1989; Nunn and Ingram, 1988).

this resource. Through an econometrical estimation, they found that small scale exchanges of water in Utah is a powerful explanatory variable of land rental price. Hartman and Seaston (1970) moved up a notch by considering the potential benefits of water transfer from agriculture to cities. They only analyzed the intra-regional trade through an "Input-Output" model without questioning inter-regional water transfers. Similarly, Walker and Skogerboe (1975) estimated a potential gain of reallocation of water from agricultural production to the city of Denver in Colorado on the order of $1000/AF of transferable water. The important study of Vaux and Howitt (1984) along with the ones of Eheart, Lyon, and Wong (1983), Gardner and Miller (1983) and Gisser (1983) strengthened these predictions by estimating the potential gains from interregional water markets in California through a spatial equilibrium trade model. Extending the model of Flinn and Guise (1970) which in turn had been adapted from the formalization of Takyama and Judge (1964), they found a total net benefit of $66 million for the year 1980 which could grow to $219 million in 2020. Other works followed to determine the potential gains of water markets (Hamilton, Whittlesey and Halverson, 1989; Howe and Goemans, 2003; Howitt, 1994, 1998; Livingston, 1995 and Moore, 1986). These studies have however assumed the absence of transaction costs from participating in the water markets (only conveyance costs were incorporated), implicitly assuming that institutionalized rules were sufficiently well-designed to foster the expected competitive behaviors. This is however hard to believe in light of the few transactions that occurred (Shaab, 1983 and Young, 1986). For example, Brajer, Cummings and Farah (1989) found through a case study of New Mexico that water markets are far from being perfect.

2.3.1.2. Institutional Inadequacies for Water Markets

Along with the different works that promoted water markets, other scholars pointed out some potential limitations of such decentralized instrument to improve the water management. A first crack in this theory appeared when Gaffney (1961) pointed out the diseconomies induced by an improper water rights system. To demonstrate this, he performed an empirical analysis of the Kaweah River area in Northern California. He stated: "In this paper I have sought to expound the conclusion I have reached from observation of water use in the Kaweah area, that water use is grossly uneconomical. I have laid the blame where I believe it belongs, on the doorstep of water law" (p. 81). For him, the problem lies thus in the institutionalized rules that lock water into low-valued uses through the difficulties induced by the law to move the water. Similar conclusion has been reach two decades later by Phelps, Moore and Graubard (1978 p.28): "We also know of several attempted transfers that were thwarted by existing legal and institutional structures. Hence, one might consider the prospects for removing impediments to transfer as an efficiency-enhancing move". In that respect, Gaffney (1961) warned any policy maker upon the supposedly efficiency of water markets without a proper institutional change: "It is a weakness of much grand-scale project planning to assume implicitly that there is an operative local market mechanism which has succeeded in equating the marginal productivities of water among different users" (p. 57). His main point was that initial distribution of rights of water uses has been done in an uneconomically way such that now the water resources are being locked into low-valued uses and, while it could be theoretically efficient to transfer the water, nothing in the law guarantee the legality of such endeavor. Trelease (1962) nuanced this view by stating "[t]hat legal factors, along with historical, physical and temperamental factors have hindered transfers of water rights in that area seems to be true, but that this can be generalized over the West I doubt" (p.435). Through that statement, there is a feeble acknowledgement that the institutional setting within the water sector may limit the development of water markets. It is however far from a certitude that major impediments could occur from the institutionalized rules composing the doctrine of the Prior Appropriation.

In this line, Ciriacy-Wantrup (1967) analyzed the water institutions through the lens of decision theory. He stated that water policy can be view as a sequence of decisions over time and at three distinct levels. The first is quasi exclusively economic and controls the production through input-output decision, the second level influences the first one by the set of rules enacted under a specific institutional framework which is specified by the third and higher level of decision. The point of such distinction is to define a criterion of efficiency based upon the notion of "survival rate" (Ciriacy-Wantrup, 1967 p.185). Thus, rather than attempting optimizing calculation, a better approach should be the comparative analysis of institutions He used this basic framework to analyze the water institutions and more specifically the blend of Riparian mixed with Prior Appropriation doctrines in California and concluded that "California water law performed relatively well" (p.188). Through that way, he joined up the point made five years earlier by Trelease (1962) in the response addressed to Gaffney (1961) upon the inadequacy of Prior Appropriation doctrine, that "[e]ven if water law were solely responsible, economic inefficiencies under particular conditions at particular points in time are not sufficient for an indictment of the whole institution" (Ciriacy-Wantrup, 1967 pp.187-188). However, because such analysis was only based upon the institutional performance from the past experiences, it is hazardous to conclude that the institutionalized rules underlying the water law are sufficiently well designed to handle the multiple and often conflictual interactional situations induced by the water markets. Indeed, as a general observation, neither in California nor in other Western U.S. States have water markets emerged as a major reallocation mechanism (Young, 1986).

Previously, Johnson (1971) pointed out that the Prior Appropriation doctrine was certainly efficient when water was not too scarce and transfers would be only on a small scale, but is today unable to account for the multiple externalities and is thus inadequate with the price mechanisms. Following this line, Davis (1968) compared the

Australian licensing system (which implies an important discretionary power by administrative agencies) to the American right system, with the Riparian (relatively unsecure with large demand) and Prior Appropriation (particularly rigid). He concluded that West U.S. may gain from the Australian system but is unacceptable politically. Drawing upon this conclusion, Howe, Alexander and Moses (1982) proposed later on, a more politically acceptable solution through the development of State's support for enacting institutionalized rules of water management including the facilitation of transfers and the improvement of climate information. More specifically, they called for the creation of a State agency "that would stand ready to buy rights at a known schedule of prices and to sell rights to new users" (Howe, Alexander and Moses, 1982 p.388). The goal would not only be to promote the transfer of water which reached their limits at a deceptively low level, but also to provide sufficient information to the users of the value of water through this benchmark price. In overall, there is a growing recognition that water markets are far from the assumption of perfect competition as conjectured by many authors in the 1960's (Gisser and Johnson, 1983; Gould, 1989; Gray, 1989; Falkenmark and Lindh, 1993; Thompson, 1993 and Williams, 1972).

Some concerns also arose about the effectiveness of water markets from the normative point of view. Boulding (1980) heavily criticized the global movement of decentralizing the management of water resources to private parties and insisted upon the symbolic value of water which may not always be accounted in water markets. He stated that …the sacredness of water as a symbol of ritual purity exempts it in some degree from the dirty rationality of the market" (p.302). Six years later, Ingram, Scaff and Silko (1986) argued that water is a social good and thus, should be fairly distributed among users: "water as commodity is a mistake [and] the use of 'efficiency' alone is a poor rule for evaluation of water projects and for water reallocation" (p195). From that assertion, they state five principle of equity: (i) equitable distribution of costs and benefits; (ii) respecting of all kind of value; (iii) inclusion of all stakeholder; (iv) building and keeping trust among users; (v) taking account of future generation and not engaging into a "faustian bargain". These principles are however somewhat vague and may add an enormous supplemental difficulty from potential opportunistic behaviors. Sax (1965) have previously pushed the question in the normative scope by asking if it is "fair" to allow private profits from the sell of federal water which is considered as a public property. More specifically, it is the princip of subsidizing water supply to agriculture which raise issue as the receiver of these subsidies can then sell water at a market price and thus earn a surplus of gain. Anderson (1967) responded to Sax by pointing out that an attempt of capturing private rent may deter the realization of much larger benefits. Indeed, Wahl (1989) extensively analysed the federal provision of surface water in the Western States of the US to show how transfers may be beneficial. More specifically, the author focus on case studies in three States (California, Colorado and Arizona) and also investigate the idea of interstates transfers along the Colorado River (such type of transfers between two or more States in the West US is also discussed by Holme (1985) from the legal point of view). The main point made in the Wahl's book is that due to the important levee that the federal organizations such as the Bureau of Reclamation have, they can play a major role in expanding water trading activity. The objective is clearly not the fairness of a situation but its efficiency and subsequent studies will fuel this argument. Later on, past centralized institutions will be openly criticized for its inability to cope with actual changes (Anderson, 1983a, 1983b). In its first book, Anderson (1983a) opposes the *traditional* resource economists who are considered to be the sole responsible of the actual water shortage to the *new* resource economics, more favorable to trading water. The author regrets the tendency of the former to center the attention on potential market failures without addressing the real deficiencies of public management. These inefficiencies decrease the social welfare through rent-seeking behavior and lobbying activities towards subsidized water for agriculture. To the contrary of this *traditional* view, the *new* resource economics should address the question of transferable water right and investigate the question of potential market failures more in depth. Among the ones who adopted this view is Kelso (1967), for whom political influence through administrative system is often the major source of water shortage, more than the actual fall of water supply.

The underlying question from these authors and more generally from the proponents of water markets is to know if non-market institutions can do a better job for managing water than the market-based instruments (Griffin, Peck and Maestru, 2013 p.9). In their well-known work, Buchanan and Tullock (1962) provided an attractive reasoning upon why government can fail as much as the markets through the basic notion that, like the latter, the former is being constituted by humans, limited cognitively and subjected to opportunistic behaviors. In the context of water institutions, while the markets would disadvantage the agents with less economic power, the non-market institutions can easily be instrumented by those with sufficient political power in a rent-seeking behavior (Ingram, 1973; Lach, Ingram and Rayner, 2005 and Rucker and Fishback, 1983). In that respect, Colby, McGinnis and Rait (1991) made the distinction between administrative reallocation (involuntary) and market reallocation (voluntary) and pointed out that both types of reallocation will continue to exist but will serve different purposes. The voluntary can be effective only when all parties have sufficient bargaining power.

The principal issues from establishing water markets are the potential externalities (technological or pecuniary) that may arise from the inadequately ruled transfer of water (Saleth and Dinar, 2004). In that respect, Dudley (1992) promoted the fragmentation of the resource into well-defined property rights in order to limit the interdependencies between users. He pointed out that, while the common property regime might be good for small water system, it is generally inappropriate for larger one. However, drawing acceptable institutionalized rules toward such fragmentation induces a supplemental cost in searching for an adequate trading partner, ascertaining the relevant characteristics of the transferable water right, negotiating prices and other terms of transfer and more importantly, obtaining the legal approval for the transfer to occur, which implies to account for the potential external effects of such transfer (Colby, 1990b p.1184). While similar costs may be also encountered in other types of markets, the one of obtaining legal approval is generally much higher in water markets than in other goods. The intricateness of water resources which leads difficulties in deciphering the adequate behavior implies the necessity to establish sufficiently well-designed institutionalized rules to steer the individual's demeanors (Archibald, Kuhnle, Marsh, et al., 1992). These types of transaction costs are also called the Policy Induced Costs designed to adjust for potential incompleteness of water contracts (Archibald and Renwick, 1998). In that respect, transaction costs, defined as the resources required to improve the institutionalized rules are increasing which in turn, are causing the water markets to be less attractive than expected by the authors promoting market-based instruments (Colby, 1988; Easter, Rosegrant, and Dinar, 1998 and Young, 1986).

Thompson (1993) and later Bretsen and Hill (2009) draw a classification of the different barriers to trade water issued at different level of the authoritative relationship (Federal, State and local). All these laws are intended to avoid technological or pecuniary externalities, but are also major deterrence to participate into the water markets and, for some of them, are inherited from past conditions inadequately fitted for the present situations (Challen, 2000; Chong and Sunding, 2006 and Libecap, 2011). Such institutionalized rules define exclusion tools for stakeholders to limit the access of water resources for certain uses in certain conditions through the determination of proxies to delineate rights and duties (Bretsen and Hill, 2009; Smith, 2008 and Thompson, 1993). While important to delegate the decision of use to private and lower authoritative level of public agents by avoiding potential misuses of the resource from these very same agents, the intricateness of the hydrological interdependencies induces such proxies to be rough and nevertheless incomplete (Garrick, 2015; Libecap, 2012 and Smith, 2008). In that respect, the tools available to the private and public agents are often inadequate in ruling a water transfer. The concept of anti-commons in that case can be understood as an effort to involve many agents in an attempt to limit the risks of under-inclusion (affected third-parties without economic or political power), but leads instead to an over-inclusion in private decision making (Smith, 2008). In other words, by trying to avoid the tragedy of the commons in water use, the regulatory may have been driven toward the development of a tragedy of the anti-commons (Bretsen and Hill, 2009, 2012).

2.3.2. The Experiences of Trading Water in California

In the same time that environmental crisis was at its highest point, one of the most severe but fortunately quick drought (from 1976 to 1977) and a series of important reports fostered the decision of Sate's officials to allow and promote markets for water (Hanak, Lund, Dinar, et al., 2011 p.67). More specifically the Governor's Commission in 1978 calls for an improvement of efficiency in water use and Phelps, Moore and Graubard (1978) conjectured that such efficiency could be attained by the establishment of a market for water. Their conclusion was that "[t]he ability of the farmers to sell title to use of his allocation of water can improve the efficiency of water within the State by providing incentives for voluntary sales or exchange of water" (p.ix). Yet, numerous regulations are required to steer the behavior of water users toward the expected actions in competitive markets. Such institutionalized rules will determine "who can sell water and what types can they sell" (Hanak and Stryjewski, 2012 p.9).

2.3.2.1. The Global Picture of Water Trades in California

While the intense, but quick drought from 1976 to 1977 have imposed the idea of market-based instruments in the minds of the policy-makers to manage water in California, the acute and much longer drought from 1987 to 1994 have been the real trigger of water markets. As depicted in figure 2.13, water trades have rose during the second half of the 1990's and stayed steady since the 2000's.

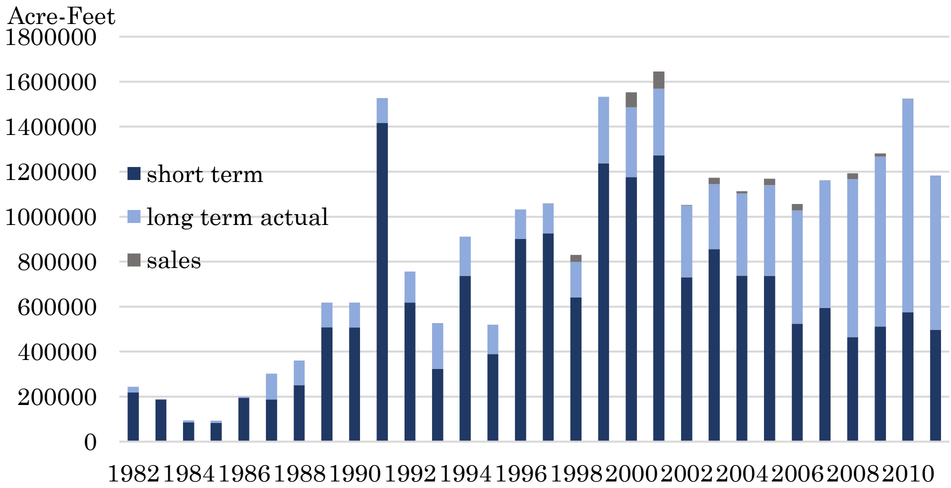


Figure 2.13: Water trades in California from 1982 to 2011

Water markets are often perceived as permanent sales where, like many other types of markets, a seller is abandoning his rights upon a resource ad vitam aeternam to a buyer. Although this may occur, such type of transfers is rare and often very conflictual such as the one between the city of Los Angeles and the Owens Valley. Much less conflictual are temporal transfers, or lease in which a seller is abandoning his rights of use upon the water only for a predetermined duration, ranging from less than a year to several decades. When transfer is less or equal to one year, it is generally referred as spot markets or short-term transfers (Griffin, 2016 p.257). Such type of instruments for trading water are particularly attractive for potential sellers since they are inducing less risks of paying an important cost from potential unintended and negative effects upon others from the water export. Indeed, a short-term transfer of one year allows to try and analyze the effect of such trade to decipher the costs and benefit (Howitt, 1998 p.123, 2014). It has however the draw-back to impose the risk upon the buyer who has to search and find potential seller every year with uncertainty upon the price the former will get from the latter. In that respect, a third instrument is the option markets which are an agreement between seller and buyer to transfer a predetermined quantity of water at a fixed price and for one year, contingent to specific events (Griffin, 2016 p.257). The event is generally the occurrence of a drought, when an index of dryness goes above a specified value. This system allows to share the risk between seller and buyer but have also a higher transaction costs since both are restricted by contract generally for several years (Howitt, 1998 p.123). In California, the spot markets have been predominant in the rise of water markets since the 1980's, mostly because of the uncertainty that surround the transfer of water. This short-term leases have then decreased to the advantage of the long-term leases which provide more security of supply for the buyer and have thus benefited from the increase of water demand from the cities. However, the use of option markets requires an up-front cost relatively important to draw a contract over several years and may be source of contentions (Howitt, 1998).

More generally, two phases in the water market's trend can be portrayed. The first phase (1987 to 2000) involves a rapid growth of water trade which induced high expectancies from policy-makers and economists that markets for water could be an effective alternative (Hanak and Stryjewski, 2012). To the contrary, the second phase is marked by a steadiness of water transfers. The main reasons for the marginal decreasing of water trades during the past decade can be found in the multiple restrictions from the development of exclusion tools as described in the following sections (Bretsen and Hill, 2009, 2012 and Hanak, 2016). The tendency is even decreasing when removing the transfer between the MWDSC (Metropolitan Water District of Southern California) and the IID (Imperial Irrigation District) which has been particularly conflictual such that it is difficult to really call that a "voluntary transfer" (Bretsen and Hill, 2009, 2012).

2.3.2.2. The Drought Emergency Water Bank as a Kick-Start

When California entered into its fifth year of drought, imbalance of water became a major issue as many cities had to be rationed and farmer suffered from cutbacks in water (Israel and Lund, 1995 p.3). State's official gave the responsibility to the Department of Water Resources (DWR) to develop and implement a Water Bank in 1991 which have been in activity during four years (from 1991 to 1995) (Archibald and Renwick, 1998). The basic principle was to provide an interactional interface supported by the State to purchase water from users in excess and selling it to users in shortage. Three possibilities were available for potential sellers to export their water: (i) transferring water conserved from fallowing, (ii) transferring water from the extraction of groundwater, or (iii) transferring water stored in local storage (Israel and Lund, 1995 p.4). Purchase and selling prices were setup respectively at $125/AF and $175/AF based upon water value estimated in agricultural production and were non-discriminatory such that any water users could sell or buy water to the bank at these prices (Archibald and Renwick, 1998 p.109). The difference of $50/AF served to conduct the necessary effort in marketing the water and in determining the potential negative impacts of the transfers. Such system allowed the water users to be accommodated with the procedure of trading water and has been particularly useful to provide a certain predictability of actions undertaken in water markets.

2.3.2.3. The Slowing Down from Institutional Limitations

Although the growing environmental concerns have been a support for the development of water markets through the attempts by the States to reallocate water toward places where the low level of in-stream flows would have endangered the ecosystem, such concerns have also caused the market to be more complicated and intricate for users willing to sell or buy water. The multiplication of regulation to protect the environment, while obviously necessary to avoid major catastrophes, has also reduced the interest in participating to the water markets due to the rise of transaction costs (Hanak, 2015 p.264) and several conflictual cases, listed by Howitt (2015) had a deterring effect on the decision to trade. More generally, a problem often exposed in water markets is the intricateness of the approval process intended either to limit the technological externalities or to compensate for the pecuniary externalities (Hanak, 2015 265).

2.3.3. The Tragedy of the Anti-Commons in Water Markets

While the tragedy of the commons can be defined as an excess of use rights which leads to an over-extraction of the resource imposing upon all extractors a technological externality (Hardin, 1968 and Ostrom, 1990), the tragedy of the anti-commons corresponds to an excess of veto rights which leads to an under-extraction of the resource, affecting all extractors in their decision through a pecuniary externality

(Buchanan and Yoon, 2000 and Heller, 1998). In that respect, the existence of multiple veto rights in water use from the exclusion tools may induce the agents willing to trade water to not undertake such action while this could be welfare enhancing, knowing that his endeavor may be challenged by other users through this veto right (Bretsen and Hill, 2009, 2012).

2.3.4. Exclusion Tools from the Federal Level

While federal authorities normally do not intervene in water institutions shaped by the States, they have nevertheless a certain authoritative power through the constitutional rules that define the global framework of the State's institutions. In that respect, federal authorities have been involved in the attempts to solve the problem of the Delta through the NEPA as previously explained. Another way to be more directly involved in water management is through the federal projects in which federal authorities have a certain discretionary power.

As previously explained, an important share of the water in California is provided through the Central Valley Project (mostly agricultural use) which is under federal jurisdiction (through the federal agency the Bureau of Reclamation) and becomes mixed with local supplies of water under the State jurisdiction (Bretson and Hill, 2009 p.739). While the section 8 of the Reclamation Act (1902) provides to the State a certain sovereignty in their water property rights such that the Secretary of Interior must proceed in conformity with the State law, the reality of such submission of the federal decisions to the State authority is not as clear (Bretson and Hill, 2009 p.739 and Walston, 2008 pp.781-782). More specifically, the Secretary of Interior have the important discretionary power to accept or revoke a water transfer by the sole reason that it may "impair the efficiency of the project for irrigation purposes" (Bretson and Hill, 2009 p.740). Furthermore, depending upon the terms of the contract between the users and the federal authority, the revenue generated by such exchange for the former may also be claimed by the latter until all financial obligations toward the Bureau of Reclamation are not fulfilled. Finally, for a majority of contracts between the users and the federal authority, the Bureau of Reclamation cannot be responsible for water shortage which implies that the latter have the discretionary power to reallocate water among its contractors without any liability from the federal authority. This substantial power of federal authority may have a chilling effect upon the decision to transfer water due to the discretionary nature of the federal decision which limit the predictability of opportunities and constraints (Bretson and Hill, 2009 pp.740-742 and Thompson, 1993 pp.727-728).

2.3.5. Exclusion Tools from the State

For all rights of use established after the Water Commission Act of 1913, any decision to change the place or the type of use must undergo a review process by the SWRCB under the Statutory Water Rights System (Bretsen and Hill, 2009 p.743; Hanak, 2016 p.255 and Walston, 2008 p.771). Since water had been over appropriated during the first decades of the twentieth century due to the lack of scientific knowledge upon the water resources, there is a chance that the right of used subjected to the transfer is actually used by another agent. In that respect, it is important for the exporter to be able to prove the continuation of the use of the water right over time to be sur that the transfer will not harm other users. First acknowledge by Harding, 1936, Hutchins, 1942 and Gardner and Fullerton (1968), the problem of return flows fall into this category (Bretsen and Hill, 2009 p.744).

The underlying reason for handling the return flows can be expressed as follow: "If a particular quantity of water is being used over and over, the value of that water is its worth not just to the first user, but to all users. If the price just exceeds the value of the water to the first user, the transfer may be inefficient. The injury to the junior appropriators who are now without water may exceed the marginal benefit of the water to the city. By protecting junior appropriators, the law internalizes that injury and forces the buyer to take it into account" (Sax, Thompson and Leshy, 2006 pp.273-274). Thus, right of use for junior appropriator of return flows is being recognized by the State's law and any change of use by senior appropriator requires to decipher between the multiple interdependencies and to delineate the consumptive use from the total diversion (Bretsen and Hill, 2009 p.744). It corresponds to what stated Hartman and Seaston (1970) that return flows can weaken the right of use and make more difficult any transfers beyond the hydrographic basin (see also Burness and Quirk, 1980 and Williams, 1972). In that respect, such process is part of the transaction costs and acts as a tax to transfer water (Bretsen and Hill, 2009 p.745). But such tax can be view also as a way to reduce the risk imposed by the technological externalities (Colby, 1990b).

Another exclusion tool may be used by the State through the Public Trust doctrine. As previously explained, the property right over water is held by the State in trust of the people of the State and through that way, the Supreme Court have a discretionary power to limit actions that may endangered the environment, navigation, fishing and recreational use. The revocation of previously granted rights is now possible through such doctrine and, while it allows an improvement in facilitating administrative reallocation of water, it also induces an increasing uncertainty upon the potential invalidation of a transfer in market-based reallocation (Bretsen and Hill, 2009 p.754). The number of exclusion tools that can be used unilaterally by the State to limit the transfer induces an ex-post transaction costs in which transferor, after having settled an agreement upon prices and quantities may be challenged and the transfer canceled. The important point here is not about the viability of the actions undertaken by the State, but rather the uncertainty that weigh upon private decisions prior the participation into the water markets (Bretsen and Hill, 2012). The expansion of the Public Trust doctrine in the case of the Owens Valley during the 1980's or the issue of the Delta still unsolved within a comprehensive governance system which obligated States to develop strict rules of extraction, are both iconic examples of such exclusion tools which are imposed to avoid the worst but may not be suitable to provide the best outcome.

2.3.6. Exclusion Tools from Local Concerns

The concern from the area of origin over potential environmental, economic or pecuniary externalities and a certain inadequacy of higher level regulation, has led some local authorities such as the districts or the counties to implement specific exclusion tools to better control for such unintended effects (Hanak 2003). Shupe, Weatherford and Checchio (1989) provided an analysis of potential economic effect of water markets upon the area of origin. More specifically he discussed a first issue that is the economic impact on the local area through county tax decreases and diminution of business related activity, and a second issue is that disincentive of investment to save water because part of this water is not owned by the saver (return flows).

Water districts are the lower level of authoritative entities to manage water resources. As previously explained, they played an important role in developing water management at the local level, but can now be source of barriers to transfer water outside of their boundaries (Bretsen and Hill, 2009, 2012 and Libecap, 2011). One first reason is that water use rights are held by the districts in the name of their members but are not vested to individuals which implies that this latter do not possess the alienation rights and thus require the approval of the board of district's direction to be allowed to transfer outside the district's boundaries the water used normally with the district's boundaries (Gardner, 1985). Since rights of use are not directly linked to individuals, a transfer from only some members of the district requires to establish an adjudication process to delineate the quantity of water applied by each user to determine the quantity consumed by the willing trader (Bretsen and Hill, 2006 pp.326-327). Furthermore, depending upon the process to elect the board, the district's officials will promote or restrict the decision to export water. Indeed, a system of vote proportional to the irrigated land generally allows a concentration of power into the hands of a few land owners with a higher ability to lobby, while a system of vote based upon one-person-one-vote dilute such power among all members with the potential rise of more conflictual situations (Bretsen and Hill, 2009 p.737).

At the county level, officials have generally fewer control upon water transfers than the districts. But, in virtue of their police power, they can impose groundwater ordinances initially intended to protect the aquifers from overexploitation (Hanak, 2003, 2005, 2015). Indeed, it is important to recall that while surface water is under the law of the State and is thus within the scope of the exclusion tools previously mentioned, the groundwater have none of such institutionalized rules. These ordinances do not prohibit the trades per se, but require potential sellers to undertake supplemental efforts and costly studies to document, under the authority of the CEQA all the potential effects of groundwater exports (Hanak 2003). Using panel data on trading, Hanak (2005) finds that the widespread adoption of ordinances in California reduced exports from 1996 to 2001 by 20%, increased within-county trades by 65%, and lowered the overall volume traded by 11%. As of 2014, 22 of California's 58 counties had implemented such ordinances, mostly during one decade (Hanak 2015). The figures 2.14 and 2.15 respectively depict the geographical distribution of counties having adopted a groundwater ordinance and the pace of their adoption.

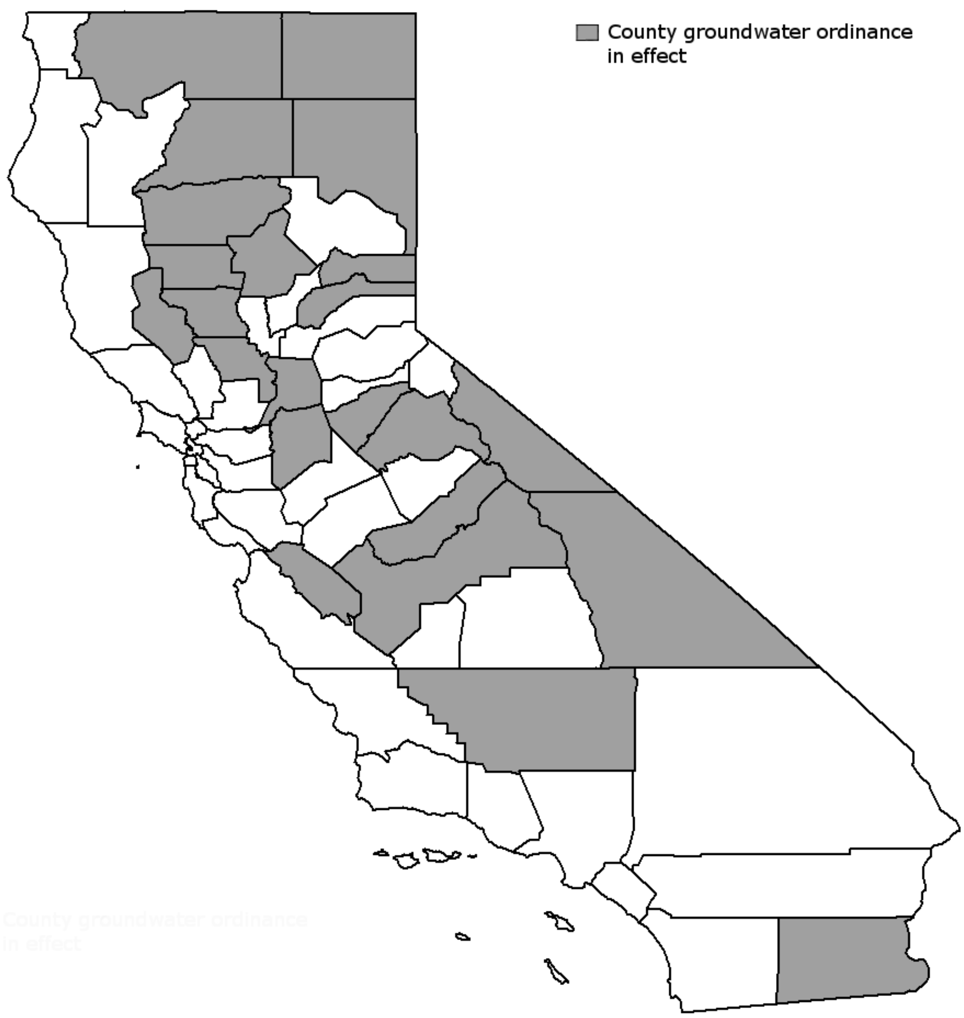


Figure 2.14: Geographical distribution of groundwater ordinances

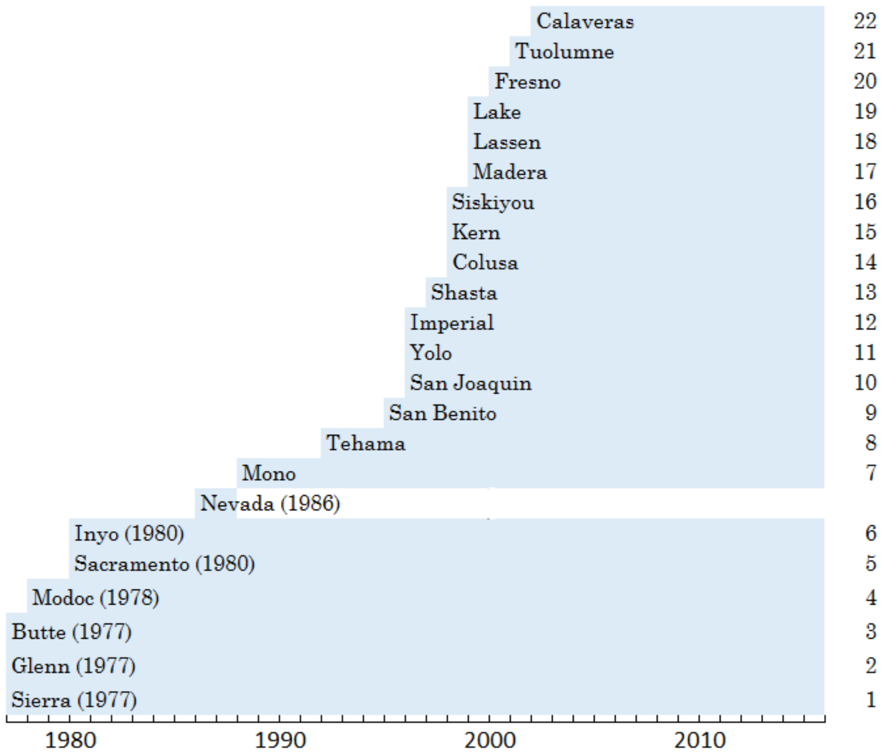


Figure 2.15: Pace of groundwater ordinances adoption (Hanak, 2003)

Most of the counties having adopted the groundwater ordinances are located in rural areas and began more specifically in the northern counties (Butte, Glenn and Sierra). However, until mid-1990's a doubt upon the legality of such regulation was growing among counties' officials. The lawsuit *Baldwin v. County of Tehama* (1994) addressed the issue and validated such tool as water management. This provides reinsurance for counties' officials that the use of groundwater ordinances and a high number of counties adopted the groundwater ordinances the years following the aforementioned case (Hanak, 2003 pp.29-31).

Such transaction costs are generally seen as a major impediment to water transfers because the required up-front investment can discourage market entry (Carey, Sunding and Zilberman 2002; Hanak 2003, 2005 and McCann and Easter 2004). More generally, these groundwater ordinances are symptomatic of a more global concern upon the area of origin. Hanak (2003) demonstrated that the underlying reasons for establishing the groundwater ordinances was not only a substantial risk of aquifer collapsing from an excess of groundwater trade, but mostly an attempt to restrict all type of water transfers (groundwater and surface).

In summary, attempts to cope with technological and pecuniary externalities from water transfers has been done through the development of exclusion-based tools rather than the governance-based management (Smith, 2008). Both, exclusion and governance tools will be expressed through institutionalized rules that prescribe specific behaviors in specific and predefined conditions. In that respect, governance tools can be view as weaker exclusion tools where attempts are not focused upon an absolute divisibility of the resource that would idealistically eliminate all unhandled interdependencies between agents, but rather contingent behaviors mutually agreed upon (Papandreou, 1994 p.208). While governance may be costlier than the exclusion for a relatively low level of precision of the institutionalized rules, the difference tends to be reversed when the required precision increases (Smith, 2008 p.462). Indeed, as explained with the different rules imposed at the different level of the authoritative relationship, exclusion tools can take the form of laws or regulatory that will trigger certain types of behaviors in predefined conditions and, in that respect, can be imposed from higher level of the authoritative relationship without the consent of the agents affected by these rules. When the situation can be easily depicted with few conditions, a high level of precision is not necessary and a broad system of institutionalized rules as exclusion tool will be sufficient to steer the adequate individual behaviors. To the contrary, a complex situation will require many exceptions upon the broad exclusion tool and, will make it even more intricate and costly to apply than without such exclusion tools. In that case, governance tools, where local organizations can develop their own system of institutionalized rules within a broader scope of State law may be a more cost effective option (Garrick, 2015 and Smith, 2008).

2.4. Conclusion

Over more than one and half century, the State of California have been able to cope with the aridity of its climate from a continuous evolution of its water institutions. Yet, past reforms to develop its agricultural production through the establishment of the Prior Appropriation doctrine and the creation of Irrigation Districts represent now limiting factors to restructure its institutions in face of structural and climatic changes (Libecap, 2011 p.76). Reshaping the institutionalized rules underlying the property rights is however a challenging and costly task for policy makers who often preferred to amend the current institutions through the multiplication of exclusion tools to account for the new conditions. While necessary to address emergency issues such as the one in the Delta or in the Owens Valley, these exclusion tools, by relieving the higher level of the political organizations from the costs of changing the institutionalized rules, are imposing supplemental costs upon the lower level of the economic organization in deciphering the intricate interdependencies. This have greatly limited the possibility of trading water through an increase of transaction costs. However, the growing incompleteness of institutionalized rules to handle the changing interactional situations imposes an increasing pressure upon the institutions to change. This led Israel and Lund (1995) to profess that in California, "transfers cannot be avoided, only delayed" (p.18).

Chapter 3: The Costs of Transacting Water in California

Coauthored with Professor Ariel Dinar and Ellen Hanak

"Why are there so few transactions among water users?" (Young 1986 p.1143). This question raised by Young 30 years ago, is still relevant today in many arid regions around the world which attempt to introduce water markets (Saleth and Dinar, 2004). In California, expectations in market-based instruments as a potentially effective system of water reallocation grew over the last decades of the twentieth century (Easter, Rosegrant, and Dinar, 1998; Easter and Huang, 2014 and Msangi and Howitt, 2007). However, despite the efforts undertaken by policy-makers to promote these water markets, notably through the emergency drought water bank in the early 1990's, transfers in the first decade of the twenty-first century stagnated at a disappointingly low level (roughly 3 to 5 percent of the total use) (Hanak, 2015). In other words, the reality of water markets in California falls short of their potential (Howitt, 2015).

It is generally advocated that underlying reasons for such disillusionments can be found in the highly complex institutional setting in which transfers occur (Carey and Sundin, 2001; Howitt, 2014; Sunding, Zilberman, Howitt, Dinar and Macdougall, 2002 and Young, 1986). Indeed, as analyzed in the previous chapters, the circuitous interdependencies from using water resources have led officials to establish a set exclusion tools to limit the risk of market failure. It follows that the multiplication these strict institutionalized rules to cope with technological and pecuniary externalities requires to invest a substantial share of the available resources to define or comply with these regulations. Consequently, such dedicated resources induce an inefficient situation in the neoclassical sense since part of the endowment is not used for the production. The wedge drawn between the actual and the ideal production possibility frontier can be interpreted as transaction costs (Griffin, 1991). While it must be pointed out that simply suppressing these exclusion tools would only have as result to lower the actual production possibility frontier instead of driving it to its ideal level since deciphering the intricate interdependencies in water uses will likely lead the agent to misbehave without a minimum of institutionalized rules (Colby, 1990b), it must be acknowledged also that such restrictions have curbed the incentives to trade water and have induced the water markets to be less liquid than it could be (Hollinshead 2008).

Inflexibility in water markets is particularly problematic during extreme events such as droughts. In such situations, water markets can lessen the costs of scarcity by enabling the reallocation of water to higher value activities. During the most recent drought in California, Howitt, Medellin-Azuara, MacEwan, Lund and Summur (2014) estimate that water scarcity resulted in agricultural sector losses of roughly $1.7 billion in 2014 (roughly 3–4% of annual revenues), along with 7,500 lost farm jobs (3%) from land fallowing. Similarly, Sunding, Zilberman, Howitt, Dinar and Macdougall (2002) measured the impacts of agricultural production reduction due to water transfers and showed in the case of the Sacramento-San Joaquin Delta that water markets may reduce the costs encountered by farmers from an improvement of water quality. They find also that the lack of conveyance in the Delta is particularly detrimental to trade water. Trading water cannot eliminate scarcity, but it can help mitigate the impact of such extreme events by reallocating water to higher-value crops. Determining how much can accomplish the water markets is thus a fundamental question for the future of California and implies to focus upon the transaction costs that weight upon the water transfers. But despite such importance, only few studies have explicitly addressed such costs and their impacts on trading behavior. Griffin (2016) stated that "[t]oo much is omitted to associate results with potential market results. The behaviors of individual agents (true market agents) are not represented, and the frictional transaction costs of market activity are neglected too" (p.356). Notable work is the one of Archibald and Renwick (1998) who estimated the impacts of transaction costs within the emergency drought water bank in the early 1990's, concluding that institutional changes are required to get the expected efficiency gains from water markets. Their analysis was however restricted in scope since they only estimate the benefit for four water districts using the water bank mechanism. Another particularly interesting work is the one of Hanak (2005) who estimated the impact upon water markets of a specific exclusion tools: the groundwater ordinances. She found that such regulation is imposing a substantial restriction in trading activity, lowering the total volume transferred by 11%. The method she used is more specifically innovative as she studied the bilateral trade of water at the county level.

Following the seminal work of Tinbergen (1962) and more recently Anderson and Van Wincoop (2003) and Helpman, Melitz and Rubinstein (2008)—who analyze the frictions in international trade— and from the aforementioned work of Hanak (2005), we estimate the costs associated with water transfers in California through a micro-founded gravity equation. In the international trade literature, the core of such an empirical tool is based on the New Economic Geography framework (NEG) that geography impacts not only the capacity to produce, but also the capacity to export through transportation costs (a function of distance) and geographically delimited institutional differences. While heterogeneity in production capacity, with differential marginal values of production between regions, is indispensable for exchanges to occur, heterogeneity in export capacity is likely to curb such exchange by increasing matching difficulties. In the context of water markets, these impediments to trade are the costs of water conveyance, which increase with distance, as well as transaction costs that increase non-linearly with distance due to formal and informal rules limiting water export outside certain geographic areas (district, county, hydrologic basin, etc.). Throughout this chapter, we define such costs associated with water trade by the broad term "trade costs" – including both transaction costs and the costs of water conveyance. We complement the existing literature on water markets with a focus on these trade costs and show that trade costs (approximated by distance and institutional impediments to trade) are an important factor in water trade. We thereby validate the relevancy of the gravity equation to the study of water markets and, more specifically, to the explanation of observed geographical patterns of water transfers and the preference toward proximity in water exchange.

3.1. The Costs of Trading Water

As explained in the previous chapter, water markets require well-defined rules to bring the expected benefits from a competitive market. However, these institutionalized rules are not always well fitted to achieve such a goal. Culp, Glennon, and Libecap (2014) considered that the intrinsic characteristics of water lead any decision regarding the allocation of this resource to be highly politicized, with an important bias toward risk aversion: "water rights holders are theoretically free to transfer their rights to upstream or downstream water users. But the reality is more nuanced, with transfers complicated by a series of procedural and regulatory requirements that characterize western water rights, making it very difficult to transfer water rights" (p.13). In other words, the transfer of water is costly in terms of time and money. By limiting transfers, such costs induce a post-trade allocation very close to the initial endowment, preventing a move toward more efficient outcomes within the economy.

However, the question of efficiency has to be considered with caution, as any institution (from decentralized market-based instruments to centralized allocation through administrative procedures) is subject to transaction costs (Griffin 1991); such costs arise because of incomplete contracts, which in practice is always the case. While such costs can be synonymous with inefficiency when comparing water markets to the idealized situation expressed in the Coase theorem, this is not always the case when comparing water markets to other possible institutions (Griffin 1991). As pointed out by Colby (1990b), such costs can be viewed as a tax to factor in various forms of externalities induced by a water transfer. For instance, by changing the time and place of use of a water right, a transfer might adversely affect the volume of water available to downstream water right-holders or to the environment. In this respect, water markets are not the sole institution to reallocate water. The legitimacy of each component of transaction costs is beyond the scope of this chapter. Whether they legitimately adjust for such externalities or not, transaction costs are not neutral in the trading process, and should be considered in water markets analysis.

Over time and across different states in the American West, a wide range of water institutions have been developed to reallocate water. In this respect, water banks (with preset purchase and sale prices) appear more common than spot water markets. One reason may be the ease of operation: the costs associated with price negotiation are generally incurred by the bank, which sets the price. Yet, banks can still incur trade costs for participants related to environmental and pecuniary externalities of trade (Archibald and Renwick 1998). And a major pitfall of water banks is the lack of price flexibility, which can limit the gains from water transfers for potential exporters and is not always suitable to cope with drought. In an analysis of the performance of California's 1991 water bank Howitt (1994) argues that existing institutions in the form of differing property rights and rules for operating transport facilities across counties were a major impediment to the performance of the water bank, which was developed in a matter of four weeks due to the emergency drought situation. Indeed, the multiplicity of exclusion tools to prevent against potential externalities are also deterring many decisions to trade water. In what follow, we analyze more in depth these frictions in the water markets which we call trade costs.

3.1.1. The Nature of Trade Costs

In this chapter, we refer to the cost of water transfers between locations using the broad term of trade cost, in order to capture terminology of both the transaction cost as well as the conveyance cost.

3.1.1.1. The Transaction Costs

The transaction cost includes any cost induced by search and negotiation with all relevant parties in the trade, such as the buyers, the sellers, the regulatory agencies and any other agents affected by the transfer (Libecap 2005). These costs correspond to the effort undertaken by the originator of the action in deciphering the legal, societal and natural environment to derive institutionalized rules and delineate the rights and duties of each participants. This makes echo to the definition previously given of transaction costs that is the costs incurred to create, use or maintain institutions and organization (Furubotn and Richter, 2000 p.48), with the objective to facilitate the obtaining of information, bargains' position and easy the bargain to arrive at a collective decision and enforce this decision (Coase, 1960 p.15; Randall, 1972 p.176 and Dahlman, 1979 p.148). Previous empirical work on this matter found that an important share of the water price is due to this component of trade cost. For example, Colby (1990b) estimated a mean supplemental cost in New Mexico at 6% of the agreed price. This is much lower than the one estimated by Brown, Mars, Minnis, Smasal, Kennedy and Urban (1992) who found a transaction costs of approximatively 13%. Howitt (1994) found a transaction costs of approximatively 8% in the water bank processing in California.

3.1.1.1.1. The Administrative and Policy Induced Costs

From the taxonomy of Archibald and Renwick (1999), the transaction cost can be distinguished into two categories. The first is the "Administratively Induced Cost" (AIC) and is generally common to any property transfer. It includes the search for a reliable partner and the negotiation process over price, quantity and time of delivery and is borne by the seller as well as the buyer. While such a cost is difficult to suppress, it can be reduced by improving the dissemination of information. For example, Bjornlund and McKay (2002) shows how the use of an Internet platform in Australia's water markets made information much more easily accessible and decreased the ex-ante cost of search for a good match. In California's water markets, water exchanges are often driven by bureaucratic processes and become abstruse (Libecap 2011) deterring small agents from entry (Carey, Sunding and Zilberman 2002).

The second type of cost, more specific to water markets is the "Policy Induced Cost" (PIC). It is designed to adjust for potential incompleteness of water contracts. Indeed, due to the complex and sometimes non-observable features of water, defining a complete set of property rights for this resource may be difficult (if not impossible). Any water transfer is thus subject to a set of policy rules to prevent agents not directly involved in the contract, but possibly affected by the exchange, to be harmed. Such so-called "no-injury" rules, combined with the "wet water" policy (designed to ensure that water is physically available for a trade at the specified time and place) define more precisely the quantity of water available for trade, the source of water (surface water or groundwater), and the approval process with which a seller has to comply. The seller generally bears the cost of demonstrating that a water export will not affect other users, which requires a closer look at the hydrological and legal aspects of the trade (Easter and McCann, 2010). As depicted in the table 3.1, while both protagonists of the transaction have to incur the AIC, the seller is the one that bear most of the PIC.

For any transfer of water, a public notice and approval by at least one of the competent authorities is required (depending on the type of water right traded, federal and/or state environmental agencies), implying a non-negligible investment in time and money. The aforementioned groundwater ordinances also fall into this category. Even in the absence of local ordinances, objections by source-region residents can also exert pressure on potential sellers to limit out-of-county trades. Holland (2012) reported the case of a potential transfer between Modesto Irrigation District (MID) and the San Francisco Public Utility Commission (SFPUC) where the City of Modesto and several local groups tried to block the contract even though the SFPUC offered a price 70 times higher than the local price. (MID ultimately chose not to finalize the transfer agreement.) As another example, a transfer from the Glenn-Colusa Irrigation District (GCID) to the Metropolitan Water District of Southern California (MWDSC) during the drought in 2009 was challenged several times by local groups, slowing down the approval process and finally preventing the transfer from occurring (Howitt 2014 p.90). Ghimir and Griffin (2014) looked at such issues in Texas, focusing on the impact of differences in water districts' institutional setting to explain the relative low participation in trade among the irrigation districts (ID). The main idea is that IDs are facing larger problems of coordination due to their decision rules. The authors show that such institutions lead to an internal over-use and external under-use of water which induces a tragedy of the anti-commons as previously explained. In this case, it is not a formal policy-induced cost (as with California's export ordinances) but rather a more diffuse cost of lobbying activities and negotiating with different conflicting parties within the district or the county (Colby, McGinnis, Rait and Wahl 1989).

Table 3.1: Distribution of transaction costs between buyer and seller (adapted from Archibald and Renwick, 1998 p.101)

Type of Transaction Cost	Incidence	
	Seller	Buyer
Administratively-Induced (AICs)		
Searching for Trading Partners.	X	X
Negotiating Terms :		
establishing price, quantity, and quality ;	X	X
negotiating payment terms;	X	X
establishing delivery dates;	X	X
negotiating physical transfer.	X	X
Policy-Induced (PICs)		
Identifying Legal Characteristics of Water-Use :		
ability to transfer;	X	
return flow obligations	X	
timing of transfers.	X	
Identifying Hydrological Characteristics of Rights.	X	
Complying with State and Federal Law regarding transfer application and approval process.	X	
Complying with Other Institutional Requirements :		
project approval process.	X	
water district approval process.	X	
Adjustment Costs of Changing Resource Base :		
third-party impacts;	X	X
litigation for damages;	X	X
litigation/risk.	X	

In that respect, a water user willing to transfer its rights to another user may undergo several auxiliary transactions with potential agents affected by the trade before being participant of the central transaction.

3.1.1.1.2. Costs from Institutionalizing the rules in the Auxiliary Transactions

The Policy Induced Costs (PIC) can be view as multiple auxiliary transaction to delineate the rights and duties of each willing (buyer and seller) or unwilling participants (agents subject to other external effects). The figure 3.1, adapted from Griffin (2016 p.267) is depicting such process, when after having been charged for the Administrative Induced Costs (AIC) to find a partner, the seller has to support the charge of the Policy Induced Costs (PIC).

This process can be decomposed into six different steps. The first is the formal application by the seller to the required agency to transfer the whole or a part of its water to another water user. This require a series of reports ranging from the simple contact information to a complete description of the water right that will be transferred. If the right has been granted after the Water Code change of 1914 and require to use the conveyance facility of the State Water Project or the Central Valley Project, the application must be submitted to respectively the Department of Water Resources (State for the SWP) or the Bureau of Reclamation (federal for CVP). In any other cases, the relevant agency is the State Water Resources Control Board (SWRCB). Then, in a second step, the competent agency review the technical information in the application and make sure that the transfer will not cause any harm to other users. From these information, the agency will select potential third parties of the water trade in a third step to give them the opportunity of contesting the information given by the applicant. If contestation occurs, a negotiation between agents can be settled to reach an agreement which will be resubmit to the agency. From these new information, the agency will decide if the water right can be exchanged or not in the fourth step and in the fifth step, appeal of this decision to the court can be undertaken by any of the participant of this process. In the final step rule decide either by the agency or the court is given.

While necessary, this process is particularly complex and is probably deterring many willing seller since time and financial resources must be spent in each of this step with potentially no gains if the final rule states that transfer cannot occur. Adding to these costs, the cost of physical moving the water can be also cumbersome.

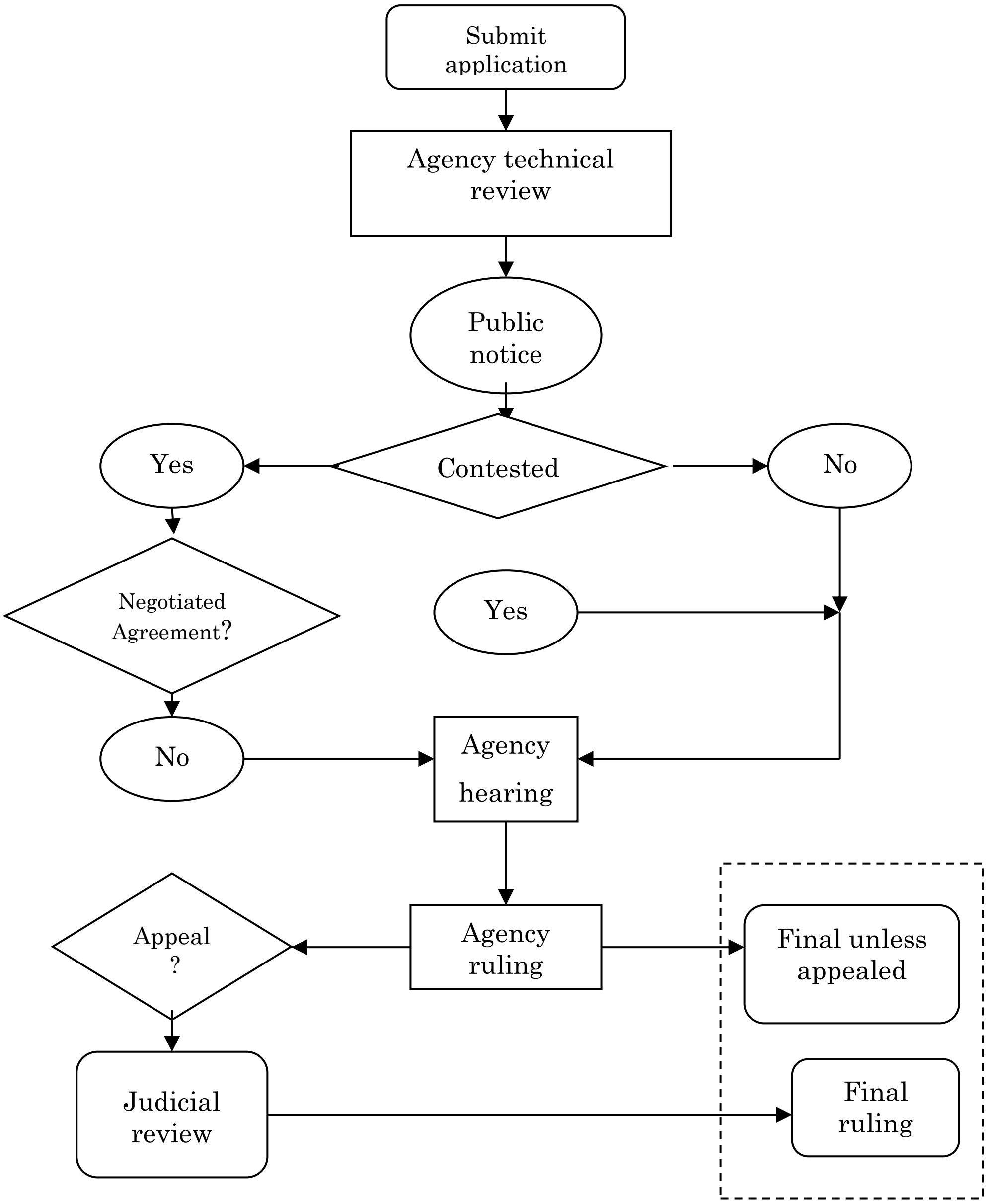


Figure 3.1: The policy induced process of transferring water

3.1.1.2. Conveyance Costs

Finally, the conveyance cost encompasses all cost related to physically moving water from the seller to the buyer, and is thus principally related to infrastructure constraints. The cost of conveying water as well as the difficulties of accessing the network of canals and storage facilities for purposes of trading can discourage districts from water market entry (Israel and Lund 1995).

For California, a century of water supply-enhancing policy and investment endowed the state with a relatively well-developed conveyance infrastructure. The two major arterial roads to convey water are the Central Valley Project (CVP) and State Water Project (SWP) which both allow to displace an important amount of water from North to South of the State (see the chapter 2 for more details upon these projects). But, nowadays this network is constrained (Hanak 2015). In particular, the Sacramento-San Joaquin Delta, the crossroad for many north-south and east-west trades, presents obstacles. Due to environmental concerns, pumping from the Delta is restricted, thereby limiting the water available for trading. In addition, a "wheeling charge" is usually required for using these conveyance facilities for transfers (see the chapter 2 for more details upon the issues in the Delta).

Private infrastructure may also be used for the purpose of trading partners. We can list three major private projects: the Hetch-Hetchy Aqueduct, the Los Angeles Aqueduct, and the Colorado River Aqueduct. While the former has never been used for trading purpose (to the best of our knowledge), the two others have often been used and more specifically by the city of Los Angeles (owner of the two aqueducts). But other cities have used it as well and not without problems. Chong and Sunding (2006) report the example of the water transfer between San Diego Water Authority (SDWA) and Imperial Irrigation District (IID), which occurred in 1998. In this case, the facilities owned by the Metropolitan Water District of Southern California (MWDSC) were required to convey the water transferred but the MWDSC charged a wheeling price of 262 dollars/AF, which doubled the initial price that the San Diego Water Authority had to pay for this water. Half of this rate is for using the facility (192 dollars/AF) and the other half is for additional administrative charges (192 dollars/AF) (Howitt, 2014 p.93). This led to what Hundley (2001) called the "the Wheeling-rate water" (p.483). The reason for such high conveyance fee comes from MWDSC's interpretation of the Section 1810 of the California Water Code which enact that "…neither the State nor any regional or local public agency may deny a bona fide transferor of water the use of a water conveyance facility which has unused capacity of the period of time for which that capacity is available, if fair compensation is paid from a use". While this clearly states that the MWDSC cannot deny the access of its conveyance facilities for use by other agencies, it stays fuzzy upon what means "a fair compensation" which is defined in the Water Code as "reasonable charges incurred by the conveyance system including capital, operation, maintenance and replacement costs, increased costs from any necessitated purchase of supplemental power, and including reasonable credit for any offsetting benefits from the use of the conveyance system". The point of discordance between the MWDSC and the SDWA is that the former calculated the rate from the costs of running the whole water system, while the latter would only use a relatively small part of this system for conveying its purchased water (Howitt, 2014 p.93).

3.2. Gravity Equations: Drawing a Parallel Between Water and International Markets

First introduced by Tinbergen (1962) to study the flows in international trade, the gravity equation is now widely used to explain many impediments that can enter in a bilateral interaction. Basic principle is that sizes of interacting entities and distance between them will affect the exchange respectively positively and negatively. Or put in the words of Helpman, Melitz and Rubinstein (2008 p.442), "the volume of trade between two countries is proportional to the product of an index of their economic size, and the factor of proportionality depends on measures of 'trade resistance' between them". Thus, in its naïve formalization, the trade between i and j is positively correlated with the economic size of these both partners and negatively correlated with the friction variables (generally distance), such that:

$$Trade_{ij} \propto G\frac{Size_i^{\theta_i}Size_j^{\theta_j}}{\left(Frictions_{ij}\right)^{\delta}} \qquad (1)$$

With δ, θ_i and θ_j being the elasticity parameters and G, a constant term.

The resemblance with the Newtonian equation gave the name to this economic tool, and despite its simplicity, it has grown in popularity due to its high power in predicting trade flows such as Kugman (1997) referred to this tool as an example of "social physics". Furthermore, the multiplicative form of this equation makes it easy to handle for theoretical modeling and empirical estimation, since by a simple log-linearization, it becomes possible to estimate exact value of the parameters δ, θ_i and θ_j (Head and Mayer, 2014).

Given the widespread acceptance and the enormous literature built upon the concept of gravity equations, not only in international trade but in many other fields as well (migration, financial markets, etc.), any attempt to draw a complete literature review of such a tool seems to be vain (other surveys can be found in Anderson, 2000, 2011; Anderson and Wincoop, 2003, 2004; Bergstrand and Egger, 2013; Feenstra, 2003 and Head and Mayer, 2014). Thus, we prefer to focus upon the most important features of gravity equation to explain why it could be used to estimate water transfers. More specifically, many refinements of this tool are dedicated to fit the context of international trade but are not relevant in the one of water markets, and for that reason, are not useful to be reviewed here. In other words, the point of this review is to draw a parallel between the missing trade in international transactions and the impediments in water markets.

3.2.1. Explaining the Missing Trade

Gravity equation did not become the widely-used tool of international economics from one article, but took several decades since its first application by Tinbergen (1962) to impose itself as an indispensable instrument to understand the pattern of international trade. From a simple "curiosity" (Bergstrand, 1985 p.480) to the indispensable "link between trade barriers and trade flows" (Anderson and Wincoop, 2004 p.692)

3.2.1.1. The Slow Recognition

During the mid-twentieth century, interrogation began to arise upon the impact of the distance in international trade theories. For example, Isard and Peck (1954) complained about the lack of consideration in the traditional theory for the geographical and spatial features that may mold the exchange patterns. But, although the first use of the gravity equation to estimate the bilateral trade flows gets back to the 1960's with Tinbergen (1962), it is only during the 1990's that such tool began to be recognized for its potential. Deardorff (1984) considered it as being dubious tool with the its sole interest being to come from an analogy with the field of physics (Head and Mayer, 2014). Empirical evidences were however not scarce. Bergstrand (1985) provided distance estimates for the years 1965, 1966, 1975 and 1976 always negative and significant at 1%, echoing the previous studies of Abrams (1980), Aitken (1973), Geraci and Prewo (1977), Linnemann (1966), Poyhonen (1963), Prewo (1978), Pulliainen (1963), Sapir (1981) and Sattinger (1978). Yet, gravity equations were still a simple curiosity inhibited by a lack of theoretical foundations (Bergstrand, 1985). Theory underlying the gravity equations has nevertheless emerged over the years, principally from the works of Anderson (1979) who assumed that each country is being specialized in the production of a particular variety and Bergstrand (1985) who used a hypothesis of monopolistic competition to derive the gravity equation. The basic formalization of a naïve gravity equation can be expressed relatively close to the equation (1), where $Y_i = \sum_j X_{ij}$ and $Y_j = \sum_i X_{ij}$

$$X_{ij} = G\frac{Y_i^{\theta_i} Y_j^{\theta_j}}{\tau_{ij}} \quad (2)$$

Where $\tau_{ij} > 1$ is the measure of trade friction, also called "iceberg costs" which account for the distances between i and j, and Y_i and Y_j are respectively the measure of the size of i and j. The measure of the trade friction is often assumed to take the following multiplicative form between $m \geq 1$ different types of friction proxies T_{ij}^m:

$$\tau_{ij} = \prod_m \left(T_{ij}^m\right)^{\delta_m} \quad (3)$$

When $T_{ij}^m = 1$, the friction of the type m is non-existent.

Derived from the works of Anderson (1979) and Bergstrand (1985), the formalization of a structural gravity equation is however more complicated, but account for the general equilibrium effects with the multilateral resistance Ω_i and Φ_j. In a simple term, it can be exposed as follow (Head and Mayer, 2014):

$$X_{ij} = \phi_{ij} \frac{Y_i X_j}{\Omega_i \Phi_j} \text{ with } \Omega_i = \sum_k \frac{\phi_{ki} X_j}{\Phi_k} \text{ and } \Phi_j = \sum_k \frac{\phi_{jk} Y_k}{\Omega_k} \quad (4)$$

Where $\phi_{ij} \in [0,1]$ is an index of the trade frictions (generally $\phi_{ij} = \tau_{ij}^{-1}$). These theoretical works have been particularly important to impose the gravity equation as a valuable alternative to explain the pattern of international trade but have been overlooked for decades.

Growing appreciation of gravity equation came from the acknowledgment that traditional tools for estimating international trade flows derived from the Heckscher-Ohlin-Vanek theory (HOV) were predicting too much trade flows than is actually observed (Head and Mayer, 2014). In its seminal article, Trefler (1995) presented "the case of missing trade", and pointed out that flows seem to be biased toward domestic trade rather than international exchanges: "HOV is rejected empirically in favor of a modification that allows for home bias in consumption and international technology differences" (p.1029). While he did not explicitly recognize the distance as impediment to trade, his article addressed in a very clear manner the inquiry for looking better explanations of such a mystery. Theoretical results from Anderson (1979) and Bergstrand (1985) as much as empirical evidences increased the gap between the traditional explanations of international trade and the new perspectives opened by gravity equations, such that it led Leamer and Levinsohn (1995) to provocatively asked "[w]hy don't trade economists 'admit' the effect of distance into their thinking?"

Yet the distance is not the sole impediment in international trade, and McCallum (1995) used the gravity equation tool to demonstrate the so-called "border effect" and refuted the hypothesis that the world is "flat". Comparing the trade among provinces in Canada and the trade between the USA and Canada, he estimated that intranational trade is 22 times larger than the international one. While it will be shown later that such differences are shrinking when accounting for general equilibrium effects (Anderson and Wincoop, 2003), this work lunched the interest toward the gravity equations to study more in depth the impediments to trade (Head and Mayer, 2014). A large number of subsequent studies reproduced the result found by McCallum (1995). The important question thus moved from knowing the relevancy of gravity equation to finding the underlying reasons of "[w]hy do nations trade (so little)?" (Anderson, 2000 p.115).

3.2.1.2. Trade Costs as Impediments to Trade

In their survey of gravity equation methods, Anderson and Wincoop (2004) attempted to devise the underlying reasons for the border effects found in McCallum (1995) to derive a trade costs function that could be used to estimate the trade frictions. They defined such trade costs as including "all costs incurred in getting a good to a final user other than the marginal cost of producing the good itself: transportation costs (both freight costs and time costs), policy barriers (tariffs and nontariff barriers), information costs, contract enforcement costs, costs associated with the use of different currencies, legal and regulatory costs, and local distribution costs (wholesale and retail)" (pp.691-692). In other words, getting sufficient information about markets is not free of charge (Anderson, 2000).

They split this broad definition into two categories, the costs imposed by policy (tariffs, quotas and the like) and costs imposed by the environment (transportation, insurance against various hazards, time costs) (p.693). While the former may be readily observable, the latter often require to be inferred from estimating the gravity equations (p.706). This last category can be subdivided into several other types of trade costs. While many different type of trade costs have been used, we focus here on the most important ones. The most classic one is the use of common language between countries through a dummy variable (one if the language is common and zero otherwise), which is assumed to approximate the degree of potential communication between both countries (see Eaton and Kortum, 2002 and Melitz, 2003 for multiple possibilities to account for such effects). Another type of trade costs potentially very high but difficult to approximate is the information barriers (Anderson and Wincoop, 2004 p.720). Relatively close to the language barrier in its intrinsic meaning, the information barrier is intended to capture the different difficulties in communication (Raush, 1999, 2001). Portes and Rey (2005) approximated such costs with the size of cellphone traffic and Raush and Trindade (2002) found the Chinese network effect particularly important to explain the bilateral trade. Recently, Chaney (2014) characterized the dynamic of network in bilateral trade and Allen (2014) estimated the cost of missing information about the other market conditions. Finally, a last problem of trading with other countries is the risks associated with the opportunistic behavior of others which implies substantial costs in writing contracts an enforcing them (Anderson and Wincoop, 2004 p.721). For example, Anderson and Marcouiller (2002) observed that corruption and difficulties in enforcing a contract lower significantly the trade and Roberts and Tybout (1997) documented the importance of sunk costs for bargaining and adequately drawing the contracts.

3.2.1.3. Distinction Between Extensive and Intensive Margin

An important distinction has been made more recently using gravity equation about the disentanglement between the extensive and the intensive margin of trade.

Simply defined by Head and Mayer (2014), “the extensive margin is the elasticity of the number of exporter with respect to trade costs, and the intensive margin is the elasticity of the average shipments of the incumbent firms, that is the firms that were exporting before the shock and still do afterwards”. The point is particularly important because it allows to account for partners that do not trade which cannot be handle in the simple formalization of the gravity equation depicted above. Indeed, the multiplicative form such equation, while good to be estimated in a log-linearized way also implies that if none of the variables are zero, then trade will never be zero. In that respect, Helpman, Melitz and Rubinstein (2008), pointing out that around half of the dyads have zero trade, developed a new model of gravity equation with a fixed cost to account for countries that were willing to trade but simply cannot do so because of the sunk costs. They derived such results by assuming heterogeneity in firm productivity similar to Chaney (2008) that causes some sector in some country to have simply no firm sufficiently productive to export. Arkolakis (2010) further endogenized these sunk costs by using an advertising model in which firms can decide to invest a chosen amount of resource in promoting their product into other countries, and through that way, gain sufficient revenue to overcome the fixed and variable costs of exporting. The higher is this investment, the more likely it is that consumer in the importing country will buy the product, but the sunk costs also increase with this investment. Export will not occur when the expected revenues (the sells diminished by the iceberg costs) cannot offset the investment in advertising the product.

In summary, trade may be reduced not only because of exorbitant transportation costs, but also because of insufficient predictability and thus reliability of partner’s behaviors in the interactional situation. In that respect, distance will play an important role since it induces a reduction of the transportation costs and often increases the predictability of other’s behavior through an easiness of communication due to proximity. As have pointed out Bowles (2006 p.265), “where contracts are incomplete, exchange is often facilitated when traders discriminate in favor of ‘insiders’ and engage in other parochial practices, when long term commitment to a trading partner are common, where exchange is personalized, and the like”. From that, it seems logical to approximate trade costs with the distance which is more than a simple analogy with the field of physics, but also a relevant proxy of the inherent incompleteness of human interactions. Thus, gravity equations may be used in other field than the sole situation of international trade, as long as transactions (in the sense of interactions) occur.

3.2.1.4. Gravity Beyond the International Trade

It is often referred at Tinbergen (1962) to mark the beginning of using gravity equation in international trade. But some authors have used such tool long before him to study other types of human relationship. More specifically, migration has been the earliest field to apply gravity equation. In the mid-nineteenth century, Carey (1858-

59) drawn a somewhat strict parallel between physics and migration in insisting that humans are like molecules that get agglomerate by the law of gravitation (pp.41-43). Later, Ravenstein (1885, 1889) confirmed the gravity-like property of human movement who defined 11 laws of migration, including among them the distance as a negative effect (everything else equal), movement are directed toward population centers, and such movement is being proceed step-by-step. Then, Stewart (1950) formalized the relation closed to the equation (2) for estimating the flows of migration. Gravity equation has been since then a very powerful tool to study the impediments or the opportunities of migrations (Poot, Alimi, Cameron and Maré, 2016). Following the work of Eaton and Kortum (2002), several authors have studied migration with a discrete choice framework such as Anderson (2011) or Ahlfeldt, Redding, Sturm and Wolf (2015).

Another field in which gravity equation has been used is the financial markets, where Portes, Rey and Oh (2001) and Portes and Rey (2005) conjectured the relevance of a gravity equation in its naïve form to study the portfolio choices. In the late 2000's, a high number of article have validated this claim. Theoretical foundation has been laid down by Coeurdacier and Martin (2009); Martin and Rey (2004) and Okawa and Wincoop (2012) to use a structural gravity equation rather than its naïve form. The two first derived a gravity model based upon the Arrow-Debreu security in which demand for takes a similar form than the one used in gravity equations for trading differentiated good (Constant Elasticity of Substitution). From that, it is relatively easy to formalize a theoretical model fitted to be estimated by gravity equations. Okawa and Wincoop (2012) however criticized such method in the ground that it violates assumptions of the Arrow-Debreu security that assets must be non-zero in only one state (or country in that case) which is not the case for many financial holdings. They also pointed out to not simply use gravity models without any underlying theory.

Finally, in the context of water resources at the international level, a recent work has used the concept of gravity equation to study the Virtual Water Trade. Delbourg and Dinar (2016) have used such econometric tool to estimate the effect of water relative endowment on water content of bilateral trade. They found that the water scarce countries tend to import more water content products from countries with a relative abundancy.

3.2.2. Gravity Equation: An Interesting Tool for Water Markets

An obvious parallel can be drawn between the question raised by Young (1986 p.1143) and the one asked by Anderson (2000 p.115) who both sought to understand the underlying reasons for the missing trade mystery, the former in water markets and the latter in international trade. In these two works from prominent authors in their respective field, uncertainties occurring in the trading process are one of the most deterrent factor in markets.

3.2.2.1. Water Markets and the Geography of Trade

Figure 3.2 depicts the geographic patterns of short-term water transfers (leases) over a 17 years' period. We divided the state into three geographic categories: the county if the seller and buyer are located in the same county, the region if the buyer is located in a contiguous county to the buyer, and finally statewide if the export of water goes beyond the contiguous county. Such depiction bolsters the statement in previous studies that water markets are predominantly local (Hanak 2015). Indeed, together, county and regional transfers account for the lion's share (roughly 4/5) of short-term water contracts, and they also dominate the volumes traded. In short figure 3.2 shows a strong bias toward proximity.

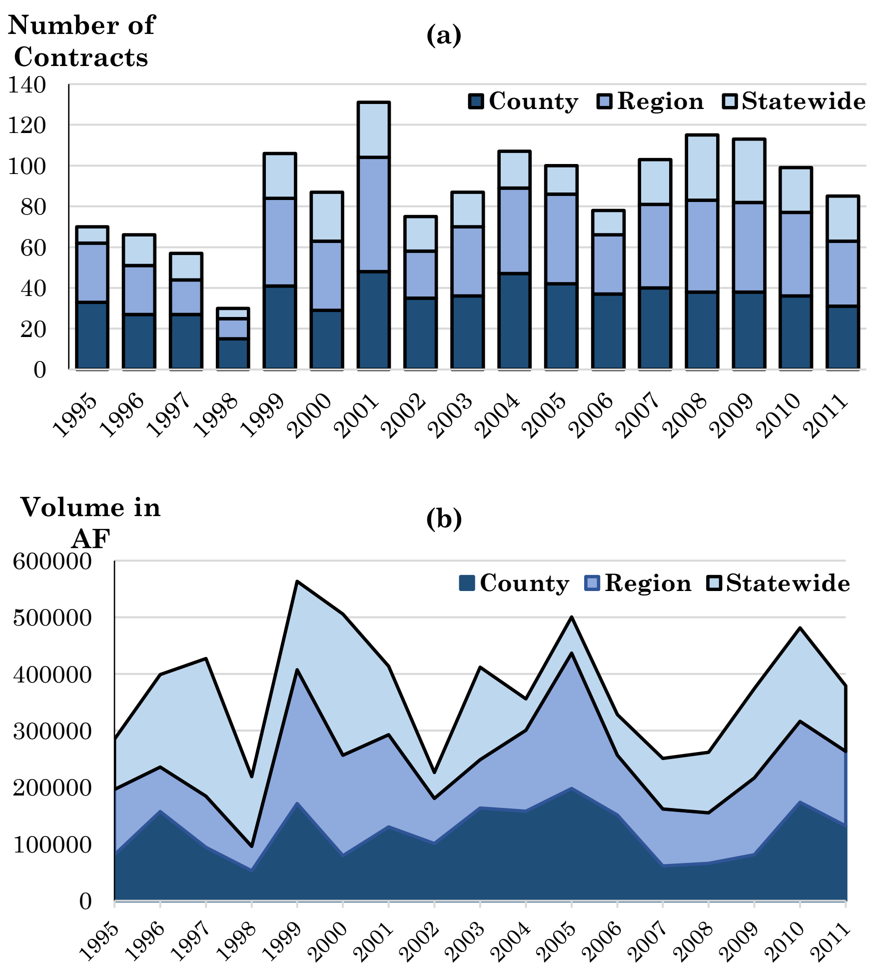


Figure 3.2: Short-term lease contract numbers (a) and volume (b) of water transferred (1995 to 2011)

The geographic pattern of water trade depicted in figures 3.2 is in agreement with the trade cost hypothesis described above. Indeed, many such costs depend on the geographic scale of water transfers. For example, groundwater ordinances make water export outside of county boundaries particularly arduous and thus tend to bias trading to occur within-county. Similarly, pumping restrictions in the Sacramento-San Joaquin Delta hinder trades across longer distances (mainly north to south of the Delta), even though northern counties tend to have more abundant water supplies available for trading.

Distance is also an important factor in conveyance costs, as the transferors have to bear the charge of carrying water through the California network plus the loss of water by evaporation or possible percolation into the ground. As assumed in the work of Chakravorty, Hochman and Zilberman (1995), the longer the distance between the seller and the buyer, the higher is this conveyance cost. Finally, due to the geographic dimension of the Policy-Induced Cost, distance can raise the costs of search for potential partners. Because it is costly to ascertain the possibility to trade water over a long distance (with a higher risk of denial) and to learn about water conditions elsewhere, potential sellers might prefer to minimize search costs by seeking local buyers rather than by conducting a statewide search. Such propensity for proximity makes the market thinner and mostly regional. For Texas, Ghimir and Griffin (2014) present some evidence that the proximity between an irrigation district and an urban center significantly increases the propensity to trade water.

The fact that distance and other related costs are potentially important factors in water trade make the well-known gravity equation tool particularly attractive to study water markets in more depth. Yet, only a very small subset of water users is actually trading their rights which need to be handled by the distinction between a fixed and a variable component of trade costs

3.2.2.2. Fixed and variable components of the trade cost

The mean trade cost of 6% of the transaction price found in Colby (1990) does not reflect important variation in trade costs. Brown, Mars, Minnis, Smasal, Kennedy and Urban (1992) estimated a trade cost ranging from 2 dollar/AF to 1,384 dollar/AF, and in other studies, trade costs range from 3% to 70% of the total cost of water acquisition (McCann and Garrick, 2014 p. 12). The authors partly explain such a variation by a large fixed cost with a mean value of 474 dollars/AF if the transfer is below 5 AF, which falls to approximately 4 dollars/AF if the exchange is above 150AF (with a progressive increase from 5 to 150 AF). Carey, Sunding and Zilberman (2002) define such fixed costs as the cost for searching a potential trading partner. They demonstrate how this trade cost can bias trade, within the same district, toward intra-network (identical canals) rather than inter-network (between different canals but still connected in the same district). Indeed, as developed in the previous section, the risk of denial increases with distance and the necessary sunk cost to enter into a water market spurs sellers to favor closer importer districts over farther districts.

As explained above, some recent work in the field of international trade introduced a fixed component to the estimation of the gravity equation (Helpman, Melitz, and Rubinstein 2008; Chaney 2008; Arkolakis 2010 and Allen 2014). Such specification is particularly attractive to explain the zeros in bilateral trade. Thus, adding to the variable trade cost, a fixed component for each participation in water markets allows us explain and predict the decision to enter into the water market and to explain the zeros in trade. We identify several types of variable and fixed trade costs (Table 3.2).

Table 3.2: Decomposition of trade costs between variable and fixed components

Variable Transfer Cost	- Water loss through evaporation and percolation - Wheeling cost for using conveyance facilities (storage, canals and pumping) - Physical network limitation (Sacramento-San Joaquin Delta)
Fixed Transfer cost	- County groundwater ordinances - Inter-project transfers - Search for potential trading partners - Negotiation over prices, quantity and quality

Both variable and fixed trade costs have an impact on the decision to trade (the so-called extensive margin of trade) but only the variable cost affects the quantity of trade (the intensive margin of trade). It is thus particularly important to disentangle these two types of costs in order to properly analyze their effects and understand the potential impacts of reforms that could reduce these costs.

3.3. Theoretical Model

In this section, we develop a simple theoretical model to highlight impediments in the water trading process. We identify the variables representing the fixed cost of water trade and provide a foundation for the gravity equation estimated in the empirical section. This model is relatively similar to that developed by Archibald and Renwick (1999), but we relax some of their assumptions to facilitate analysis of different types of trade costs and to improve the tractability. This enables us to derive an analytical solution to the model.

3.3.1. The Setup

We present in this sub-section the economy of water use inside a district and without any water export (the intra-district water economy). Then we introduce the economy of a potential exporter district (the inter-district water economy).

3.3.1.1. Intra-district water economy

Consider a discrete set of $n \in N$ water districts distributed over a continuum but finite space S. Each district is designated to share out its total entitlement of water W_n among a set of $k_n = 1, \ldots, K_n$ discrete and heterogeneous members at a non-discriminatory price of α_n that cover the marginal cost of extraction for the district (assumed to be constant and noted c_n). Thus, net revenues for district without any trade activity is:

$$\bar{Y}_n = W_n(\alpha_n - c_n) \tag{5}$$

Each member k_n receives a quantity $\omega_{k_n} \geq 0$ of water and earn a marginal value ψ_{k_n} from the water use. As the district is generally a non-profit organization, the net income given by equation (5) is redistributed in equal share to all members such that the private profit function for members without any trade activity is:

$$\bar{\pi}_{k_n} = \omega_{k_n}\left(\psi_{k_n} - \alpha_n\right) + W_n \frac{\alpha_n - c_n}{K_n} \tag{6}$$

As the water right of use is generally held by the district, it is this latter that have the final decision on water management such as the price α_n or the decision to enter into the water markets. However, such choices can be orientated by members' voice if the district's structure is sufficiently decentralized and power can be exercised on district's board. In that case, the profit maximization is not based on district income from water deliveries (right term of equation (6)), but on the private profit from water use (left term of equation (6)). Therefore, pressure is generally exercised to lower the water price α_n toward its minimum c_n which means that district's income tends to zero while private profit increases. Furthermore, we assume throughout the paper that the share of water delivered to each member is symmetric such that $\omega_{k_n} = \omega_n = W_n/K_n, \forall\, k_n \in K_n$. While such assumption is somewhat simplistic, it allows to encompass a broad range of organizational structure of districts (from decentralized to centralized governance and from private to public organization).

From these assumptions, we can redefine more formally the profit function in equation (6) in order to account for multiple structure type of water district. Therefore equation (6) becomes:

$$\bar{\pi}_{k_n} = W_n \frac{\psi_{k_n} - c_n}{K_n} = \omega_n(\psi_{k_n} - c_n) \tag{7}$$

The more the decision of district is centralized, the less is the number of differentiated agents K_n until a complete centralization of decision (when $K_n = 1$). In other words, when the organizational structure of districts allows members to get power over decision, the district's board has to accommodate with heterogeneous needs, but when a highly-centralized structure is in place it vanishes such heterogeneity in which there is only one value of water use: the delivery of water.

3.3.1.2. Inter-district water markets

During a drought, the demand of a district subset $J \in N$ could exceed the current supply while districts in a subset $I \in N$ can be in excess of supply (or at least, not in water shortage). This makes water exchange between districts economically possible, leading to an inter-district water market.

Therefore, members in a district $i \in I$ can participate in a water market through the exportation of a share $x_{k_i,j} \in [0;1]$ of its water allocation ω_n to a district $j \in J$ at a price $p_{ij} > 0$ negotiated beforehand between the district i and j. We assume that this market price p_{ij} is independent from the water value ψ_{k_i} for any members in district i: members in the exporter district are price-taker[24]. But frictions in the form of trade costs (combination of transaction and conveyance cost) limit the amount of water that can be exported by a member in district i.

3.3.1.2.1. Trade Costs Formalization

As explained in the section on trade costs above, we differentiate between a variable and a fixed trade cost (similar to Carey, Sunding and Zilberman, 2002) but both are dependent on the distance D_{ij} between i and j. We define more formally the different trade costs as follow.

The function of the variable trade costs is an increasing function of the water share traded $x_{k_i j}$ with a parameter τ_{ij} dependent of the distance D_{ij} and other institutional frictions such as the Sacramento-San Joaquin delta. The variable trade costs function[25] is therefore $\tau_{ij} x_{k_i j}^2$ and, assuming for the moment that water market price is equals to unity ($p_{ij} = 1$), the gains of water export is $x_{k_i j}(1 - \tau_{ij} x_{k_i j})$. Therefore, we explicitly follow the postulate 3 from Griffin (1991) that: "[Trade] costs increase with the distance between initial endowment and final (post trade) allocation". The reason for this functional form can be better understood if we consider the situation

[24] Such assumption is a simplification of the real process as the market price is more probably the result of a negotiation within the district. However, such effect is beyond the focus of this paper and left for future research.

[25] Raising the share of water $x_{k_i j}$ to the power of 2 is made for easy of exposition, but the model is still solvable with any power value superior to 1.

where x_{k_ij} correspond to the share of water entitlement planned for export and $x_{k_ij}(1-\tau_{ij}x_{k_ij})$, the actual share of the water entitlement that can be exported. For value of x_{k_ij} close to zero the difference between the planned and the actual export is low but as long as x_{k_ij} increases, the supplemental quantity of water that can be conveyed is diminishing until it reaches the threshold $1/(2\tau_{ij})$, which correspond to the potential amount of water that can be exported[26]. Beyond that value, any intention to export $x_{k_ij} > 1/(2\tau_{ij})$ implies an actual export of less than $1/(4\tau_{ij})$.

This variable trade costs can be interpreted as an aggregative function of the auxiliary transactions in which an agent i must go through to trade water. At each of these auxiliary transactions, there is a possibility that the transfer is being denied because it harms other users. Thus, it is worth noting that as the variable trade cost is dependent not only on distance but also on other factors such as institutional frictions, we define two districts as being close to each other in terms of the variable trade cost and in terms of geographic distance. In other words, for three district i, j and l (all within N), we say that i is closer to j than l if $\tau_{ij} < \tau_{il}$.

The fixed trade cost f_{ij} is independent from the water share x_{k_ij} and has to be incurred for each transfer to occur. Different functional forms can depict this fixed cost depending on how this cost is shared among members. It can be a specific value attached to each members (f_{k_ij}), a reallocation of a total fixed cost F_{ij} between members (F_{ij}/K_i) or a reallocation only between exporter members ($F_{ij}/\sum_{k_i}\mathbf{1}\{x_{k_ij}>0\}$ with $\mathbf{1}\{x_{k_ij}>0\}$ the indicator variable equals one if $x_{k_ij} > 0$ and zero if $x_{k_ij} = 0$). However, in the rest of the paper we keep the general form of this fixed cost f_{ij}.

3.3.1.2.2. Profit from Participating in the Water Markets

From equation (7), the profit function of a member k_i when engaging in water markets is thus:

$$\pi_{k_ij} = \omega_i\left[p_{ij}x_{k_ij}\left(1-\tau_{ij}x_{k_ij}\right) + \psi_{k_i}(1-x_{k_ij}) - c_n\right] - f_{ij} \qquad (8)$$

It is straightforward to see that $x_{k_ij}\left(1-\tau_{ij}x_{k_ij}\right) < x_{k_ij}\ \forall\, x_{k_ij} > 0$. The limit of unity imposed for the variable trade cost ensures that the share of water allocated to transfer is less than one (however, this condition could be easily relaxed with some cautions on the value of parameters). The maximum value of x_{k_ij} is thus $1/\tau_{ij}$ because the revenue from trading activity is then negative and thus induces a loss compared with the profit when $x_{k_ij} = 0$. Assuming that total endowment is $\omega_i = 1$, figure 3.3 is depicting the profit function of equation (8).

[26] Inserting the threshold into the actual water export $1/(2\tau_{ij})$ yields the potential amount of water exported as $1/(4\tau_{ij})$

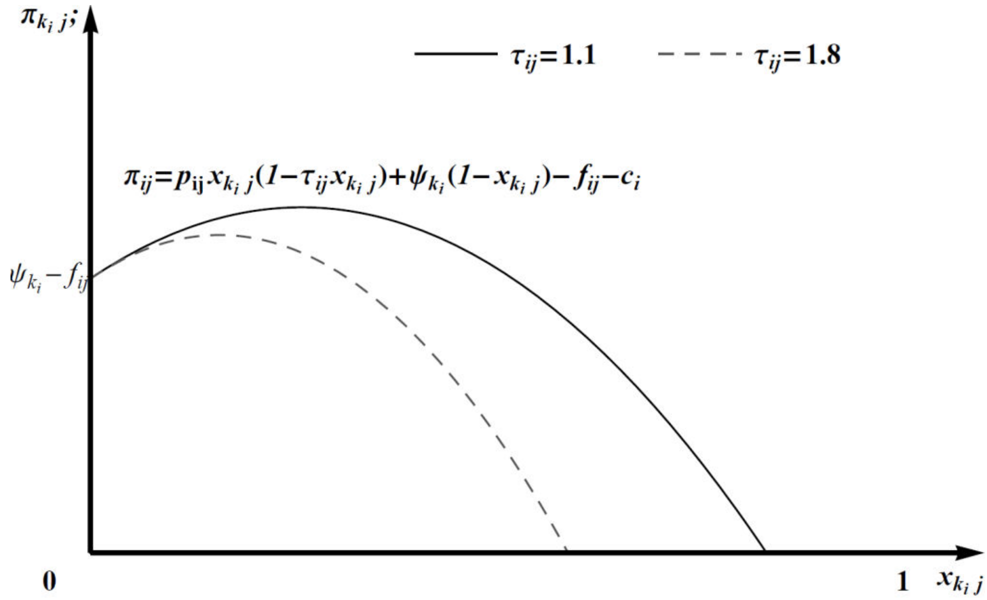


Figure 3.3: Profit function from participating in the water markets

3.3.2. The Water Markets

So far, we have set the different assumptions needed in this model and presented the situation of each district with respect to water markets. In this section, we determine analytically the extensive and intensive margins of trade. The former corresponds to the decision to trade or not and the latter refers to the quantity of water (in acre-feet) that a district i will transfer to a district j when a contract has already been agreed upon. For each district willing to enter into the water market, the extensive margin question has to be answered before the intensive margin question, however here, we first calculate the intensive margin because it is the determining factor in the decision to finalize a water contract.

3.3.2.1. The intensive margin of water trade

Solving the derivative of equation (8) with respect to $x_{k_i j}$ gives the optimal share of water that can be traded by the member k_i in district i with district j:

$$x_{k_i j} = \frac{p_{ij} - \psi_{k_i}}{2\tau_{ij}p_{ij}} < 1 \quad \forall\, p_{ij} > \psi_{k_i} \;\text{ and }\; \tau_{ij} > 1 \tag{9}$$

In order to insure a non-negative value of transfer $x_{k_i j}$, we impose the condition that $x_{k_i j} = 0$ for all value of $p_{ij} < \psi_{k_i}$. Such condition will be demonstrated in the next section on the extensive margin of water trade and will prove that this condition is necessary but not sufficient to have non-zero water transfers.

Proposition 1: Compared to the zero trade costs situation, the variable trade cost τ_{ij} is the first measure of water market potential inefficiency.

Proof: As a proof for proposition 1, it is straightforward to see and quite intuitive to understand that the quantity of water traded by i is decreasing with the variable trade cost (τ_{ij}) and increasing with the water market price p_{ij}. This leads to a total quantity of water transfer inferior when compared to the case without variable trade costs. The total quantity of water traded by the district i is thus the sum of water exported by all members k_i that accept to engage in water markets. ■

3.3.2.2. The extensive margin of water trade

Equation (9) is a depiction of the quantity of water exported by each member in the district i. However, this sole equation is not sufficient to explain the low occurrence of water trade observed in reality. Indeed, districts would always export water in that case (as long as internal prices ψ_{k_i} is less than the water market price p_{ij}). But the existence of a fixed cost for entering into the water markets brings another constraint to agents willing to transfer water.

Plugging (9) into the profit function in (8):

$$\pi_{k_i j} = \omega_i \left(\psi_{k_i} + \frac{\left(p_{ij} - \psi_{k_i}\right)^2}{4\tau_{ij} p_{ij}} - c_i \right) - f_{ij} \tag{10}$$

The member k_i will engage in water market if and only if the gains from transferring water outside of the district is superior to the status quo of using water inside the district defined in equation (7). Therefore $\pi_{k_i j} > \bar{\pi}_{k_n}$ and with rearrangement with get a threshold value of ψ_{k_i} for which a district's member is indifferent between engaging in water market or use its entire water allocation for its normal use within the district:

$$\bar{\psi}_{k_i} = p_{ij} \left(1 - 2 \left(\frac{\tau_{ij} f_{ij}}{\omega_i p_{ij}} \right)^{\frac{1}{2}} \right) \tag{11}$$

All agents having a water value below the threshold $\bar{\psi}_{k_i}$ will enter into the water market while agents above will not. As we have assumed that the share of water allocated between members ω_i is symmetric, the threshold of water value is no longer dependent from the heterogeneity of members: $\bar{\psi}_{k_i} = \bar{\psi}_i \ \forall \ k_i \in K_i$. It is also important to note that this threshold value will never exceeds the water market price p_{ij} for any non-negative value of τ_{ij}, f_{ij} or ω_i. We can thus develop the second proposition:

Proposition 2: Compared with the zero trade costs situation, the value of $2(\tau_{ij}f_{ij}/\omega_i p_{ij})^{1/2}$ is the second measure of water market potential inefficiency.

Proof: Indeed, the maximum value of the threshold is p_{ij} when fixed cost f_{ij} is set to zero and in this case, the sole variable trade cost is a source of inefficiency (as stated in proposition 1). However, with any non-zero and positive value of f_{ij}, the participation to water trade is dependent of the both types of costs (fixed and variable). ■

3.3.2.3. The district water export

From the equation (9) and (11) we can now depict in one simple equation the total quantity of water exported by a district i to a district jWe define an indicator variable $\mathbf{1}_{\{\psi_{k_i}<\bar{\psi}_i\}}$ that takes the value one if the water value for member k_i is inferior to the threshold value $\bar{\psi}_i$ calculated by equation (11) and zero otherwise. Using the fact that each member that engage in water market will export a quantity $\omega_i x_{k_i j}$ of water and with equation (9) we get the total water exported from a district i to a district j.

$$X_{ij} = \frac{\omega_i}{2\tau_{ij}} \sum_{k_i} \frac{p_{ij} - \psi_{k_i}}{p_{ij}} \mathbf{1}_{\{\psi_{k_i}<\bar{\psi}_i\}} \tag{12}$$

At least one agent in the district i has to satisfy the condition stated in equation (5) for a transfer of water to occur between i and j. If it is not the case, then $X_{ij} = 0$ and no water transfer is taking place.

3.4. Empirical Evidences

The framework presented in the theoretical model is associated with estimation challenges due to the highly non-linear nature of the equations. Furthermore, the limited coverage and reliability of data available at the district level is of particular concern for developing a structural estimation. Thus, in this section we provide empirical evidence by estimating a reduced form of the equation (6). We use water trade data from California, which was collected at the water district level, and we construct a table of bilateral relations for 237 water districts distributed among 45 counties and over a period of 17 years.

3.4.1. Data Sources and Variables

In this section, we summarize the different datasets we are using in estimating the gravity equations. Since data at the district level are scarce, we explain the strategies used to cope with this issue.

3.4.1.1. Water Trade

The water trade X_{ij} is our endogenous variable and is collected at the water district level, appropriate to the bilateral estimation. This point can be considered as the main impediment on such empirical studies, because it is generally difficult to find sufficient data on water trade. Several previous studies attempted to use water trade data from the Water Strategist dataset. This source provides trading information for the western United States, and it is particularly interesting because it gives also the prices for many transactions. Unfortunately, this database generally presents importers and exporters as a group of districts, which makes it impossible to use in a bilateral study. Such aggregation makes the analysis of trade costs particularly difficult because it becomes impossible to differentiate between districts engaging in water markets and those who do not. We thus use the data set collected by Hanak and Stryjewski (2012) for water transfers in California from 1977 to 2011. This dataset accounts for most of the trade that occurred between districts, and it identifies each district. For more details on this dataset, see Hanak (2003) and Hanak and Stryjewski (2012).

While this dataset presents transfers during 1977 to 2011, the low occurrence of trade in early years and the lack of accurate data on districts' characteristics before the 1990's, led us to focus our analysis on the most recent 17-year period (1995-2011). Such a choice removed approximately one-fifth of the observations but allowed us to estimate a more robust model. Furthermore, other variables cannot be used prior to 1995 (district financial records). We also decided to focus our estimation only on short-term water leases. Indeed, three types of water transfer are reported in the database: short-term (one-year) leases, long-term (multi-year) leases, and sales. Sales are permanent transfers of water rights; multi-year leases vary from 2 to 75 years.

An underlying reason to focus on short-term lease of water instead of the two other types of transfers is that, given its non-definitive character (in contrast to permanent sales and even long-term leases), exporters and importers can adjust and experience water trade without experiencing a high risk from potential "mistakes". Although long-term leases are not definitive, as Hansen, Howitt and Williams (2012) show, a substantial number of long-term leases are for more than 20 years – far less flexible than short-term leases. Thus, short-term lease appears to be more suitable to cope with unpredictable and extreme events such the drought that California is currently experiencing, especially for smaller districts, which are less likely to have the capacity to pay the sunk costs for long-term leases.

Furthermore, as we focus on the extensive margin of trade, the low occurrence of long-term leases makes the estimates particularly difficult and unsuitable in our analytical context. Indeed, trade costs associated with such long-term leases are generally very high for the first year (when the contract is enacted) and lower for the subsequent years. The trade costs of water transfer decision in a long-term lease cannot be compared with the trade cost associated with short-term lease. Furthermore, the geographic pattern of water transfers stays relatively similar with or without long-term leases. We thus drop this type of trade and analyze only short-term leases.

3.4.1.2. District Specific Data

From equation (12) we can see that several district-specific variables are needed to estimate the quantity of water traded. However, these data are particularly difficult to collect at this level because water districts do not always make them available. The first difficulty is to approximate the ratio of prices $(p_{ij} - \psi_{k_i})/p_{ij}$. Indeed, we do not know the water market price p_{ij} as well as the value of water use within the district ψ_{k_i}. In order to be able to test the theoretical model, we need to make the following assumption: the more the revenue of district n is important, the more likely it is to find a member with a high value of water use ψ_{k_n}. Therefore, we approximate such ratio by:

$$\hat{\rho}_{ijt} = \frac{Y_{jt}}{Y_{it} + Y_{jt}} \qquad (13)$$

Where Y_{it} and Y_{jt} are respectively the total income (net of treatment cost) of district i and j at time t. We extracted data for the first variable from the California State Controller's Office, which publishes annual financial reports for many special districts in California (including water districts). These reports provide district-level annual revenues and costs. To account for differences in water treatment cost between urban and agricultural districts (since the latter supply untreated water), we subtracted treatment costs from the total operating and non-operating revenues. Due to some irregularities in this dataset, we needed to apply some transformations. We first corrected and completed this database by collecting financial reports provided on several districts' websites and calculated the moving average over a three-year period to reduce the effects of some extreme values; we also replaced missing values with a log-OLS estimation (independent variables are the mean income over the 17 years period and the year). Given the low share of missing values and the relatively low year-to-year variation in revenues, this method provides a relatively good approximation of the true value.

The second variable is the water right of use by each member (ω_i). Again, we do not possess such information, implying that we need to find an approximation of this variable. In the theoretical model developed above, the underlying mechanism of water trade is that a member in i is able to trade with a district j and reversely, a member in the district j is able to find water in a district i. Therefore, the lager is the size of water use in both district, the higher is a likelihood that a member in district i have sufficient water to sell (at a low value of use) and a member in district j has a need for water (at a high value use). We thus use the total quantity of water use in the importer and exporter district (respectively W_j and W_i). As we need to consider both urban and agricultural water use, we used two types of data sources for this variable. First, we approximated the quantity of water used by the district with the population served within the boundaries. For urban districts, we used water data as reported in Urban Water Management Plans, and include this quantity for each year in the 17-year analysis period. For agricultural districts, we use the service area multiplied by the evapotranspiration (ET^0_{nt}) net of rainfall (R_{nt}). For two-thirds of these districts, the surface area is taken from the database of Cal-Atlas. Information for the remaining third is extracted from official documents from the districts. All surface area values are expressed in acres. The evapotranspiration value is given by Land and Water use estimates (at county level) from DWR[27], which estimates the need for applied water depending on the agricultural production in each county. However, the measures begin in 1998 and in order to fill in the missing value for 1995-1997 we use the California Irrigation Management Information System (CIMIS) database. This program collects climatic data from around 200 stations distributed throughout California. Because the CIMIS stations do not always correspond to the location of the districts, we calculated the weighted mean of ET_0 from CIMIS data to approximate the district location. The methodology is as follow.

In order to have a relatively close value of the weather condition in district $n \in N$, we calculate the distance as a "flying bird" between each station s in the entire State and district n. Then we calculate the weighted mean for evapotranspiration and rainfall:

$$ET^0_{nt} = \frac{\sum_s \left(\frac{d^{max}_{sn} - d_{sn}}{d^{max}_{sn} - d^{min}_{sn}} ET^0_{st} \right)}{\sum_s \left(\frac{d^{max}_{sn} - d_{sn}}{d^{max}_{sn} - d^{min}_{sn}} \right)} \quad \text{and} \quad R_{nt} = \frac{\sum_s \left(\frac{d^{max}_{sn} - d_{sn}}{d^{max}_{sn} - d^{min}_{sn}} R_{st-1} \right)}{\sum_s \left(\frac{d^{max}_{sn} - d_{sn}}{d^{max}_{sn} - d^{min}_{sn}} \right)} \qquad (14)$$

Where d_{sn}, d^{max}_{sn}, and d^{min}_{sn} are respectively the distance, maximum and minimal distance between the station s and the center of district n. We then regress through OLS the calculated data from CIMIS and the data from DWR for the years 1998-2010 and predict values for 1995-1997 and 2011.

All the variables described in this section are assumed to have a positive impact on the bilateral water trade.

3.4.1.3. Trade Costs

We need to estimate the impact of frictions that could exist between districts, but this information is not directly available. A classical assumption from the bilateral trade studies is to approximate such variable by the distance between the exporter and the importer, which holds also in the context of water market. Indeed, as discussed in

[27] Data accessible at: http://www.water.ca.gov/landwateruse/anaglwu.cfm#

the section on trade costs, the physical limitation on water conveyance and wheeling costs, which reach, in some circumstances a very high level, curb the incentive to transfer or even to search for potential trade partner outside of the region. We thus construct our variable of conveyance cost (expressed by the variable τ_{ij} in the theoretical model) by using the distance between the two districts and a binary variable that captures whether the districts are separated by the Sacramento-San Joaquin Delta.

In order to calculate the distance between districts, we use the GPS coordinates of each district's centroid of their area provided by Cal-Atlas database and approximate the distance using a "flying bird" approach represented by Vincenty's (1975) equation. The database does not report all districts; for those lacking a GPS coordinate we approximate with the coordinates of the district's office.

While it is expected that distance has a negative and significant coefficient, it is not the sole impediment to water transfers. The Sacramento-San Joaquin Delta is also a matter of concern for any northern transferor willing to trade water with a district located south of the delta. To account for this limitation, we use a binary variable T_{ij}^{delta} taking the value 1 if the potential transfer requires crossing the Delta and 0 otherwise. We consider that any districts located in San Joaquin County or further south must incur the supplemental cost of moving water through the Delta to receive water from any district located north of San Joaquin County. We use a factor variable that multiplies the income of the importer district with the dummy T_{ij}^{delta} in order to account for the effect of the expected price on the decision to cross or not the delta.

We assume that distance also plays a role in the fixed costs of transfers, since geographic proximity is generally known to induce more exchanges. It is hypothesized that districts close to each other have more contact and hence greater ease of trading. We also account for other types of fixed costs with several other binary variables. County groundwater *Ordinance*s are included as T_{ijt}^{ord}, which takes the value 1 if the county is subject to a groundwater ordinance and 0 otherwise. This variable takes the value 0 when two districts are located in the same county because such regulation typically applies for transfers outside of a county's boundaries. It is time-dependent, as some counties have passed such restrictions after 1995. As the cost of a county's ordinance (to the water district) is assumed fixed (see Table 1), it affects variable f_{ij} in equation (11). We therefore introduce a variable *Ability to cope ordinance*, $\widehat{FT}_{ijt}$, which accounts for the capability of the exporter district to overcome the fixed cost that is implied by ordinances:

$$\widehat{FT}_{ijt} = T_{ijt}^{ord} \log\left(\frac{D_{ij}}{\hat{\rho}_{ijt} W_{it}}\right) \tag{15}$$

The logarithm transformation in equation (12) is because all continuous variables are transformed as such (see the section on empirical strategy for more details). It equals zero if a dyad is not subject to groundwater ordinances from the exporter's county and decreasing (increasing) with the total water demand W_{it} and revenue ratio $\hat{\rho}_{ijt}$ (Distance D_{ij}). Following the threshold value $\bar{\psi}_{k_i}$ calculated in equation (11), we interpret this interaction term as the second measure of inefficiency of water markets (stated in proposition 2) and it is expected to have a negative impact on trade. We also expect that the Ordinances variable will have a more important role in affecting the extensive margin decision rather than the intensive margin decision, mainly because ordinances are set to prevent the migration of water outside of the county, no matter how much water is shipped.

We also include a binary variable that accounts for institutional networks within which trading is more likely because the approval process is easier – specifically when districts are served by the same water supply project—*Different project*. (Technically, this often means the districts have contracts for deliveries of shares within the same overall water rights, which are held by the project operator). We consider the State Water Project (SWP), the Central Valley Project (CVP) and within the latter project, we differentiate between various regional sub-projects (e.g., the Friant-Kern, the Madera, the Delta Mendota, the Tehama-Colusa, the San-Luis and Cross Valley Canal and deliveries from the Sacramento and San-Joaquin rivers)[9]. Here we define the trade cost $T_{ijt}^{pro} = 1$ if the districts are not located in the same project and 0 otherwise.

Finally, we include a binary variable, *Trade inexperience*, which captures the "learning" effect of participating in inter-district water market. We expect that when a district enters into the water market for the first time, frictions and thus fixed costs are higher, but repeated market participation confers experience and decreases trade costs. Thus, we define the variables $T_{it,trade}$ and $T_{jt,trade}$ equals to 0 if the district i or the district j has participated in the water market before year t. The equation for the variable and the fixed trade cost is:

$$\hat{\tau}_{ijt} = D_{ij}^{\delta_\tau} \prod_c \exp(\beta_{\tau c} T_{ijt}^c) \qquad \hat{f}_{ijt} = D_{ij}^{\delta_f} \prod_c \exp(\beta_{fc} T_{ijt}^c) \tag{16}$$

where δ_τ, δ_f, $\beta_{\tau,c}$ and $\beta_{f,c}$ are the estimated coefficients for distance and the set of binary variables and $\lambda_f T_{ijt}^{ord}$ is the coefficient for the *Ability to cope ordinance*. We expect that all variable defined in this section will have a negative association with the bilateral trade.

3.4.1.4. Summary statistics for variables participating in the regressions

Table 3.3 and 3.4 provides respectively the the variables employed and the summary statistics of the continuous and binary of these variables included in our empirical model.

Table 3.3: The variable definition for the empirical estimation

variables		Definition	unit
District's income	Y_{nt}	Adjusted income (net of water treatment cost) of the district	Dollars
District's water use	W_{nt}	Water use in the district	Acre-feet
Distance	D_{ij}	Distance between the exporter and importer districts	Kilometers
Ordinances	T_{ijt}^{ord}	If the exporter county is subject to groundwater ordinance	Dummy
Different project	T_{ijt}^{pro}	If exporter and importer district are not located into the same project	Dummy
Cross Delta	T_{ijt}^{pro}	If exporter and importer district are on either side of the Sacramento-San Joaquin Delta	Dummy
Trade inexperience	T_{ijt}^{trade}	If the district had never experienced the water market at year t	Dummy

Table 3.4: Summary statistics

Variables	Mean	Standard Deviation	Min	Max
The whole sample (950,844 observations)				
Revenue ratio	0.50	0.35	0.00	1.00
Water use (all districts)	93902.7	282892.5	150.2	4032000
Distance	352.89	232.64	0.01	1170.97
Ordinances	0.41	0.49	0	1.00
Different project	0.96	0.20	0	1.00
Cross Delta	0.39	0.49	0	1.00
Ability to cope ordinance (exporter)	-1.291117	2.04769	-12.669280	12.99992
Trade inexperience	0.63	0.48	0.00	1.00
Sample restricted to positive trades (1374 observations)				
Revenue ratio	0.59	0.32	0.00	1.00
Water use (exporter)	135614.6	228578.8	470.57	3935000
Water use (importer)	347386.9	525774	470.57	4032000
Distance	69.52	77.31	0.04	833.68
Ordinances	0.23	0.42	0.00	1.00
Different project	0.33	0.47	0.00	1.00
Cross Delta	0.02	0.13	0.00	1.00
Ability to cope ordinance (exporter)	-1.393148	2.665989	-12.59202	0
Trade inexperience (exporter)	0.04	0.19	0.00	1.00
Trade inexperience (importer)	0.10	0.30	0.00	1.00

The summary statistics suggest a large difference in the average distance between the whole dataset (upper panel) and the dyads with trade (lower panel). This shows a large bias toward proximity in the decision to engage in short-term trades.

3.4.2. Strategy and Estimation Issues

The gravity equation tool has been applied in numerous previous studies within the international trade literature, and many improvements in empirical methods have been introduced since Tinbergen (1962). More specifically, the recent contribution of Santos and Tenreyro (2006) addressed the problem of choosing the right econometric model. The classical way to estimate the gravity equation is to perform a log-linear OLS, with k explanatory variables Z_{ijk}

$$\ln(X_{ij}) = a_0 + \beta_k \ln(Z_{ijk}) + \varepsilon_{ij} \quad (17)$$

However, Flowerdew and Aitken (1982) showed that with this method the estimated coefficients are severely biased when the errors ε_{ij} are heteroskedastic (which is generally the case in bilateral trade models). The main reason is that trade data exhibit more variation for smaller volumes of trade, which implies an increase in the variance of ε_{ij}. Another, more technical, problem arises when the dependent variable has some zero values because the logarithm of zero is not defined. Several solutions have been proposed to deal with this issue. The simplest is to throw away the zeros from the database and perform the regression only on the non-zero observations (as in Brada and Mendez 1985 and Bikker 1987). This method is certainly not suitable in our case as we intend also to estimate the factors associated with no water trading (the extensive margin of trade). Simply suppressing the zeros would thus lead to an important selection bias and would allow us to only estimate half of the model (the intensive margin of trade expressed by equation (12)). Other methods imply using a Tobit model (Eaton and Tamura 1994) or keeping the log-linear OLS and adding for each dyad the term $\ln(X_{ij}+1)$ as a dependent variable instead of $\ln(X_{ij})$ (as in Eichengreen and Irwin 1995). As pointed by Santos and Tenreyro (2006), these two approaches will generally produce inconsistent estimators of coefficients, particularly when the proportion of zeros is high. In our estimation, the non-zero trade data only represent approximately 0.14% of the total number of dyads of water districts. It is thus particularly important to have a model that can handle the estimation with such a large share of zeros.

The problem of the traditional method to estimate the gravity equations led some researchers to prefer other types of econometric models such as the Poisson family (Santos and Tenreyro 2006). In this case the assumption is that the volume of trade is represented by a Poisson distribution with a conditional mean as a function of the explanatory variables. Such a model is originally designed to estimate (non-negative) count data, but by imposing the assumption of integer value on trade volumes, we can use this distribution to estimate water trade. Thus, the equation to be estimated becomes:

$$X_{ij} = \exp(a_0 + \beta_k \ln(Z_{ijk}))\varepsilon_{ij} \tag{18}$$

The first striking point is that, due to the multiplicative form implied by the Poisson distribution, the dependent variable is not log-transformed, which eliminates the issue of logs of zeros previously mentioned. Secondly, King (1988) showed that coefficients estimated by Poisson are consistent and generally efficient even in the presence of heteroskedastic errors. The reduced form that we will intend to estimate is as follows:

$$\hat{X}_{ij} = a_0 \frac{\hat{\rho}_{ijt}^{\eta} W_{it}^{\theta_i} W_{jt}^{\theta_j}}{D_{ij}^{\delta}\left(\prod_c \exp(\beta_c T_{ijt}^c\right)} \left(\frac{D_{ij}}{\hat{\rho}_{ijt} W_{it}}\right)^{-\lambda_f T_{ijt}^{ord}} \tag{19}$$

Where γ, δ, η, β_c, λ_f, θ_i and θ_j are the coefficients to be estimated. One problem with using Poisson is that it is no longer possible to disentangle the extensive margin from the intensive margin. We thus run a Probit regression with the similar right-hand-side variables using the probability of trade as the dependent variable:

$$P(\hat{X}_{ij} > 0) = \Phi \left\{ \frac{\hat{\rho}_{ijt}^{\eta} W_{it}^{\theta_i} W_{jt}^{\theta_j}}{D_{ij}^{(\delta_f + \delta_\tau)}\left(\prod_c \exp((\beta_{\tau c} + \beta_{fc}) T_{ijt}^c)\right)} \left(\frac{D_{ij}}{\hat{\rho}_{ijt} W_{it}}\right)^{-\lambda_f T_{ijt}^{ord}} \right\} + \eta_{ijt} \tag{20}$$

Where Φ is the standard normal cumulative distribution function. To control for year heterogeneity, we introduce year fixed effects in both the Poisson and the Probit regressions (not shown in results, but available upon request). We used Stata 13.0 for all regressions and data preparation.

3.4.3. Results

We first present the results for the Probit model (to determine the extensive margin of water trade), and then the results for the Poisson estimation (to include the intensive margin of water trade). As the model is in multiplicative form, we transform all non-binary independent variables into logs. The estimated coefficients are thus elasticities.

3.4.3.1. The Extensive Margin

We start by estimating whether a given district decides to engage in trading. We test different forms for equation (20) to show the importance of the different trade costs variables. For all models, we provide the pseudo R-square, the AIC and BIC criterion and the measure of the Receiver Operating Characteristic (ROC). This last indicator can be viewed as the goodness of fit of the model. Columns (I), (II) and (II) depict trade for districts-districts dyads, while column (IV) and (V) are for districts-counties dyads. Columns (I) and (IV) test the simplest model with no trade cost variables. Column (II) includes the same variables as in column (I) but with the binary transaction cost variables. Finally, columns (III) and (V) show the results with all trade cost variables included. Results are shown in Table 3.5.

Table 3.5: Probit Estimation (Extensive margin)

Variables	**(I)**	**(II)**	**(III)**	**(IV)**	**(V)**
Log(Revenue ratio)	**0.06**	**0.07**	**0.05**	**.036**	**.002**
	0.007 ***	0.013 ***	.014 ***	.009 ***	.024
Log(Water use-exporter)	**0.12**	**0.09**	**.064**	**.140**	**.06**
	0.005 ***	0.007 ***	.009 ***	.007 ***	.014 ***
Log(Water use-importer)	**0.15**	**0.15**	**0.14**	**.416**	**.431**
	0.005 ***	0.009 ***	.009 ***	.014 ***	.020 ***
Log(Distance)		**-0.38**	**-.285**		**-.592**
		0.007 ***	.009 ***		.023 ***
Ordinances			**-.29**		**-.286**
			.080 ***		.125 **
Different project			**-.45**		**-.589**
			.027 ***		0.055 ***
Cross Delta			**-.42**		**-.183**
			.063 ***		0.07 ***
Ability to cope ordinance (exporter)			**-.033**		**-.017**
			.014 **		.023
Trade inexperience-exporter		**-1.1**	**-1.02**		**-1.29**
		0.050 ***	.050 ***		.067 ***
Trade inexperience-importer		**-1.06**	**-.93**		**-.862**
		0.045 ***	.045 ***		.061 ***
Constant	**-5.92**	**-2.84**	**-2.52**	**-9.43**	**-4.16**
	0.09 ***	0.126 ***	0.13 ***	.224 ***	.287 ***
McFadden adjusted R^2	0.082	0.385	0.408	0.196	0.509
AIC	18994.611	12720.971	12650.05	10499.988	6413.681
BIC	-1476.596	-7714.940	-8140.052	-2365.892	-6381.45
ROC	0.79	0.9781	0.9803	0.8965	0.98

In each model, we have introduced year fixed effects to control for climatic variability and unobserved heterogeneity over time (not reported but available upon request). As can be seen in table 3.5 most of the coefficient are significant at 1% percent level and show the expected sign for Revenue ratio for exporter, and Water use for both exporter and importer. Adding distance improves the robustness as all criteria show better fit. Furthermore, the distance variable exhibits a negative coefficient, which is consistent with the theoretical model and indicates that districts prefer to trade water with partners at closer distances. Similarly, Trade inexperience (for both districts) is negative and significant in all models, which implies that districts without prior experience may be reluctant to enter the market.

County groundwater Ordinances have also a strong negative impact on the decision to trade, and our results are in line with findings in Hanak (2005). The Ability to cope ordinance is negative, implying that the lower is the relative size of the district the more difficult it is to overcome the ordinances and the lower is the likelihood of trade. The coefficients of the Different project and the Cross-Delta variables are negative and significant, in accordance with our expectations and indicating lower likelihood to engage in trading if the districts are either in different water projects or on the opposite side of the Delta.

When we aggregate the trades to the county level (models IV and V) we observe that the coefficients of the Revenue ratio and the Ability to cope ordinances variables become not significant. This can be explained by the aggregation of the trade contracts at the county level which eliminates the inter-district differences.

3.4.3.2. The Intensive Margin

We now turn to the results including the intensive margin of water trade (the quantity of water that was actually traded, once the district engaged itself in trade) using a Poisson regression (table 3.6). The different columns represent the same data procedure as in the Probit estimate in table 3.5. Similar to the Probit estimation, we use year fixed effects to control for heterogeneity across years (not reported).

As depicted in table 3.6, a qualitatively similar result as in the Probit estimates (table 3.5) emerges for models I, II, III: all coefficients exhibit expected sign and same significance level as in the extensive margin, except for model III, where Ordinances, Ability to cope Ordinance, and Trade inexperience (exporter) that moved to a lower significance level. The inclusion of distance and trade inexperience allows significant increases of all GOF criteria; at the aggregate level (models IV and V), the predicted values with inclusion of the trade costs variables increased the explained variance. This suggests a particularly important and significant impact of the distance on participation in the water market. However, for models IV and V we can see that Revenue ratio is not significant, and for model V the variables Ordinances, Cross Delta, and Ability to cope ordinances are not significant. We expected that in the intensive margin estimations ordinances may be less important and indeed the variables that measure the transaction costs turned to be not significant.

Table 3.6: Poisson Regression (Intensive margin)

Variables	**(I)**		**(II)**		**(III)**		**(IV)**		**(V)**	
Log(Revenue ratio)	**.426**		**.441**		**.435**		**-.0082**		**.02**	
	.041	***	.067	***	.072	***	.034		.067	
Log(Water use-exporter)	**.704**		**.552**		**.484**		**.594**		**.442**	
	0.04	***	.049	***	0.05	***	.032	***	.049	***
Log(Water use-importer)	**.844**		**.799**		**.770**		**1.43**		**1.313**	
	.027	***	.036	***	.041	***	.044	***	.077	***
Log(Distance)			**-.643**		**-.507**				**-.991**	
			.020	***	.028	***			.071	***
Ordinances					**-1.31**				**.312**	
					.439	**			.448	
Different project					**-.91**				**-.676**	
					.148	***			.160	***
Cross Delta					**-.686**				**-.473**	
					.397	*			.400	
Ability to cope ordinance (exporter)					**-.183**				**.104**	
					.073	**			.075	
Trade inexperience-exporter			**-3.16**		**-2.99**				**-3.09**	
			0.300	***	.298	***			.304	***
Trade inexperience-importer			**-2.62**		**-2.32**				**-.951**	
			.250	***	.265	***			.196	***
Constant	**-15.20**		**-7.63**		**-6.53**		**-22.22**		**-11.50**	
	.702	***	.836	***	.844	***	.809	***	1.38	***
McFadden adjusted R^2	0.242		0.465		0.482		0.319		0.557	
AIC	6.229e+07		4.402e+07		4.259e+07		4.467e+07		2.906e+07	
BIC	-1.994e+07		-3.821e+07		-3.965e+07		-2.094e+07		-3.655e+07	
GOF	0.0080		0.0236		0.0248		0.0155		0.0919	

Table 3.7 presents OLS regression results for correlation between aggregate observations and aggregate predictions.

Table 3.7: Goodness of Fit

	(I)	(II)	(III)
District-County	0.0185	0.0646	0.0803
County-County	0.1240	0.4573	0.4424

We sum the observed volume of water transfer for each exporter district (row 1) and for each exporter county (row 2) and regress it with the predicted coefficient of the three first models of the Poisson regression (from table 3.6). We find a significant improvement of the adjusted R-square between the simple model of column (I) and the complete model of column (III). It appears that the binary variables of transaction costs are important in the disaggregated model (district-county). However, at the aggregate level (county-county), the dummy variables appear to be less important as the R-square between model (II) and model (III) is slightly decreasing.

3.5. Conclusion

In this chapter, we have developed a simple theoretical model and tested it to highlight the impacts of trade costs on California water markets. While some of these costs reflect legitimate means to protect a natural resource, rationalizing the trading process might allow traders to lower trade costs without increasing risks of unintended externalities. Thus, the main result of this chapter is that trade costs impede transfers, likely limiting water users from benefitting from the advantages of water markets. While some regions need to protect their water resources (and more particularly groundwater) from the risk of depletion, the ordinances discriminate against exports instead of regulating groundwater use more generally within the basin, thereby preventing transfers that might be welfare-enhancing (Hanak 2005). Streamlining the institutional framework and developing more transparent administrative mechanisms seem to be necessary for increased trade. Indeed, facilitating the search for trading partners is also important to enhance market participation. As pointed out by Culp, Glennon and Libecap (2014), an online platform – such as those operated in Australia's Murray-Darling Basin – could lower the fixed trade cost of search. Finally, encouraging better collection and management of information at the state level could facilitate water market entry. The example of the state of Colorado is interesting in this regard, where most water trade is under the supervision of one water district: Northern Water, which oversees the operations of the Colorado Big-Thompson Project in conjunction with the federal government (Libecap 2012). Such a system could provide a healthy balance between the necessary protection for third parties and lowering trade cost to improve market flexibility.

This chapter also contributes to the literature by presenting water trading within a micro-based trade theoretical framework, including the gravity equation, which allows studying the frictions in bilateral interactions. We show empirically that this approach provides insights into analyzing water trading. We believe that the theoretical model and the empirical inference developed in this article could be applied and enhanced in future research to improve understanding of water markets.

However, further research should focus on improving the accuracy of the data collected and finding a good approximation of prices of water traded, which would make it possible to improve estimates of the impact of trade costs. Limited information in our dataset on the seniority of water rights, which affects availability during droughts, may have affected our results. Such information is becoming available with the advent of new reporting requirement in the state.

Conclusion

The aim of this dissertation is to contribute to both the theoretical and empirical literature on the potential advantages and the limits of water markets in hydrologically scarce regions. On the theoretical ground, it provides the argumentations to account for technological and pecuniary externalities which arise from inadequately ruled interactions between water users. These two effects are the consequence of trade costs (combination of transaction and conveyance costs) which need to be measured to know the real potentiality of water markets. In that respect, this thesis contributes also to the empirical literature by estimating in a third chapter the magnitude of these trade costs with the use of gravity equations, widely used in international trade studies. More than the simple use of this tool, the innovation brought by this dissertation is the adaptation of the gravity equations to the specific trade costs of water markets as defined in the first two chapters.

Indeed, in the first chapter, an analysis of property rights over water which represents the core issue to manage this resource has been performed. The intricate nature of water implies that property rights over this particular resource will never be complete, and as a result, some interdependencies between users will still be inadequately ruled by the institutional infrastructure in place. Delineating the rights and duties of each interdependent agents who may be affected by the transfer of water is a challenging task for the private decision makers and substantially increases the required effort to participate in water markets. In that respect, the concept of transaction costs has been defined as the monetary valuation of such efforts which grow larger with the number of interdependencies that need to be ruled in a different way. Since it is costly to participate in an interaction with potential parties affected by the water transfer to reach an agreement and adequately rule an interdependency, whether it is a hydrological or an economic one, the interest toward trading water diminishes. Following such a definition has allowed to consider not only the technological externalities, but also the pecuniary ones as potential deterrent of water trading. The pecuniary externalities are an important feature of water markets because beneficiaries from past reforms will likely lose from the institutional change and therefore will resist an alteration of the institutionalized rules.

In the second chapter, concepts of externalities, transaction costs and property rights with their underlying institutionalized rules as developed in the first chapter have been used to explain the institutional path of water management in California. By heavily relying upon the local organizations to manage its water resources in the wake of the Gold Rush, this State has created a specific pattern of interdependencies upon water use. Indeed, during the first half of the twentieth century, the agricultural production got the bulk of the available water resources from the multiple physical infrastructures such as the Central Valley Projects or from the institutional infrastructures such as the relatively democratic organizations of Water and Irrigation Districts or the security of property rights with the Prior Appropriation doctrine. This fostered the development of rural areas by thwarting the tragedy of the commons and providing stability in the interactional situations between water users. But this has been done at the costs of urban development which could catch only a dwarf share of the available water resources. When the ratio of economic and demographic power got reversed in the second half of the twentieth century, resistance grew from the rural areas to avoid potential technological externalities, but mostly the pecuniary externalities that will most probably arise from the water markets. From these two externalities, conflicts emerged between water users where cooperation would be more profitable. As a result, federal and governmental agencies have been involved not to support the definition of adequate rules, but rather to provide such rules in the form of exclusion tools. The inaccuracy of such institutional instruments to fit the complexity of the local context gave rise to the "tragedy of the anti-common" where status quo is the preferred option instead of institutional change toward the water markets.

From this framework, the size of the trade costs associated with the transfer of water can be estimated through the use of the gravity equations and has been the focus of the third chapter. Results demonstrated the importance of considering institutional impediments in water markets. While the overall robustness of the performed estimations is relatively low which implies that the estimated coefficients must be interpreted with a lot of care, the method used to do that is important since it allows future research with better data set to perform a structural estimation of trade costs in water markets. Indeed, with more recent data, it should be possible to implement fixed effects in the econometric model to avoid the naïve estimation, particularly sensitive to omitted variables. This way, it will be possible for future work to calculate a market potential which can more accurately determine the real availability of water for transfer and measure what might be the impact of changing the institutionalized rules. Another avenue for future research is to improve the precision of estimates by accounting for political aspects within water districts or counties which is conjectured as a possible source of opposition to water markets.

Introduction (french)

Condition indispensable à l'existence de toute société, l'eau se dilue dans l'ensemble des activités humaines au gré des différents besoins de consommation et des spécialisations de production. De cette grande ubiquité d'usage naît la crainte dans de nombreuses régions arides à travers le monde d'une inadéquation entre les ressources disponibles et les nouveaux besoins qui apparaissent au fil du développement économique. Une adaptation des infrastructures physiques à travers la construction de larges projets a été le paradigme des politiques d'investissement durant plusieurs décennies dans ces régions (Saleth and Dinar, 2004). Cependant, en assumant que les systèmes hydriques ne varient que dans un intervalle constant, nombre de ces solutions pour résoudre les problèmes de rareté de l'eau dans le passé ont été basées sur une hypothèse de stationnarité environnementale et sociale. Pourtant, face aux changements structurels et climatiques présent, il est possible de dire que cette « hypothèse de stationnarité est morte » (Milly, Betancourt, Falkenmark, et al., 2008 p.573).

Afin de surmonter ces défis, les responsables politiques dans la plupart de ces régions arides ont centré leur attention sur le développement d'infrastructures institutionnelles suffisamment flexibles pour faire face aux changements rapides de ce nouveaux millénaire. Les marchés de l'eau, où des acheteurs et vendeurs interagissent volontairement dans un système de prix décentralisé afin d'échanger leurs droits d'usage sur l'eau ont été d'un intérêt grandissant pour les responsables politiques (Easter, Rosegrant, and Dinar 1998; Easter and Huang 2014; Griffin, Peack and Maestru, 2013 and Msangi and Howitt 2006). En effet, en accord avec la théorie traditionnelle du commerce, le transfert de ressources en eau entre les usagers à travers un système de gestion décentralisé est vu comme un mécanisme efficient de réallocation, non seulement permet à cette ressource d'évoluer d'un usage à faible valeur ajoutée à un usage à forte valeur ajoutée, mais aussi fournit les incitations de conservation et les améliorations technologiques de son utilisation (Garrick, 2015 p.181). Mais, étant donnée la complexité des relations entre une société et ses ressources hydriques, avec notamment d'importantes difficultés à appréhender les multiples interdépendances entre utilisateurs (Smith, 2008 p.445), les marchés de l'eau ont besoin d'institutions fortes pour être efficaces (Challen, 2000 p.205; Garrick, 2015 p.9; Livingston, 1998 p.19 and Howitt, 2014 p.95).

Une institution peut être généralement définie comme les « prescriptions que les humains utilisent pour organiser toutes les formes d'interactions répétitives et structurées » (Ostrom, 2005 p.3). Puisque de telles prescriptions fournissent les rôles pro-forma et ainsi, réduisent les efforts requis pour appréhender l'environnement social et naturel dans lequel l'individu évolue, elles améliorent la prédictibilité des situations interactionnelles à travers une délinéation claire des droits et devoirs entre les individus. Dans ce sens, les prescriptions sont le résultat de règles institutionnalisées sous-tendent les droits de propriété en donnant à chaque individu un ensemble d'attentes exactes quant aux comportements des autres (Commons, 1934 p.58; Hamilton, 1932 p.84; Schmoller, 1900 p.149 and Veblen, 1919 p.239). Plus la situation interactionnelle entre individus est complexe, plus les règles institutionnalisées qui sous-tendent les droits de propriété doivent être précises afin d'éviter des conséquences inattendues d'actions individuelles sur les autres utilisateurs, aussi appelées externalités. Il s'agit là d'un des plus problèmes les plus épineux des marchés de l'eau (Challen, 2000; Garrick, 2015; Libecap, 2012; Livingston, 1998 and McCann and Garrick, 2014).

Un ensemble de règles institutionnalisées adéquates doit ainsi être mis en place afin d'établir et de maintenir une certaine prédictibilité des actions entreprises par les différents utilisateurs de l'eau (incluant l'acte de transférer l'eau). Mais, définir de telles règles requiert de collecter une quantité suffisante d'information sur le complexe cycle hydrologique et les multiples interconnections ave le monde social et environnemental. Due à sa caractéristique de fluidité, qui induit une difficulté supplémentaire à mesurer cette ressource (Libecap, 2012 p.400), et à la résistance de sa molécule qui lui permet d'être réutilisée (Griffin, Peck and Maestru, 2013 p.5), l'eau ne peut pas être facilement divisée et ne peut donc pas être aisément partitionnée en parts bien définies sur lesquelles les individus pourraient avoir un contrôle complet. A la lumière d'une telle difficulté pour saisir la complexité des relations entre les cycles hydriques et les tortueuses interactions avec les phénomènes sociaux et biologiques, les multiples interdépendances entre les individus seront, en toutes probabilités, inadéquatement prises en compte par les règles institutionnalisés sous-tendant les droits de propriété (Garrick, 2015 p.43). A ce titre, les marchés de l'eau ne seront probablement jamais en situation de compétition parfaite, et, en dépit de leur avantage potentiel par rapport à des institutions plus centralisés, ces instruments décentralisés ne peuvent amener l'ensemble des bénéfices que suppose la théorie traditionnelle du commerce (Garrick, 2015).

Ainsi, autant Hayek (1945) stipula que tout l'intérêt d'un système de prix décentralisé avec un minimum de règles réside dans « la faible quantité d'informations nécessaires aux individus participants à une interaction pour prendre les bonnes décisions » ((p.527), Ostrom (2005) pointa dans les premières pages de son livre que « les opportunités et les contraintes auxquelles les individus font face dans n'importe quelle situation, les informations qu'ils obtiennent, les bénéfices qu'ils obtiennent ou qu'ils en sont exclus, et comment ils raisonnent à propos d'une situation, sont affectés par les règles ou l'absence de règles structurant la situation » (p.3). Ceci implique que les instruments basés sur les marchés ne sont pas le seul résultat d'un comportement spontané vers un certain ordre, mais plutôt qu'il s'agit de l'aboutissement d'un effort continuel de conception des règles pour faciliter la décentralisation des échanges d'une ressource bien complexe (Challen, 2000; Garrick, 2015 and McCann and Garrick, 2014). De tels efforts, aussi appelés coûts de transaction « incluent le coût d'utiliser des ressources pour la création, la maintenance, l'utilisation ou le changement des institutions et organisations » (Furubotn and Richter, 2000 p.48). En d'autres termes, il s'agit des ressources déployées ou des efforts nécessaires pour faire convenir les règles institutionnalisées à la situation interactionnelle présente. Il est généralement accepté que ces coûts de transaction agissent comme une entrave aux marchés de l'eau, induisant dans bon nombre de régions arides ayant institué de tels systèmes de gestion décentralisées, un niveau particulièrement bas de commerce d'eau (Carey and Sundin, 2001; Howitt, 2014; Sunding, Zilberman, Howitt, Dinar and Macdougall, 2002 and Young, 1986).

Cette thèse se concentre sur le cas iconique de la Californie pour analyser l'impact des coûts de transaction sur les marchés de l'eau. En dépit de très grandes différences des valeurs marginales de cette ressource entre les usagers et un effort important des agences gouvernementales pour promouvoir ce mode de réallocation, force est de constater que les marchés de l'eau ont peine à émerger comme mécanisme majeur de réallocation pour lutter contre les croissants déséquilibres entre des demandes en constantes augmentations et une offre limitée dans cet Etat en particulier (Howitt, 2014). Le résultat est une ressource tiraillée entre une des agricultures les plus productives du monde, plusieurs mégalopoles comptant des millions d'habitants et un environnement à préserver (Hanak, 2015 and Howitt, 2014). La conséquence à une telle pression est une incapacité à faire face à des évènements climatiques extrêmes comme la récente sécheresse qu'a connu le sud-ouest des Etats-Unis, considérée comme la plus sévère depuis que les mesures existent (PPIC, California's Latest Drought). Bien que les villes aient souffert de cette récente sécheresse avec un moratoire imposant aux agglomérations Californienne une réduction de 25% de leur consommation d'eau, la production agricole et l'environnement ont été tout aussi sévèrement touchés. La mise en jachère des terres due au manque d'eau a coûté approximativement $1.7 milliard et 7 500 emplois saisonniers (Howitt, Medellin-Azuara and MacEwan, 2014), et ce n'est pas moins de 18 espèces animales qui seront en risque d'extinction si la sécheresse persiste (PPIC, California's Latest Drought).

Autant un usage extensif des ressources en eau durant ces dernières décennies a pu soutenir le développement de cet Etat pour devenir l'un des plus riches au monde (Hundley, 2001), autant, à l'aube du nouveau millénaire et face aux défis majeurs du changement climatique, la Californie ne peut plus subvenir simultanément aux différents besoins seulement grâce à ses infrastructures physiques comme cela a été possible dans le passé, et doit maintenant composer avec les ressources disponibles. C'est donc durant une sécheresse particulièrement importante dans les années 1990 que les responsables politiques ont tenté d'adapter les institutions gérant l'eau pour développer les marchés sur cette ressource. Après une augmentation importante à ses débuts, les niveaux d'échanges ont stagné à un pallier plutôt décevant de 3 à 5 pourcents du total de l'eau utilisée (Hanak, 2015). Les raisons sous-jacentes d'un tel dédain de la part des usagers de l'eau sont de deux natures conjointes.

Premièrement, le risque important d'externalité technologique à transférer l'eau impose un effort substantiel de la part des détenteurs du droit d'usage qui peut en décourager plus d'un dans leur décision de participer ou non aux marchés de l'eau ; en effet, une « balkanisation » de la gestion de l'eau initiée il y a plus d'un siècle rend difficile la connexion entre usagers afin de faciliter les échanges d'informations et ainsi réduit la prédictibilité de toutes les parties prenantes d'un transfert de l'eau. Cela accroît le coût de transaction d'une participation aux marchés de l'eau puisqu'un acheteur ou un vendeur doivent s'engager dans une fastidieuse tâche pour vérifier que son action ne cause pas de préjudices significatifs à d'autres usagers.

La seconde raison est plus particulièrement liée à l'histoire de la Californie. A l'instar des autres Etats de l'Ouest des USA durant la majeure partie du vingtième siècle, la Californie a répondu à la demande en eau croissante par le développement de large infrastructures physiques afin de fournir l'offre nécessaire. A ce moment de son histoire, l'agriculture était de très loin la plus grosse consommatrice d'eau, tout autant qu'elle était un facteur majeur de développement économique. Les régions rurales ont ainsi largement bénéficié de ces politiques d'amélioration de l'offre et les relations entre usagers ont façonné leurs opportunités stratégiques dans un réseau complexe d'interdépendances formelles et informelles, principalement conduites par les bénéficiaires de ces solutions d'ingénieries hydrauliques (Freyfogle, 1989 p.1545). Il en résulte une dépendance au passé où « l'utilisation de l'eau devient fixée historiquement dans des régions agricoles, principalement pour l'irrigation et souvent pour des cultures et communautés choisies pour des raisons politiques et de développement territorial, plus que d'efficiences économiques en termes de maximisation du bien-être » (Garrick, 2015 p.81). Une telle dépendance n'influence pas seulement le mode d'usage de l'eau, mais plus généralement l'ensemble des institutions attachées à gérer cette ressource, et par ce fait, une grande variété d'interactions entre usagers. En effet, la balkanisation de la gestion de l'eau en Californie a conduit à une dilution du pouvoir entre un important nombre d'organisations locales dont beaucoup ont bénéficié des allocations initiales de l'eau. Sa réallocation induite par les marchés de l'eau afin de maximiser le bien-être global induit d'importante tensions politiques puisque les bénéficiaires des réformes passées seront les perdants des nouvelles réformes à travers la perte de certains avantages. Une certaine résistance aux changements a ainsi émergé, augmentant la difficulté à aligner les institutions aux nouvelles situations et donc, accroissant les coûts d'échange de l'eau.

Le lien entre ces deux causes se trouve dans l'inadéquation des règles institutionnalisées qui induisent des droits de propriété sur l'eau incomplets et ainsi augmentent les coûts de transaction pour prendre en compte les multiples interdépendances. Le point de départ de cette thèse prend racine dans la conclusion de Coase (1960) dans son célèbre article « commençons à étudier le monde de coûts de transaction positifs » (p.717).

Dans un premier chapitre, ce monde de coûts de transaction positifs dans la gestion de l'eau est vu dans une perspective institutionnelle, et une explication est donnée pour l'existence de règles afin d'éviter les externalités préjudiciables qui peuvent être causées par le commerce de l'eau. Plus spécifiquement, le concept un peu flou d'externalité est clairement défini à travers l'importante notion des coûts de transaction qui limitent les possibilités de prendre en compte les multiples interdépendances.

Dans un second chapitre, les concepts développés dans le chapitre précédant sont mobilisés pour étudier plus spécifiquement le cas des institutions de l'eau en Californie et aident à comprendre les différentes frictions au sein des marchés de l'eau qui existent dans cet Etat. La dépendance au passé des institutions de l'eau y est présentée comme de multiples tentatives pour élargir les échanges et la gestion de cette ressource, où les réformes précédentes destinées à favoriser le développement local des institutions représentent aujourd'hui une part importante des coûts de transaction.

Finalement, dans un troisième chapitre, la question de la mesure de ces coûts de transaction est explicitement posée à travers une analyse empirique des marchés de l'eau en Californie durant une période de dix-sept années. A cette fin, les modèles gravitaires bien connus de la théorie du commerce international pour estimer les frictions entre pays sont ici adaptés et utilisés dans le contexte des marchés de l'eau. Dans un premier temps, un modèle théorique est développé afin de distinguer entre coûts de transaction variables et fixes, ce qui permet de distinguer la décision de commercer (marge extensive) de la quantité d'eau qui sera commercée (marge intensive). Ensuite, les équations de gravité sont utilisées afin de valider la théorie formalisée dans la première partie du chapitre. Les coûts de transaction et coûts de convoyage sont évalués approximativement avec une multitude de variables institutionnelles et la distance entre détenteurs du droit d'usage de l'eau. Les résultats valident les prédictions théoriques et démontrent l'importance de considérer ces deux types de variables explicatives dans la décision de commercer l'eau.

Conclusion(french)

Le but de cette thèse est de contribuer à alimenter la littérature autant théorique qu'empirique sur les limites et les avantages potentiels des marchés de l'eau dans des régions où la ressource hydrologique est rare. D'un point de vue théorique, une argumentation y est produite pour considérer les externalités technologiques et pécuniaires qui émergent de l'inadéquation de règles institutionnalisées qui régissent les interactions entre usagers de l'eau. Ces deux effets sont la conséquence de ce qui a été défini comme les coûts de commerce (combinaison des coûts de transaction et convoyage) qui ont besoin d'être mesuré pour connaître la réelle potentialité des marchés de l'eau. A ce titre, cette thèse contribue aussi à la littérature empirique en estimant dans le troisième chapitre l'importance de ces coûts de commerce par l'utilisation des modèles gravitaires, largement utilisés dans les études de commerce international. Plus qu'une simple utilisation de cet outil, l'innovation de cette thèse est d'adapter les équations de gravité au cas spécifique des coûts de commerce dans les marchés de l'eau comme défini dans les deux premiers chapitres.

En effet, dans le premier chapitre, nous réalisons une analyse des droits de propriété sur l'eau qui représentent le cœur du problème de gestion de cette ressource. La nature complexe de l'eau implique que ces droits de propriété ne peuvent être complets, et donc, certaines interdépendances entre les usagers seront toujours régulées de façon inadéquate par l'infrastructure institutionnelle en place. La délinéation des droits et devoirs de chaque agent interdépendant qui pourrait être affecté par un transfert d'eau est particulièrement difficile pour un agent privé et accroît substantiellement les efforts requis pour participer aux marchés de l'eau. A ce titre, le concept de coûts de transaction y est défini comme l'évaluation monétaire de ces efforts qui augmentent avec le nombre d'interdépendances nécessitant d'être régulées d'une façon différente que celle qui est actuellement appliquée. Comme il est coûteux de participer à ces interactions avec de potentielles parties-prenantes pour arriver à un accord, qu'il soit sur un lien hydrologique ou économique, l'intérêt envers les marchés de l'eau diminue. En suivant une telle définition, il a été possible de considérer non seulement les externalités technologiques, mais aussi les externalités pécuniaires comme possible effets dissuasifs aux commerces de l'eau. Les externalités pécuniaires sont tout particulièrement un important aspect des marchés de l'eau puisque les bénéficiaires des réformes passés sont souvent enclins à résister aux changements institutionnels lorsque ces derniers leur font perdre de substantiels avantages.

Dans un second chapitre, les concepts développés précédemment sont mobilisés pour expliquer la trajectoire de développement de la gestion de l'eau en Californie. En ne se basant que sur des infrastructures physiques pour arriver à un équilibre offre-demande, et ce depuis la « ruée vers l'or », cet Etat a créé un modèle d'interactions spécifique aux problèmes rencontrés. En effet, durant la première moitié du vingtième siècle la production agricole s'est vue octroyer une part substantielle des ressources en eau disponible à travers la multiplication d'infrastructures physiques tel que le CVP ou institutionnelles tel que le « Prior Appropriation ». Cela a permis un développement sans précédent des régions rurales en limitant le risque de tragédie des communs et en fournissant une stabilité interactionnelle entre les usagers. Mais cela a été fait au détriment des possibilités du développement urbain qui ne pouvait obtenir qu'une part minime des ressources disponibles. Lorsque le rapport de pouvoir économique et démographique s'est inversé au cours de la seconde moitié du vingtième siècle, les résistances aux changements dans les milieux ruraux ont augmenté par crainte d'externalités technologiques et pécuniaires. De ces deux types d'externalités des conflits ont émergé entre les usagers alors qu'une coopération aurait été plus souhaitable. Ainsi, les autorités fédérales et le gouvernement se sont impliqués pour fournir des règles d'exclusion plutôt qu'un support nécessaire à l'élaboration de règles adéquates à chaque situation. L'imprécision des outils d'exclusion utilisés dans la délinéation des droits et devoirs conduit à l'émergence de tragédies « d'anti-communs » où le statu quo est préféré à un changement institutionnel vers les marchés de l'eau.

A partir de ce cadre de travail, la taille des coûts associés au transfert de l'eau peut être estimée à travers l'utilisation des équations de gravité. C'est l'objet du chapitre trois. Les résultats démontrent l'importance de prendre en compte les freins institutionnels aux marchés de l'eau. Bien que la robustesse globale du modèle soit relativement faible, ce qui implique que les coefficients estimés doivent être interprété avec beaucoup de précaution, la méthode utilisée permettra à de futures recherches ayant un jeu de données plus complet de réaliser une estimation structurelle des coûts de commerce dans les marchés de l'eau. En effet, avec des données plus récentes, il devrait être possible d'implémenter des effets fixes dans le modèle économétrique afin d'éviter l'utilisation de la méthode naïve des équations de gravité qui est particulièrement sensible aux variables omises. Ainsi, il deviendrait possible à ces futurs travaux de calculer un potentiel marchand permettant une mesure plus précise des gains associés aux marchés de l'eau et aux changements institutionnels nécessaires à l'établissement de tels marchés. Une autre possibilité de recherche est d'améliorer la précision des frictions aux échanges de l'eau en incluant les aspects politiques à l'intérieur des districts et comtés qui sont tous deux supposés limiter le commerce de l'eau.

Bibliography

Abelson, P., Dyckman, J., Fox, W., Hiatt, L., Leopold, L. R., Malone, T., . . . Borchert, J. (1968). *Water and Choice in in the Colorado Bassin: An Example of Alternatives in Water Managemen.* Washington DC: National Academy of Sciences.

Abrams, R. K. (1980). "International Trade Flows under Flexible Exchange Rates. *Economic Review, Federal Reserve Bank of Kansas City*, 3-10.

Acemoglu, D., & Robinson, J. A. (2006). *Economic Origins of Dictatorship and Democracy.* New York: Cambridge University Press.

Ahlfeldt, G., Redding, S., Sturm, D., & Wolf, N. (2015). The Economics of density: Evidence from the Berlin Wall. *Econometrica, 83*(6), 2127-2189.

Aitken, N. D. (1973). The Effect of EEC and EFTA on European Trade: A Temporal Cross-Section Analysis. *American Economic Review, 63*(5), 881-892.

Akbulut, B., & Soylu, C. (2012). An Inquiry Into Power and Participatory Natural Resource Management. *Cambridge Journal of Economics, 36*(5), 1143-1162.

Akerlof, G. A. (s.d.). The Economics of Caste and of the Rat Race and other Woeful Tales. Dans *An Economic Theorists Book of Tales* . Cambridge: Cambridge University Press.

Alchian, A. (1965). Some Economics of Property Rights. *Il Politico, 30*, 816-829.

Alchian, A. A. (1950). Uncertainty, Evolution, and Economic Theory. *The Journal of Political Economy, 58*(3), 211-221.

Alchian, A. A., & Woodward, S. (1988). Review of Williamson's 'The Economic Institutions of Capitalism'. *Journal of Economic Literature, 26*, 69-79.

Alchian, A., & Allen, W. (1969). *Exchange and Production: Theory in Use.* Belmont: Wadsworth.

Alchian, A., & Demsetz, H. (1973). The Property Rights Paradigm. *Journal of Economic*, 16-27.

Aligica, P. D., & Tarko, V. (2012). Polycentricity: From Polanyi to Ostrom, and Beyond. *Governance: An International Journal of Policy, Administration, and Institutions, 25*(2), 237-262.

Allen, D. (2000). Transaction Costs. Dans B. a. Bouckaert, *The Encyclopedia of Law and Economics* (pp. 893-926). Chelthenham: Edward Elgar.

Allen, T. (2014). Information Friction in Trade. *Econometrica, 82*(6), 2041-2083.

Allen, T. (2014). Informational Frictions in Trade. *Econometrica, 82*(6), 2041–2083.

Anderson, J. E. (1979). A Theoretical Foundation for the Gravity Equation. *American Economic Review, 69*(1), 106-116.

Anderson, J. E. (2000). Why Do Nations Trade (so little)? *Pacific Economic Review, 5*(2), 115-134.

Anderson, J. E. (2011). The Gravity Model. *Annual Review of Economics, 3*(1), 133-160.

Anderson, J. E., & Marcouiller, D. (2002). Insecurity and the Pattern of Trade: An Empirical Investigation. *Review of Economics and Statistics, 84*(2), 342-352.

Anderson, J. E., & Wincoop, E. (2003). Gravity with Gravitas: A Solution to the Border Puzzle. *American Economic Review, 93*(1), 170-192.

Anderson, J. E., & Wincoop, E. (2004). Trade Costs. *Journal of Economic Literature, 42*(3), 691-751.

Anderson, R. (1961). The Irrigation Water Rental Market: A Case Study. *Agricultural Economics Research*, 54-58.

Anderson, R. (1967). Windfall Gains from Transfer of Water Allotments within the Colorado-Big Thompson Project. *Land Economics, Vol. 43, No. 3* , 265-273.

Anderson, T. (1983a). *Water Crisis: Ending the Policy Drought.* Baltimore: John Hopkins University Press.

Anderson, T. (1983b). *Water Rights: Scarce Resource Allocation, Bureaucracy and the Environment.* Cambridge: Ballinger.

Anderson, T. L., & Johnson, R. N. (1988). The Problem of Instream Flow. *Economic Inquiry, 24*, 535-554.

Anderson, T., & Hill, P. (1975). The Evolution of Property Rights: A Study of the American West. *Journal of Law and Economics, 18*(1), 163-179.

Anderson, T., & Hill, P. (1990). The Race for Property Rights. *Journal of Law and Economics*, 177-197.

Aoki, M. (2001). *Toward a Comparative Institutional Analysis.* Cambridge : MIT Press.

Archibald, M. (1977). Appropriative Rights in California. *Governor's Commision to Review CaliforniaWater Rights Law Staff Paper No.1*.

Archibald, S. O., & Renwick, M. E. (1998). Expected Transaction Costs and Incentives for Water Market Development. Dans W. K. Easter, M. W. Rosegrant, & A. Dinar, *Markets for Water, Potential and Performance* (pp. 95-118). Dordrecht: Kluwer Academic.

Archibald, S. O., Kuhnle, T. E., Marsh, R., Renwick, M., & Thompson, B. (1992). An Economic Analysis of Water Availability in California Central Valley Agriculture-Phase III Report. *Center for Economic Policy Research Working Paper Series, Stanford University*.

Arkolakis, C. (2010). "Market Penetration Costs and the New Consumers Margin in International Trade. *Journal of Political Economy, 118*(6), 1151-1199.

Arrow, K. (1963). Uncertainty and the Welfare Economics of Medical Care. *American Economic Review*, 91-96.

Arrow, K. (1969). The Organization of Economic Activity: Issues Petrinent to the Choice of Market versus nonmarket allocation. Dans J. E. Commision, *Analysis and Evaluation of Public Expenditures: The PBS System* (pp. 47-64). Washington: US Congress.

Arrow, K. (1971). Political and Economic Evaluation of Social Effects and Externalities. Dans M. Intriligator, *Economics, Frontiers of Quantitative* (pp. 3-23). Amsterdam.

Arrow, K. (1973). Higher Education as a Filter. *Journal of Public Economic, 2*(3), 193-216.

Arrow, K. (1974). *The Limits of Organization.* New York: W. W. Norton.

Arrow, K. (1977). The Property Rights Doctrine and Demand Revelation under Incomplete Information. *Technical Report No. 243.*

Arrow, K. J. (1951). Alternative Approaches to the Theory of Choice in Risk-Taking Situations. *Econometrica, 19*(4), 404-437.

Arrow, K. J. (1971). *Essays in the Theory of Risk-Bearing.* Chicago: Markam.

Arrow, K., & Deubreu, G. (1954). Existence of an Equilibrium for a Competitive Economy. *Econometrica, 22*(3), 265-290.

Balleau, W. P. (1988). Water Appropriation and Transfer in a General Hydrogeologic System. *Natural Resources Journal, 18*, 259-291.

Banzhaf, H., Fitzgerald, T., & Schnier, K. (2013). Nonregulatory Approaches to the Environment: Coasean and Pigouvian Perspectives. *Review of Environmental Economics and Policy, 7*(2), 238-258.

Barnard, C. (1938). *The Functions of the Executive.* Cambridge: Harvard University Press.

Barzel, Y. (1977). Some Fallacies in the Interpretation of Information Costs. *Journal of Law and Economics, 20*, 291-307.

Barzel, Y. (1982). Measurement Cost and the Organization of Markets. *Journal of Law and Economics, 25*, 27-48.

Barzel, Y. (1985). Transaction Costs: Are They Just Costs? *Journal of Institutional and Theoretical Economics, 141*, 4-16.

Bates, R. H. (1989). *Beyond the Miracle of the Market: The Political Economy of Agrarian Development in Kenya.* Cambridge: Cambridge University Press.

Bator, F. (1958). The Anatomy of Market Failure. *Quaterly Journal of Economics, 72*(3), 351-379.

Bauer, C. (2004). *Siren Song: Chilean Water Law as a Model for International Reform.* Washington DC: International Reform, RFF Press.

Baumol, W. (1972). On Taxation and the Control of Externalities. *American Economic Review, 62*(3), 307-322.

Baumol, W. J. (1952). The Transactions Demand for Cash: An Invotory Theoretic Approach. *Quaterly Journal of Economics, 66*, 545-556.

Baumol, W. J., & Oates, W. E. (1988). *The Theory of Environmental Policy.* Cambridge: Cambridge University Press.

Bergstrand, J. H. (1985). The Gravity Equation in International Trade: some Microeconomic Foundations and Empirical Evidence. *Review of Economics and Statistics,, 67*(3), 474-481.

Bergstrand, J. H., & Egger, P. (2013). Gravity Equations and Economic Frictions in the World Economy. Dans D. Bernhofen, R. Falvey, D. Greenaway, & U. Krieckemeier, *Palgrave Handbook of International Trade* (pp. 532-570). Palgrave Macmillan UK.

Bikker, J. (1987). An international trade flow model with substitution: an extension to the gravity model. *Kyklos, 40*, 315-337.

Bjornlund, H., & McKay, J. (2002). Aspects of Water Markets for Developing Countries: Experiences from Australia, Chile and the US. *Journal of Environment and Development Economics, 7*(4), 767-793.

Blomquist, W. (1988). the performance of groundwater management blomquist: Volume 1. Dans *Workshop in Political Theory and Policy Analysis.* Bloomington: Indiana University.

Blomquist, W. (2012). A Political Analysis of Property Rights. Dans D. Cole, & E. Ostrom, *Property in Land and Other Resources* (pp. 369-384). Cambridge: Lincoln Institute of Land Policy.

Blumm, M. (1992). Fallacies of Free Markets Environmentalism. *Harvard Journal of Law and Public Policy*, 371.

Boulding, K. E. (1980). The Implications of Improved Water Allocation Policy. Dans M. Duncan, *Western Water Resources: Coming problem and alternatives* (pp. 299-311). Boulder : Westview Press.

Bowles, S. (2006). *Microeconomics: Behavior, Institutions, and Evolution.* Princeton: Princeton University Press.

Bowles, S., & Gentis, H. (1988). Contested Exchange: Political Economy and Modern Economic Theory. *American Economic Review, 78*(2), 145-150.

Bowles, S., & Gentis, H. (1993). The Revenge of Homo Economicus: Contested Exchange and the Revival of Political Economy. *Journal of Economic Perspectives, 7*(1), 83-102.

Bowles, S., & Polania-Reyes, S. (2012). Economic Incentives and Social Preferences: Substitutes or Complements? *Journal of Economic Literature, 50*(2), 368-425.

Brajer, V., Cummings, A. R., & Farah, P. (1989). The Strengths and Weaknesses of Water Markets as They Affect Water Scarcity and Sovereignty Interests in the West. *Natural Resources Journal, 29*, 489-509.

Brander, J., & Mendez., J. (1985). Economic integration among developed, developing and centrally planned economics: a comparative analysis. *Review of economics and statistics, 67*(4), 549-556.

Brander, J., & Taylor, M. (1998). The Simple Economics of Easter Island: A Ricardo-Malthus Model of Renewable Resource Use. *The American Economic Review, 88*(1), 119-138.

Brennan, M. J., & Copeland, T. E. (1988). Stock splits, stock prices, and transaction costs. *Journal of Financial Economics, 22*(1), 83-101.

Bretsen, S., & Hill, P. (2006). Irrigation Institutions in the American West. *Journal of Environmental Law*, 283-331.

Bretsen, S., & Hill, P. (2009). Water Markets as a Tragedy of the Anticommons. *Willaim & Mary Environmental Lawand Policy Review*, 723-783.

Brewer, J., Glennon, R., Ker, A., & Libecap, G. D. (2007). Water Markets in the West: Prices, Trading, and Contractual Forms. *Economic Inquiry, 46*(2), 91-112.

Bromley, D. W. (1989a). *Economic Interests and Institutions: The Conceptual Foundations of Public Policy.* New York: Basil Blackwell.

Bromley, D. W. (1989b). Institutional change and economic efficiency. *Journal of Economic Issues, 23*(3), 735-759.

Bromley, D. W. (1991). *Environment and Economy: Property Rights and Public Policy.* Oxford, UK and Cambridge, MA: Blackwell.

Bromley, D. W. (1999). *The Management of Common Property Natural Resources: Some Conceptul and Operational Fallacies.* The World Bank. Washington DC: World Bank Discussion Paper 57.

Brown, F. L., Mars, C., Minnis, M., Smasal, S. A., Kennedy, D., & Urban, J. A. (1992). *Transfers of Water Use in New Mexico.* Albuquerque: New Mexico Water Resources Research Institute.

Brown, L. R., Kimmerer, W., & Brown, R. (2009). Managing Water to Protect Fish: A Review of California's Environmental Water Account, 2001–2005. *Environmental Management, 43*, 237-261.

Brown, T. C. (2006). Trends in Water Market Activity and Price in the Western United States. *Water Resources Research, 42*, 1-14.

Bruns, B. R., & Meinzen-Dick, R. S. (2001). Water Rights and Legal Pluralism: Four Contexts for Negotiation. *Natural Resources Forum, 25*, 1-10.

Buchanan, J. M., & Yoon, Y. J. (2000). Symmetric Tragedies: Commons and Anticommons. *Journal of Law and Economics, 43*(1), 1-13.

Buchanan, J., & Stubblebine, W. (1962). Externality. *Economica, 29*(116), 371-384.

Buchanan, J., & Tullock, G. (1962). *The Calculus of Consent: Logical Foundations of Constitutional Democracy*. Ann Arbor: University of Michigan Press.

Buchanan, J., & Yoon, Y. (2000). Symmetric Tragedies: Commons and Anticommons. *Journal of Law and Economics, 43*(1), 1-13.

Burness, M., & Quirk, J. (1979). Appropriative Water Rights and the Efficient Allocation of Resources. *The American Economic Review, 69*, 25-37.

Burness, M., & Quirk, J. (1980). Water Law, Water Transfers, and Economic Efficiency: The Colorado River. *The Journal of Law & Economics, 23*, 111-134.

Busemeyer, J., & Myung, I. (1992). An Adaptive Approach to Human Decision Making: Learning Theory, Decision Theory, and Human Performance. *ournal of Experimental Psychology: General, 121*(2), 177-194.

Calabresi, G. (1968). Transaction Costs, Resource Allocation, and Liability Rules: A Comment. *Journal of Law and Economics, 11*, 67-73.

Calabresi, G., & Melamed, A. (1972). Property Rules, Liability Rules, and Inalienability: One View of the Cathedral. *Harvard Law Review, 85*, 1089-1128.

Calvert, R. L. (1995). Rational Actors, Equilibrium, and Social Institutions. Dans J. Knight, & I. Sened, *Explaining Social Institutions* (pp. 57-94). Ann Arbor: University of Michigan Press.

Camerer, C. (2003). *Behavioral Game Theory: Experiments in Strategic Interaction.* Princeton: Princeton University Press.

Camic, C. (1986). The Matter of Habit. *American Journal of Sociology, 91*(5), 1039-1087.

Carey, H. C. (1858-59). *Principle of Social Science.* Philadelphia: J. B. Lippincott.

Carey, J. M., & Sunding, D. L. (2001). Emerging Markets in Water: A comparative Institutional Analysis of the Central VAlley and Colorado-Big-Thompson Project. *Natural Resources Journal, 41*, 283-328.

Carey, J. M., Sunding, D., & Zilberman, D. (2002). Transaction Costs and Trading Behavior in an Immature Water Market. *Environment and Development Economics, 7*(4), 733-750.

Carruthers, I., & Stoner, R. (1981). Economic Aspects and Policy Issues in Groundwater Development. *World Bank staff waorking paper*.

Caswell, M., & Zilbermann, D. (1985). The Choice of Irrigation Technologies in California. *American Journal of Agricultural Economics*, 224-234.

CDWR, C. D. (1951). *Water Resources of California.* Sacramento. Consulté le Jully 18, 2016, sur http://www.water.ca.gov/waterdatalibrary/docs/historic/Bulletins/Bulletin_1/Bulletin_1__1951.pdf

CDWR, C. D. (1963). *The California State Water Project in 1963.* Sacramento.

Chakravorty, U., Hochman, E., & Zilberman, D. (1995). A Spatial Model of Optimal Water Conveyance. *Journal of Environmental Economics and Management, 29*(1), 25-41.

Challen, R. (2000). *Institutions, Transaction Costs and Environmental Policy: Institutional Reform for Water Resources.* Cheltenham: Edward Elgar.

Chaney, T. (2014). The Network Structure of International Trade. *American Economic Review, 104*(11), 3600-3634.

Chaney, T. (2014). The Network Structure of International Trade. *The American Economic Review, 104*(11), 3600-3634.

Chayes, A. (1976). The Role of the Judge in Public Law Litigation. *Harvard Law Review, 89*, 1281-1284.

Cheung, S. (1969). Transaction Costs, Risk Aversion, and the Choice of Contractual Arrangements. *Journal of Law and Economics, 12*(1), 23-42.

Cheung, S. (1970). The Structure of a Contract and the Theory of a Non-Exclusive Resource. *Journal of Law and Economics, 13*(1), 49-70.

Cheung, S. (1998). The Transactions Costs Paradigm. *Economic Inquiry, 36*, 514-521.

Cheung, S. N. (1992). On the New Institutional Economics. Dans L. Werin, & H. Wijkander, *Contract Economics* (pp. 48-65). Oxford: Blackwell.

Chong, H., & Sunding, D. (2006). Water Markets and Trading. *Annual Review of Environment and Resources, 31*, 239-264.

Ciriacy-Wantrup, S. (1967). Water Policy and Economic Optimizing: Some Conceptual Problems in Water Research. *The American Economic Review, 57*, 179-189.

Clapham, J. (1922). On Empty Economic Boxes. *Economic Journal, 32*, 305-314.

Clark, A. (1997). Economic Reason: The Interplay of Individual Learning and External Structure. Dans J. Drobak, & J. Nye, *The Frontiers of the New Institutional Economics* (pp. 269-290). San Diego : Academic Press.

Clark, C. (1976). *Mathematical Bioeconomics*. New York: Wiley.

Clark, J. M. (1918). Economics and Modern Psychology, parts I and II. *Journal of Political Economics, 26*(1 and 2), 1-30 and 136-166.

Clyde, S. E. (1989). Adapting to the Changing Demand for Water Use Through Continued Refinement of the Prior Appropriation Doctrine: An Alternative Approach to Wholesale Reallocation. *Natural Resources Journal, 29*, 435-455.

Coase, R. (1960). The Problem of Social Cost. *Journal of Law and Economics*, 1-44.

Coase, R. (1988). *The Firm, the Market, and the Law*. Chicago: University of Chicago Press.

Coase, R. (1992). The Institutional Structure of Production. *American Economic Review, 82*(4), 713-719.

Coase, R. H. (1937). The Nature of the Firm. *Economica, 4*, 386-405.

Coeurdacier, N., & Martin, P. (2009). The Geography of Asset Trade and the Euro: Insiders and Outsiders. *Journal of Japanese and International Economics, 23*(2), 90-113.

Colby, B. G. (1989). Estimating the Value of Water in Alternative Uses. *Natural Resources Journal, 29*, 511-527.

Colby, B. G. (1990a). Enhancing Instream Flows in an Era of Water Marketing. *Water Resources Research, 26*(6), 1113-1120.

Colby, B. G. (1990b). Transaction Costs and Efficiency in Western Water Allocation. *American Journal of Agricutural Economics, 75*(5), 1184-1192.

Colby, B. G. (1995). Regulation, Imperfect Markets, and Transaction Costs: The Elusive Quest for Efficiency in Water Alloction. Dans D. W. Bromley, *The Handbook of Environmental Economics* (pp. 475-502). Cambridge: Blackwell.

Colby, B. G. (1998). Negotiated Transactions as Conflict Resolution Mechanisms: Water Bargaining in the U.S. West. Dans K. W. Easter, M. W. Rosegrant, & A. Dinar, *Markets for Water: Potential and Performance* (pp. 77-94). Dordrecht: Kluwer Academic Publisher.

Colby, B. G., McGinnis, A. M., Rait, K. A., & Wahl, R. W. (1989). *Transferring Water Rights in the Western States: A Comparison of Policies and Procedures*. University of Colorado School of Law: Natural Resource Law Center.

Colby, B. G., McGinnis, M. A., & Rait, K. A. (1991). Mitigating Environmental Externalities Through Voluntary and Involuntary Water Reallocation: Nevada's TruckeeCarson River Basin. *Natural Resources Journal, 31*, 757-783.

Colby, B. G., Saliba, B. C., & Bush, D. B. (1987). *Water Markets in Theory and Practice: Market Transfers, Water Values, and Public Policy*. Colorado: Westview Press.
Colby, B., Frisvold, G., & Mealy, M. (2015). Managing Climate Risks Through Water Trading. Dans H. R. Burnett K., *Routledge Handbook of Water Economics and Institutions* (pp. 236-250). London, UK and New York, USA: Routledge Taylor & Francis Group.
Coleman, J. S. (1990). *Foundation of Social Theory*. Cambridge: Belknap Press of Harvard University Press.
Colorado River Compact. (2016, Jully 15). *The Law of the River*. Récupéré sur US Bureau of Reclamation: http://www.usbr.gov/lc/region/g1000/pdfiles/crcompct.pdf
Coman, K. (1911). Some Unsettled Problems of Irrigation. *American Economic Review, 1*(1), 1-19.
Commons, J. ([1924] 1968). *Legal Foundation of Capitalism*. Madisson: University of Wisconsin Press.
Commons, J. (1921). Institutional Economics. *American Economic Review*, 648-657.
Commons, J. R. (1934). *Institutional Economics: Its Place in Political Economy. Vol. I.* New York: Macmillan.
Conslik, J. (1996). Why Bounded Rationality. *Journal of Economic Literature, 34*, 669-700.
Convention, L. I. (1885). *Address to the Legislature of the State of California, Twenty-sixth session.*
Cooter, R. (1982). The Cost of Coase. *Journal of Legal Studies, 11*, 1-33.
Cooter, R. D., & Ulen, T. S. (1996). *Law and Economics*. Reading: Addison-Wesley.
Copeland, B. R., & Taylor, M. S. (2009). Trade, Tragedy, and the Commons. *American Economic Review, 99*(3), 725-749.
Cropper, M., & Oates, W. (1992). Environmental Economics: A Survey. *Journal of Economic Literature, 30*(2), 675-740.
Culp, P., Glennon, R., & Libecap, G. (2014). Shopping for Water: How the Market Can Mitigate Water Shortages in the American West. *Discussion Paper for The Hamilton Project and Stanford Woods Institute for the Environment*.
Dahl, A. (1957). On the Concept of Power. *Behavioural Science, 2*(3), 201-215.
Dahl, A. (1973). *Polyarchy: Participation and Opposition*. Yale University Press.
Dahlman, C. (1979). The Problem of Externality. *Journal of Law and Economics, 22*, 141-162.
Dales, H. (1968). Land, Water, and Ownership. *The Canadian Journal of Economics, 4*, 791-804.
Dales, J. (1968). *Pollution, Property and Prices*. Toronto: University of Toronto Press .
Dasgupta, P., & Heal, G. (1979). *Economic Theory and Exhaustible Resources*. Cambridge: Cambridge University Press.
Davidson, P. (1991). Is Probability Theory Relevant for Uncertainty? A Post Keynesian Perspective. *Journal of Economic Perspectives, 5*(1), 129-143.
Davis, L., & North, D. (1970). Institutional change and American economic growth: a first step towards a theory of institutional innovation. *Journal of Economic History, 30*, 131-149.
Davis, P. N. (1968). Australian and American Water Allocation Systems Compared. *B.C.L. Rev., 9*, 647-710.
Deardorff, A. (1984). Testing Trade Theories and Predicting Trade Flows. Dans *Handbook of International Economics* (pp. 467-517). Elsevier.

Delbourg, E., & Dinar, S. (2016). Resource, The Globalization of Virtual Water Flows: Explaining Trade Patterns of a Scarce. *Working Paper*.

Dellapenna, J. W. (2013). The Myth of Markets for Water. Dans J. Maestru, *Water TRading and Global Water Scarcity: International Experiences* (pp. 199-213). Abingdon: Resources For the Future Press.

Demsetz, H. (1967). Toward a Theory of Property Rights. *American Economic Review*, 347-359.

Demsetz, H. (1968). Why Regulate Utilities? *Journal of Law and Economics, 11*(1), 55-65.

Demsetz, H. (1988). The Theory of the Firm Revisited. *Journal of Law, Economics, and Organization, 4*(1), 141-161.

Demsetz, H. (2011). The Problem of Social Cost: What Problem? A Critique of the Reasoning of A.C. Pigou and R.H. Coase. *Review of Law and Economics, 7*(1), 1-13.

Demstez, H. (1964). The Exchange and Enforcement of Property Rights. *Journal of Law and Economics, 7*, 11-26.

Denzau, A., & North, D. (2000). Shared Mental Models: Ideologies and Institutions. Dans A. Lupia, M. McCubbins, & S. Popkin, *Elements of Reason - Cognition, Choice, and the Bounds of Rationality* (pp. 23-46). Cambridge: Cambridge University Press.

Dessein, W., Galeotti, A., & Santos, T. (2016). Rational Inattention and Organizational Focus. *American Economic Review, 106*(6), 1522-1536.

Ditwiler, C. (1975). Water Problem and Property Rights: An Economic Perspective. *Natural Resources Journal*, 663-680.

Dowd, M. ([1956] 2012). *IID: The First 40 Years.* Consulté le July 17, 2016, sur http://www.iid.com/home/showdocument?id=6000

Dudley, N. J. (1992). Water Allocation by Markets, Common Property and Capacity Sharing: Companions or Competitors? *Natural Resources Journal, 32*, 757-778.

Durkheim, E. (1895 (1950)). *The Rules of Sociological Method.* New York: Free Press.

Easter, K. W., & McCann, L. M. (2010). Nested institutions and the need to improve international water institutions. *Water Policy, 12*(4), 500-516.

Easter, K. W., Dinar, A., & Rosegrant, W. M. (1998). Water Markets: Transaction Costs and Institutional Options. Dans K. W. Easter, W. M. Rosegrant, & A. Dinar, *Water Markets: Potential and Performance* (pp. 1-18). Springer US.

Easter, K., Rosegant, W. M., & Dinar, A. (1999). Formal and informal markets for water: institutions, performance and constraints. *World Bank Reseach Observer, 14*(1), 99-116.

Easton, D. (1953). *The Political System: An Inquiry into State of Political Science.* New York: Knopf, A. A.

Eaton, J., & Kortum, S. (2002). Technology, Geography, and Trade. *Econometrica, 70*(5), 1741-1779.

Eaton, J., & Tamura, A. (1994). Bilateralism and Regionalism in Japanese and U.S. Trade and Direct Foreign Investment Patterns. *Journal of the Japanese and International Economies, 8*(4), 478-510.

Eggertsson, T. (1990). *Economic Behavior and Institutions: Principles of Neoinstitutional Economics.* Cambridge: Cambridge University Press.

Eggertsson, T. (1994). Property Rights, Economic Analysis, and the Information Problem. *Working Paper*.

Eheart, J. W., Lyon, R. M., & C., W. B. (1983). *Alternative Structures for Water Rights Markets: Overview and Hypothetical Case Study*. University of Illinois, Urbana: Research Report 174, Water Resources Center.

Ehrenfield, D. (1972). *Conserving Life on Earth.* Oxford: Oxford University Press.

Eichengreen, B., & Irwin, D. A. (1995). Trade Blocs, Currency Blocs and the Reorientation of World Trade in the 1930s. *Journal of international economics, 38*, 1-24.

Ellis, H., & Fellner, W. (1943). External Economies and Diseconomies. *American Economic Review, 33*(3), 493-511.

Epstein, R. (1997). A Clear View of the Cathedral: The Dominance of Property Rules. *Yale Law Journal* , 2091.

Epstein, R. A. (2012). Playing by Different Rules? Property Rights in Land and Water. Dans D. H. Cole, & E. Ostrom, *Property in Land and other Resources* (pp. 317-355). Lincoln Institute of Land Policy.

Falkenmark, M., & Lindh, G. (1993). Water and Economic Development. Dans P. H. Gleick, *Water in Crisis: A Guide to the World's Fresh Water Resources.* New York: Oxford University Press.

Farrell, J. (1987). Information and the Coase Theorem. *Journal of Economic Perspectives, 1*(2), 112-129.

Feenstra, J. (2003). *Advanced International Trade Theory and Evidence.* Princeton: Princeton University Press.

Feiock, R. (2013). The Institutional Collective Action Framework. *Policies Studies Journal, 41*, 397-425.

Fennell, L. (2011). Commons, Anticommons, Semicommons. Dans K. Ayotte, & H. Smith, *Research Handbook on the Economics of Property Law* (pp. 35-56). Cheltenham, UK and Northampton, MA, USA: Edward Elgar.

Field, B. C. (1986). Induced Changed in Property Rights Institutions. *Research Paper, Amherst.*

Fine, G. (2008). Does Socrates Claim to Know that He Knows Nothing? *Oxford Studies in Ancient Philosophy, 35*, 49-88.

Flack, J. (1967). Meeting Future Water Requirements Through Reallocation. *Journal of the American Water Works Association, 59*, 1340-1350.

Flack, J. (1967). Meeting Future Water Requirements Through Reallocation. *Journal (American Water Works Association)*, 1340-1350.

Flinn, J., & Guise, J. (1970). An Application of Spatial Equilibrium Analysis to Water Resource Allocation. *Water Resource Research, 6*(2), 398-409.

Flowerdew, R., & Aitkin, M. (1982). A Method of Fitting the Gravity Model Based on Poisson Distribution. *Journal of regional Science, 22*, 191-202.

Freyfogle, E. (1989). Context and Accomodation in Modern Property Law. *Stanford Law Review*, 1529-1556.

Frohlich, N., & Oppenheimer, J. (2001). Choosing a Cognitive Model of Economic and Political Choice. *Working Paper.*

Fuller, L. (1978). The Forms and Limits of Adjudication. *Harvard Law Review, 92*, 353-409.

Furubotn, G. E., & Richter, R. (2000). *Institutions and Economic Theory: The Contribution of the New Institutional Economics.* Ann Arbor: University of Michigan Press.

Gaffney, M. (1961). Diseconomies Inherent in Western Water Laws: A California Case Study. *Economic Analysis of Multiple Use*, 52-82.

Gaffney, M. (1962). Water Law and Economic Transfers of Water: A Reply. *American Journal of Agricultural Economics, 44*, 427-434.

Gardner, B. D. (1983). Water Pricing and Rent Seeking in California Agriculture. Dans W. Rights, *Anderson, T. L.* Cambridge: Ballinger Publishing Co.

Gardner, B. D. (1985). Institutional Impediments to Efficient Water Allocation. *Review of Policy Research, 5*(2), 353–363.

Gardner, B., & Fullerton, H. (1968). Transfer Restrictions and Misallocations of Irrigation Water. *American Journal of Agricultural Economics, 50*, 556-571.

Garner, E. L., & Willis, J. N. (2005). Right Back Where We Started From: The Last Twenty-Five Years of Groundwater Law in California. *McGeorge Law Review, 36*(2), 413.

Garrick, D. E. (2015). *Water Allocation in River under Presure.* Cheltenham: Edward Elgar.

Geraci, V. J., & Prewo, W. (1977). Billateral Trade Flows and Trnasport Costs. *Review of Economics and Statistics, 59*, 67-74.

Getches, D. (1997). *Water Law in a Nut Shell.* St. Paul: West Publishing Co.

Ghimire, N., & Griffin, R. C. (2014). The Water Transfer Effects of Alternative Irrigation Institutions. *American Journal of Agricultural Economics, 96*(4), 970-990.

Gisser, M., & Johnson, R. (1983). Institutional Restrictions on the Transfer of Water Rightsand the Survival of an Agency. Dans T. Anderson, *Water Rights: Scarce Resource Allocation, Bureaucracy and the Environment.*

Gode, D. K., & Sunder, S. (1997). What Makes Markets Allocationally Efficient? *Quaterly Journal of Economics, 112*(2), 603-630.

Goodhue, R. E., Sayre, S. S., & Simon, L. K. (2012). The Sacramento-San Joaquin Delta and the Political Economy of California Water Allocation. Dans B. D. Gardner, & R. T. Simmons, *Aquanomics: Water Markets and the Environment* (pp. 281-320). Oakland: The Independent Institute.

Gordon, H. (1954). The Economic Theory of a Common Property Resource: The Fishery. *Journal of Political Economy*, 124-142.

Gordon, R. (1994). *Regulation and Economic Analysis: A Critic Over Two Centuries.* Kluwer Academy.

Gould, G. (1995). Recent Developments in the Transfers of Wter Rights. Dans M. Carr, & J. Crammond, *Water Law: Trends, Policies, and Practices* (pp. 93-103). Chicago: American Bar Association.

Gould, G. A. (1989). Transfer of Water Rights. *Natural Resources Journal, 29*, 457-477.

Gould, G. A. (1998). Water Rights Transfers and Third-Party Effects. *Land and Water Law Review*.

Grafton, R. (2000). Governance of the Commons: A Role for the State? *Land Economics, 76*(4), 504-517.

Granovetter, M. (1985). Economic Action, Social Structure, and Embeddedness. *American Journal of Sociology, 91*(3), 481-510.

Gray, B. (1989). A Primer on California Water Transfer Law,. *Arizona Law Review, 31*, 745-781.

Gray, B. E. (1989). A Primer on California Water Transfer Law. *Arizona Law Review, 31*, 745-781.

Grief, A. (1994). Cultural Beliefs and the Organization of Society: Historical and Theoretical Reflection on Collectivist and Individualist Societies. *Journal of Political Economy*(102), 912-950.

Grief, A. (2006). *Institutions and the Path to the Modern Theory*. Cambridge: Cambridge University Press.

Griffin, R. (1991). The Welfare Analytics of Transaction Costs, Externalities and Institutional Choice. *American Journal of Agricultural Economics*, 601-614.

Griffin, R. (2016). *Water Resource Economics: The Analysis of Scarcity, Policies, and Projects*. Cambridge: MIT Press.

Griffin, R. C., & Boadu, F. O. (1992). Water Marketing in Texas: Opportunities for Reform. *Natural Resources Journal, 32*, 265-288.

Griffin, R., Peck, D., & Maestru, J. (2013). *Water Trading and Global Water Scarcity*. (J. Maestru, Éd.) Abington: RFF press.

Haan de, E. J. (1997). Balancing Free Trade in Water and the Protection of Water Resources in GATT. Dans E. H. Brans, E. J. Haan, A. Nollkaemper, & J. Rinzema, *The Scarcity of Water: Emerging Legal and Policy Responses* (pp. 245-259). Berlin: Springer.

Hadaad, B. M. (2000). *Rivers of Gold: Designing Markets To Allocate Water In California*. Washington, D.C.: Island Press.

Hamilton, J. R., Whittlesey, N. K., & Halverson, P. (1989). Interruptible Water Markets in the Pacific Northwest. *American Journal of Agricultural Economics, 71*, 63-75.

Hamilton, W. H. (1932). Institution. Dans *Encyclopedia of the Social Sciences. Vol. 8* (pp. 84-89). New York: Macmillan.

Hanak, E. (2003). *Who Should Be Allowed to Sell Water in California? Third-Party Issues and the Water Markets*. Sacramento: Public Policy Institute of California.

Hanak, E. (2005). Stopping the Drain: Third-Party Responses to California's Water Markets. *Contemporary Economic Policy*, 59-77.

Hanak, E. (2015). A CAlifornia Postcard: Lessons for a Maturing Water Market. Dans K. Burnett, R. Howitt, J. A. Roumasset, & C. A. Wada, *Routledge Handbook of Water Economics and Institutions* (pp. 253-280). Abingdon: Routledge.

Hanak, E., & Dyckman, C. (2003). Counties Wresting Control: Local Responses to California's Statewide Water Market. *University of Denver Water Law Review, 6*(2), 490-518.

Hanak, E., & Stryjewski, E. (2012). *California's Water Market, By the Numbers, Update 2012*. San Francisco: Public Policy Institute of California.

Hanemann, H. W. (2006). The Economic Conception of Water. Dans P. P. Rogers, M. R. Llamas, & L. Martinez-Cortina, *Water Crisis : Myth or Reality?* (pp. 61-91). London; New York: Taylor & Francis.

Hansen, K., Howitt, R. E., & Williams, J. (2015). An Econometric Test of Water Market Structure in the Western United States. *Natural Resource Journal, 55*, 127.

Hardin, G. (1968). The Tragedy of the Commons. *Science, 162*, 1243-1248.

Hardin, G. (1978). Political Requirement for Preserving our Common Heritage. Dans H. Bokaw, *Wildlife and America* (pp. 310-317). Washington DC: Concil of Environmental Quality.

Harding, S. (1936). *Water Rights for Irrigation*. Stanford, CA: Stanford University Press.

Hartman, L., & Seaston, D. (1970). *Water Transfers Economic Efficiency and Alternative Institutions*. Baltimore, US and London, UK: The Johns Hopkins Press.

Hayek, F. A. (1945). The Use of Knowledge in Society. *American Economic Review, 35*(4), 519-530.

Hayek, F. A. (1976). *Law Legislation and Liberty. Vol. 2.* Chicago: University of Chicago Press.

Hayek, F. A. (1982). *Law, Legislation and Liberty, Vol. I.* London: Routledge and Kegan Paul.

Hayek, F. A. (s.d.). Notes on the Evolution of Systems of Rules of Conduct. Dans *Studies in Phylosophy, Politics, and Economics.* Chicago: University of Chicago Press .

Head, K., & Mayer, T. (2014). Gravity Equations: Workhorse,Toolkit, and Cookbook. Dans G. Gopinath, E. Helpman, & K. Rogoff, *Handbook of International Economics* (pp. 131-195). Elsevier.

Heiner, R. (1983). The Origin of Predictable Behavior. *American Economic Review, 73*(4), 560-595.

Heller, M. (1998). "The Tragedy of the Anticommons: Property in the Transition from Marx to Market. *Harvard Law Review, 111*, 621-688.

Heller, M. A. (1998). The Tragedy of the Anticommons: Property in the Transition from Marx to Market. *Harvard Law Review, 111*(3), 621-688.

Heller, W., & Starrett, D. (1976). On the nature of externalities. Dans S. Lin, *Theory and Measurement of Economic Externalities* (pp. 9-22). New York: Academic Press.

Heller, W., & Starrett, D. (1976). On the Nature of Externalities. Dans A. Steven, *Theory and Measurement of Economic Externalities.* New York: Academic Press.

Helpman, E., Melitz, M., & Rubinstein, Y. (2008). Estimating Trade Flows: Trading Partners and Trading Volumes. *Quarterly Journal of Economics, 123*(2), 441-487.

Hirshleifer, J. (1973). Exchange Theory - The Missing Chapter. *Economic Inquiry, 11*(2), 129-146.

Hirshleifer, J. (1977). Economics from a Biological Viewpoint. *Journal of Law and Eonomics, 20*, 1-54.

Hirshleifer, J. (1989). Conflict and rent-seeking success functions: Ratio vs difference models of relative success. *Public Choice, 63*(3), 101-112.

Hirshleifer, J., De Haven, J. C., & Milliman, J. W. (1960). *Water Supply: Economics, Technology and Policy.* University of Chicago Press.

Hodgson, G. M. (1988). *Economics and Institutions: A Manifesto for a Modern Institutional Economics.* Cambridge: Polity Press.

Hodgson, G. M. (1997). The Ubiquity of Habits and Rules. *Cambridge Journal of Economics, 21*, 663-684.

Hodgson, G. M. (1998). The Approach of Institutional Economics. *Journal of Economic Literature, 36*, 166-192.

Hodgson, G. M. (2000). What Is the Essence of Institutional Economics? *Journal of Economic Issues, 34*(2), 317-329.

Hodgson, G. M. (2004). *The Evolution of Institutional Economic: Agency, Structure, and Darwinism in American Institutionalism.* London: Routledge.

Hoffman, A. (1981). *Vision or Villain: Origins of the Owens Valley-Los Angeles Water Controversy.* College Station: Texas A&M University Press.

Hohfeld, W. (1913). Some Fundamental Legal Conception as Applied in Judicial Reasonning. *Yale Law Journal, 23*, 16-59.

Holland, J. (2012). Modesto Irrigation District Kills Proposed Water Sale. *Modesto Bee.*

Holland, J., Holyoak, K., Nisbett, R., & Thagard, P. (1986). *Induction: Processes of inference, learning and discovery*. Cambridge: Bradford Books/MIT Press.

Hollinshead, S. P. (2008). Water Is Not Liquid: Securitization, Transactions Costs, and California's Water Market. *Columbia Journal of Environmental Law, 33*, 323-366.

Holme, H. (1985). Interstate Transfers of Water: Many a Slip 'Twixt the Cup and the Lip". *Colorado Water Issues and Options: The 90's and Beyond: Toward Maximum Beneficial Use of Colorado's Water Resources (October 8).*

Hornbeck, R. (2010). Barbed Wire: Property Rights and Agricultural Development. *The Quarterly Journal of Economics, 125*(2), 767-810.

Horowitz, D. (1977). *The Courts and Social Policy*. Washington, DC: Brookings Institution Press.

Howe, C. (1986). Innovative Approaches to Water Allocation: The Potential for Water Markets. *Western Water: Expanding Uses/Finite Supplies (Summer Conference, June 2-4).*

Howe, C. W. (1998). Water Market in Colorado: Past Performance and Nedded Changes. Dans K. W. Easter, M. W. Rosegrant, & A. Dinar, *Markets for Water: Potential and Performance* (pp. 65-76). Norwell: Kluwer Academic Publisher.

Howe, C. W., & Goemans, C. (2003). Water transfers and their impacts: lessons from three Colorado water markets. *Journal of the American Water Resources Association, 39*, 1055-1065.

Howe, C. W., Alexander, P. K., & Moses, R. J. (1982). The Performance of Appropriative Water Rights Systems During Drought. *Natural Resources Journal, 22*, 379-389.

Howitt, R. (2015). Water Scarcity and the Demand for Water Markets. *in the Routlege Handbook of Water Economics and Institutions. (eds) Burnett K., Howitt R., Roumasset J.A. and Wada C.A.*, 30-39.

Howitt, R. E. (1994). Empirical Analysis of Water Market Institutions: The 1991 California Water Market. *Resource and Energy Economics, 16*, 357-371.

Howitt, R. E. (1995). Malleable Property Rights and Smooth Pasting Conditions. *American Journal of Agricultural Economics, 77*, 1192-1198.

Howitt, R. E. (1998). Spot Prices, Option Prices, and Water MArkets: An Analysis of Emerging Markets in California. Dans K. W. Easter, M. W. Rosegrant, & A. Dinar, *Markets for Water: Potential and Performance* (pp. 119-140). Dordrecht: Kluwer Academic Publishers.

Howitt, R. E. (2002). Drought, Strife, and Institutional Change. *Western Economics Forum, 1*, 11-14.

Howitt, R. E. (2014). Are Lease Water Markets Still Emerging in California? Dans K. W. Easter, & Q. Huang, *Water Markets for the 21st Century: What Have We Learned?* (pp. 83-102). Dordrecht: Springer.

Howitt, R. E., Medellin-Azuara, J., MacEwan, D., Lund, J. R., & Sumner, D. A. (2014). *Economic Analysis of the 2014 Drought for California Agriculture.* Center for Watershed Sciences, University of California, Davis, California. Récupéré sur http://watershed.ucdavis.edu

Huffman, J. L. (2012). The Evolving Public Trust Doctrine: An Obstacle to Water Marketing. Dans B. D. Gardner, & R. T. Simmons, *Aquanomics: Water Markets and the Environment* (pp. 183-208). Oakland: The Independent Institute.

Hutchins, W. (1942). *Selected Problems of the Law of Water Rights in the West.* Washington DC: United States Department of Agricuture.

Ingram, H. M. (1973). The Political Economy of Regional Water Institutions. *American Journal of Agricultural Economics, 55*(1), 10-18.

Isard, W., & Peck, M. (1954). Location Theory and International and Interregional Trade Theory. *Quaterly Journal of Economics, 68*(1), 97-114.

Israel, M., & Lund, J. R. (1995). Recent California Water Transfers: Inplications for Water Management. *Natural Resources Journal, 35*(1), 1-32.

Jandoc, K., Howitt, R., Roumasset, J., & Wada, C. (2015). Institutions for Managing Ground and Surface Water and the Theory of the Second Best. Dans K. Burnett, R. Howitt, J. Roumasset, & W. C.A., *Routledge Handbook of Water Economics and Institutions* (pp. 165-180). NY: Routledge.

Jenkins, M. (1992). *Yolo County, California's Water Supply System: Conjunctive Use Without Management.* University of California, Davis: Department of Civil and Environmental Engineering.

Johnson, D. (1971). An Optimal State Water Law: Fixed Water Rights and Flexible Market Prices. *Virginia Law Review, 57*, 345-374.

Johnson, N. K., & DuMars, C. T. (1989). A Survey of the Evolution of Western Water Law in Response to Changing Economic and Public Interest Demands. *Natural Resources Journal, 29*, 347-387.

Johnson, N. L. (2007). Property Without Possession. *Yale Journal on Regulation, 24*(2), 205-251.

Johnson, O. (1972). Economic Analysis, the Legal Framework and Land Tenure System. *Journal of Law and Economics, 15*, 259-276.

Johnson, R., Gisser, M., & Werner, M. (1981). The Definition of a Surface Water Rights and Transferability. *Journal of Law and Economics, 27*(1), 159-185.

Kanasawa, M. (2010). The Extralegal Origins of First Possession: Water Law During the California Gold Rush. *Unpublished*.

Kanazawa, M. (1998). Efficiency in Western Water Law: The Development of the California Doctrine, 1850-1911. *The Journal of Legal Studies* , 159-185.

Kanazawa, M. (2015). *Golden Rules: The Origins of California Water Law in the Gold Rush.* Chicago: University of Chicago Press.

Katz, D. (2013). Cash Flows: Markets for Environmental Flow Allocations. Dans W. T. Experiences, *Maestru, J.* (pp. 214-232). Abingdon: Resources For the Futur Press.

Kelso, M. (1967). The Water-Is-Different Syndrome or What Is Wrong With the Water Industry. *Paper presented to the American Water Resources Association*, (pp. 176-183). San Francisco.

Keynes, J. M. (1936). *The General Theory of Employment, Interest and Money*. London: Macmillan.

Keynes, J. M. (1973). *The General Theory and After: Defence and Development, The Collected Writtings of John Maynard Keynes* (Vol. 14). London: Macmillan.

Kimmich, C. (2013). Linking Action Situations: Coordination, Conflicts, and Evolution in Electricity Provision for Irrigation in Andhra Predesh, India. *Ecological Economics, 90*, 150-158.

King, G. (1988). Statistical Models for Political Science Event Counts: Bias in Conventional Procedures and Evidence for the Exponential Poison Regression Model. *American Journal of Political Sciences, 32*, 839-863.

Kiser, L. L., & Ostrom, E. (1982). The Three Worlds of Action: A Metatheoretical Synthesis of Institutional Appraches. Dans E. Ostrom, *Strategies of Political Inquiry.* Beverly Hills: Sage.

Knight, F. (1924). Some Fallacies in the Interpretation of Social Cost. *Quaterly Journal of Economics, 38*, 582-606.

Knight, F. (1965). *Freedom and Reform: Essays in Economics and Social Philosophy.* New York: Harper and Row.

Knight, J. (1921). *Risk, Uncertainty, and Profit.* New York: Houghton Mifflin and Co.

Knight, J. (1992). *Institutions and Social Conflict.* Cambridge: Cambridge University Press.

Know, A., & Meinzen-Dick, R. (2001). Collective Action, Property Rights, and Devolution of Forest and Protected Area Management. Dans A. Know, R. Meinzen-Dick, & M. DiGregorio, *Collective Action, Property Rights, and Devolution of Natural Rsource Management* (pp. 41-74). Feldafing: Deutsche Stiftung für Internationale Entwicklüng.

Knutson, C. L. (2013). Managing Water Stress, Drought and Climate Change in the Twenty-First Century. Dans J. Maestru, *Water Trading and Global Water Scarcity* (pp. 20-37). Abington: Resources for the Future Press.

Kreps, D. M. (1990). Corporate Culture and Economic Theory. Dans J. E. Alt, & K. A. Shepsle, *Perspective on Positive Political Economy* (pp. 121-155). Cambridge: Cambridge University Press.

Krieger, J. (1955). Progress in Ground Water Replenishment in Southern California. *Journal of the American Water Works Association, 47*, 909-913.

Krugman, P. (1997). *Development, Geography, and Economic Theory.* MIT Press.

Lach, D., Ingram, H., & Rayner, S. (2005). Maintening the Status Quo: How Institutional Norms and Practices Create Concervative Water Organizations. *Texas Law Review, 83*, 2027-2053.

Laffont, J. (1988). *Fundamentals of Public Economics.* Cambridge: MIT Press.

Laplace, P. S. (1902 [1814]). *A Philosophical Essay on Probabilities.* (F. W. Truscott, & F. L. Emory, Trads.) New York: John Wiley & Sons.

Leamer, E., & Levinsohn, J. (1995). International Trade Theory: The Evidence. Dans *Handbook of International Economics* (pp. 1339-1394).

Levi, M. (1988). *Of Rule and Revenue.* Berkeley: University of California Press.

Levin, J., & Nalebuff, B. (1995). An Introduction to Vote-CountingSchemes. *Journal of Economic Perspectives*, 3-26.

Libecap, G. D. (1989). *Contracting for Property Rights.* New York: Cambridge University Press.

Libecap, G. D. (1989a). Distributional Issues in Contracting for Property Rights. *Journal of Institutional and Theoretical Economics, 145*, 6-24.

Libecap, G. D. (2011). Institutional Path Dependence in Climate Adaptation: Comment, Some Unsettled Problems of Irrigation. *American Economic Review*, 64-80.

Libecap, G. D. (2012). Water Rights and Markets in the U.S. Semi-Arid West: Efficiency and Equity Issues. *The Evolution of Property Rights Related to Land and Natural Resources, Property in Land and Other Resources, Edited by Daniel H. Cole & Elinor Ostrom*.

Libecap, G. D. (2015). Water Sales, Pecuniary Externalities and Local Development: Chinatown Revisited. Dans K. Burnett, R. Howitt, J. A. Roumasset, & C. A. Wada, *Routledge Handbook of Water Economics and Institutions* (pp. 325-340). Abingdon: Routledge.

Linnemann, H. (1966). *An Econometric Study of International Trade Flows.* Amsterdam.

Littleboy, B. (1990). *On Interpreting Keynes: A Study in Reconciliation.* London: Routledge and Kegan Paul.

Livingston, M. L. (1995). Designing Water Institutions: Market Failures and Institutional Response. *Water Resources Management, 9*, 203-220.

Livingston, M. L. (1998). Institutional Requisites for Efficient Water Markets. Dans W. K. Easter, M. W. Rosegrant, & A. Dinar, *Markets for Water, Potential and Performance* (pp. 19-33). Dordrecht: Kluwen Academic.

Lucas, R. (1981). Tobin and Monetarism: A review Article. *Journal of Economic Literature, 19*(2), 558-567.

Lueck, D. (1995). The Rule of First Possession and the Design of the Law. *Journal of Law and Economic, 38*(2), 393-436.

Lukes, S. (1974). *Power: A Radical View.* Palgrave.

Lund, J. R. (1993). Transaction Risk Versus Transaction Costs in Water Transfers. *Water Resources Research, 29*(9), 3103–3107.

Lund, J. R., Hanak, E., Fleenor, W. E., Mount, J. F., Howitt, R., Bennett, B., & Moyle, P. B. (2010). *Comparing Futures for the Sacramento San Joaquin Delta.* Berkeley: University of California Press and Public Policy Institute of California.

Lund, J., Hanak, E., Fleenor, W., Howitt, R., Mount, J., & Moyle, P. (2007). *Envisioning Futures for the Sacramento–San Joaquin Delta.* San Francisco: Policy Institute of California.

MacKenzie, I., & Ohndorf, M. (2016). Coasean bargaining in the presence of Pigouvian taxation. *Journal of Environmental Economics and Management, 75*, 1-11.

Maestru, J. (2013). *Water Trading and Global Water Scarcity: International Experiences.* New York: Resources For the Future Press.

Makowski, L., & Ostroy, M. (2001). Perfect Competition and the Creativity of the Market. *Journal of Economic Literature, 39*, 479-535.

Manski, C. F. (1996). Treatment unde Ambiguity. *Sant Fe Institute Working Paper No. 96-10-078.*

March, G. J., & Olsen, J. P. (1989). *Rediscovering Institution: The Organizational Basis of Politics.* . New York: Free Press.

March, J. G., & Olson, J. P. (1989). *Rediscovering Institutions: The Organizational Basis of Policies.* New York: Free Press.

March, J. G., & Simon, H. A. (1958). *Organizations.* New York: Wiley.

Marshal, G. (2005). *Economics for Collaborative Environmental Management.* Abington: Routledge.

Marshall, A. (1890). *Principles of Economics.* London: Mcmillan.

Martin, P., & Rey, H. (2004). Financial Super-Markets: Size Matters for Asset Trade. *Journal of International Economics, 64*(2), 335-361.

McCallum, J. (1995). National Borders Matter: Canada-US Regional Trade Patterns. *American Economic Review, 85*(3), 615-623.

McCann, L., & Easter, K. (2004). A FRamework for Estimating the Transaction costs of Alternative Mechanisms for Water Exhange and Allocation. *Water Resources Research, 40*(W09S09), 1-6.

McCann, L., & Garrick, D. (2014). Transaction Costs and Policy Design for Water Markets. Dans K. W. Easter, & Q. Huang, *Water Markets for the 21st Century: What Have We Learned?* (pp. 11-34). Dordrecht: Springer Netherlands.

McCann, L., Colby, B., Easter, K. W., Kasterine, A., & Kuperan, K. V. (2005). Transaction cost measurement for evaluating environmental policies. *Ecological Economics, 52*, 527-542.

McGinnis, M. (1999). *Polycentricity and Local Public: Readings from the Workshop in Political Theory and Policy Analysis.* Ann Arbor: University of Michigan Press.

Meade, D. (1973). Meade, Bees, and Externalities. *Journal of Law and Economics, 16*(1), 35-52.

Meade, J. (1952). External Economies and Diseconomies in a Competitive Situation. *The Economic Journal, 62*(245), 54-67.

Medema, S. G. (2011). A Case of Mistaken Identity: George Stigler, the 'Problem of Social Cost', and the Coase Theorem. *European Journal of Law and Economics, 31*, 11-38.

Medema, S. G., & Zerbe Jr., R. O. (2000). The Coase Theorem. Dans B. Bouckaert, & G. De Geest, *Encyclopedia of Law and Economics* (pp. 836-892). Cheltenham: Edward Elgar.

Meinzen-Dick. (2007). Beyond Panaceas in Water Institutions. *The National Academy of Sciences of the USA, 104*(39), 15200-15205.

Melitz, J. (2003). Language and Foreign Trade. *Working Paper*.

Michelman, F. (1982). "Ethics, Economics and the Law of Property. Dans J. R. Chapman, *In Nomos XXIV: Ethics, Economics and the Law*. New York: NYU Press.

Milliman, J. (1959). Water Law and Private Decision Making: A critique. *Journal of Law and Economics, 2*, 41-63.

Milly, P. C., Betancourt, D. J., Falkenmark, M., Hirsh, M., Kundzewics, Z. W., Lettenmaier, D. P., & Stouffer, R. J. (2008). Stationarity Is Dead: With Water Management. *Science, 319*, 573-574.

Mishan, E. (1965). Reflections on Recent Developments in the Concept of External Effects. *Canadian Journal of Economics and Political Science / Revue canadienned'Economique et de Science politique, 31*(1), 3-34.

Mishan, J. (1971). The Postwar Literature on Externalties: An Interpretive Essay. *Journal of Economic Literature, 9*(1), 1-28.

Moore, M. R. (1986). *Economic Approaches to Western Surface Water Allocation.* Ann Arbor: Ph.D. diss. University of Michigan.

Moyle, P. B., & Bennett, W. A. (2008). *The Future of the Delta Ecosystem and Its Fish.* San Francisco: Public Policy Institute of California.

Msangi, S., & Howitt, R. E. (2007). Income Distributional Effects of Using Market-based Instruments for Managing Common Property Resources. *Agricultural Economics, 37*(1), 249-259.

Musgrave, R. (1959). *The Theory of Public Finance: A Study in Public Economy.* New York: McGraw-Hill.

Myles, G. (1995). *Public Economics.* Cambridge: Cambridge Press University.

Negri, D. (1989). The Common Property Aquifer as a Differential Game. *Water Resources Research, 25*, 9-15.

Nelson, A., & Winter, S. G. (1974). Neoclassical Versus Evolutionary Theories of Eonomic Growth. *Economic Journal, 84*, 886-905.

Nelson, A., & Winter, S. G. (1982). *An Evolutionary Theory of Economic Capabilities and Behavior.* Cambridge: Harvard University Press.

Nelson, R. R. (1994). The Co-evolution of Technology, Industrial Structure and Supporting Institutions. *Industrial and Corporate Change, 3*, 47-63.

Nicholson, W. (1995). *Imicroeconomics Theory: Basic Principles and Extensions.* Fort Worth: Dryden Press.
Niehans, J. (1987). Transaction Costs. Dans J. Eatwell, M. Milgate, & P. Newman, *The New Palgrave: A Dictionary of Economics* (pp. 676-679). London.
North, D. (1990). *Institutions, Institutional Change and Economic Performance.* Cambridge, UK: Cambridge University Press.
North, D. (1999). In Anticipation of the Marriage of Political and Economic Theory. Dans J. E. Alt, M. Levi, & E. Ostrom, *Competition and Cooperation: Conversatios with Nobelists About Economics* (pp. 314-317). New York: Russell Sage Foundation.
North, D. C. (1992). Transaction Costs, Institutions, and Economic Performance. *An International Center for Economic Growth Publication*.
North, D. C. (2005). *Understanding the Process of Economic Change.* Princeton: Princeton University Press.
North, D. C., & R., W. (1989). Constitutions and Commitment: The Evolution of Institutions Governing Public Choice in Seventeenth-Century England. *Journal of Economic History, 49*(4), 803-832.
Null, S., Bartolomeo, E., Lund, J., & E., H. (2011). *Managing California's Water: Insights from Interviews with Water Policy Experts.".* Sacramento: Public Policy Institute of California.
Nunn, S. C., & Ingram, H. M. (1988). Information, the Decision Forum, and Third-Party Effects in Water Transfers. *Water Resources Research, 24*, 473-480.
Oakerson, R., & Parks, R. (2011). The Study of Local Public Economies: Creating the Civic Metropolis. *Policy Studies Journal, 39*, 147-167.
Okawa, Y., & Wincoop, E. (2012). Gravity in International Finance. *Journal of International Economics, 87*(2), 205-215.
Olievera de, A. C., Croson, R. T., & Eckel, C. (2009). Are Preferences Stable Across Domains? An Experimental Investigation of Social Preferences in the Field. *CBEES XWorking Paper*.
Olson, M. (1965). *The Logic of Collective Action: Public Goods and the Theory of Groups* . Cambridge: Harvard University Press.
Ophuls, W. (1973). Leviathan or Oblivion. Dans H. Daly, *Toward a Steady State Economy* (pp. 215-230). San Francisco: Freeman.
Ostrom, E. (1972). Metropolitan Reform: Propositions Derived from Two Traditions. *Social Science Quaterly, 53*, 474-493.
Ostrom, E. (2005). *Understanding Institutional Diversity.* Princeton US: Princeton University Press.
Ostrom, E. (2010). Beyond Markets and States: Polycentric Governance of Complex Economic Systems. *American Economic Review, 100*(3), 641-672.
Ostrom, E. (2011). Reflection on "Some Unsettled Problem of Irrigation". *American Economic Review, 101*(1), 49-63.
Ostrom, E., Gardner, R., & Walker, J. (1994). *Rules, Games and Common Pool Resources.* Ann Harbor: University of Mchigan Press.
Ostrom, V. (1953). *Water and Politics: A Study of Water Policies and Administration in the Development of Los Angeles.* Los Angeles: Haynes Foundation.
Ostrom, V. (1976). John R. Common's Foundations for Policy Analysis. *Journal of Economic Issues, 10*, 839-857.

Ostrom, V. (1986). AFallabilist's Approach to Norms and Criteria of Choice. Dans F. Kaufmann, G. Majone, & V. Ostrom, *Guidance, Control, and Evaluation in the Public Sector* (pp. 229-244). Berlin: Walter de Gruyter.

Ostrom, V. (1997). *The Meaning of Democracy and the Vulnerability of Democracies: A REsponse to Tcqeville's Challenge.* Ann Harbor: University of Michigan Press.

Ostrom, V. (1999). Polycentricity (Part1). Dans M. D. McGinnis, *Polycentricity and Local Public Economies: Readings from the Workshop in Political Theory and Policy Analysis* (pp. 52-74). University of Michigan Press.

Ostrom, V., & Ostrom, E. (1977). Public Goods and Public Choibces. Dans E. S. Savas, *Alternatives for Delivering Public Services: Toward Improved Performance* (pp. 7-49). Boulder: Westview Press.

Ostrom, V., Tiebout, C. M., & Warren, R. (1961). The Organization of Government in Metropolitan Areas: A Theoretical Inquiry. *American Political Science Review, 55*(4), 831-842.

Ouchi, W. G. (1980). Markets, Bureaucraties, and Clans. *Administrative Science Quaterly, 25*, 129-141.

Papendreou, A. (1994). *Externality and Institutions.* Clarendon Press.

Phelps, C., Moore, N., & Graubard, M. (1978). *Efficient Water Use in California Water Rights, Water Districts, and Water Transfers.* Santa Monica US: RAND.

Pigou, A. (1932). *The Economics of Welfare.* London: Macmillan and Co.

Pisani, D. (1992). *To Reclaim a Divided West: Water, Law , and Public Policy.* Albuquerque: University of New Mexico Press.

Polanyi, M. (1951). *The Logic of Liberty.* Chicago, IL: University of Chicago Press.

Polanyi, M. (1967). *The Tacit Dimension.* London: Routledge and Kegan Paul.

Polanyi, M., Ziman, J., & Fuller, S. (2000). The Republic of Science: Its Political and EConomic Theory. *Minerva, 38*(1), 1-32.

Poot, J., Alimi, O., Cameron, M. P., & Maré, D. C. (2016). The Gravity Model of Migration: The Successful Comeback of an Ageing Superstar in Regional Science. *Discussion Paper No. 10329, October*.

Portes, R., & Rey, H. (2005). The Determinants of Cross-Border Equity Transaction Flows. *Journal of International Economics, 65*, 269-296.

Portes, R., Rey, H., & Oh, Y. (2001). Information and Capital Flows: The Determinants of Transactions in Financial Assets. *European Economic Review, 45*, 783-796.

Posner, K. (1961). *The Poverty of Historicism.* New York: Harper & Row.

Pöyhönen, P. (1963). A Tentative Model for the Volume of Trade between Countries. *Weltwirtschaftliches Archiv*, 93-100.

Prewo, W. (1978). Determinants of the Trade Pattern among OCDE Countries from 1958 to 1974. *Jahrebucher für Nationalekonomie und Statistik*, 341-358.

Pulliainen, K. (1963). A World Trade Study: An Econometric Model of the Pattern of the Commodity Flows of International Trade in 1948-60. *Economiska Samfundets Tidskrif, 16*, 78-91.

Radnitzky, G. (1987). Cost-Benefit Thinking in Methodology of Research: The "Economic Approach" Applied to Key Problem of the Phylosophy of Science. Dans G. Radnitzky, & P. Bernholz, *Economic Imperialism. The Economic Approach Applied Outside the Field of Economics* (pp. 283-331). New York: Paragon House.

Rauch, J. (1999). Networks versus Markets in International Trade. *Journal of International Economics, 48*(1), 7-35.

Rauch, J. E., & Casella, A. (2003). Overcoming Informational Barriers to International Resource Allocation: Prices and Ties. *The Economic Journal, 113*(484), 21-42.

Rauch, J. E., & Trindade, V. (2003). Information, International Substitutability, and Globalization. *The American Economic Review, 93*(3), 775-791.

Rauch, J. E., & V., T. (2002). Ethnic Chinese Networks in International Trade.". *Review of Economics and Statistics, 84*(1), 116-130.

Ravenstein, E. (1885). The laws of migration, Part 1. *Journal of the Royal Statistical Society, 48*(2), 167-235.

Ravenstein, E. (1889). The laws of migration, Part 2. *Journal of the Royal Statistical Society, 52*(2), 241-305.

Rittel, H. W., & Webber, M. M. (1973). Planning Problems Are Wicked. *Polity, 4*, 155-169.

Roberts, M., & Tybout, J. (1997). The Decision to Export in Colombia: An Empirical Model of Entry with Sunk Costs. *American Economic Review, 87*, 545-564.

Rosegrant, M. W., & Binswanger, H. P. (1994). Markets in Tradable Water Rights: Potential for Efficiency Gains in Developing Country Water Resource Allocation. *World Development, 22*(11), 1613-1625.

Rosegrant, M. W., Ringler, C., & Zhu, T. (2014). Water Markets as an Adaptive Response to Climate Change. Dans W. K. Easter, & Q. Huang, *Water Markets for the 21st Century: What Have We Learned?* (pp. 35-56). Dordrecht: Springer.

Rosen, M. D., & Sexton, R. J. (1993). Irrigation Districts and Water Markets: An Application of Cooperative Decision-Making Theory. *Land Economics, 69*(1), 39-53.

Rosenkranz, S., & Schmitz, P. (2007). Can Coasean bargaining justify Pigouvian taxation? *Economica, 74*, 573-585.

Rucker, R. R., & Fishback, P. V. (1983). The Federal reclamation program: An analysis of rent-seeking behavior. Dans T. L. Anderson, *in Water Rights*. San Francisco: Pacific Institute.

Rucker, R., & Fishback, P. (1983). The Federal reclamation program: An analysis of rent-seeking behavior. Dans T. Anderson, *Water Rights: Scarce Resource Allocation, Bureaucracy, and the Environment* (pp. 45-81). San Francisco: Anderson, T.L.

Rutherford, M. (2001). Institutional Economics: Then and Now. *Journal of Economic Perspectives, 15*(3), 173-194.

Saleth, M. R., Braden, J. B., & Eheart, J. W. (1991). Bargaining Rules for a Thin Spot Water Market. *Land Economics, 67*(3), 326-339.

Saleth, R., & Dinar, A. (2004). *The institutional Economics of Water*. Cheltenham UK, Northampton USA: Edward Elgar.

Saliba, B. C., Bush, D. B., Martin, W. E., & Brown, T. C. (1987). Do Water Market Prices Appropriately Measure Water Values? *Natural Resources Journal, 27*, 617-651.

Samuels, W. (1972). Welfare Economics, Power and Property. Dans G. Wunderlich, & W. Gibson, *Perspectives of Property*. Pennsylvania State University.

Santos Silva, J., & Tenreyro, S. (2006). The Log of Gravity. *Review of Economics and Statistics, 88*(4), 641-658.

Sapir, A. (1981). Trade Benefits under the EEC Generalized System of Preferences. *European Economic Review, 15*, 339-355.

Sattinger, M. (1978). Trade Flows and Differences between Countries. *Atlantic Economic Journal, 6*, 22-29.

Sax, J. (1965). Selling Reclamation Water Rights: A Case Study in Federal Subsidy Policy. *Mich. L. Rev. 13*, 13-46.

Sax, J. L., Thompson, B. H., & Leshy, J. D. (2006). *Legal Control of Water Resources: Cases and Materials.*

Scarborough, B. (2012). Buying Water for the Environment. Dans B. D. Gardner, & R. T. Simmons, *Aquanomics: Water Markets and the Environment* (pp. 75-106). Oakland: The Independent Institute.

Schaab, W. C. (1983). Prior Appropriation, Impairment, Replacements, Models and Markets. *Natural Resources Journal, 23*, 25-51.

Schiemann, J. W. (2002, August). History and Emotions, Beliefs and Mental Models: Toward a Hermeneutics of Rational Choice. *Paper presented at the American Political Science Association meeting*.

Schlager, E., & Ostrom, E. (1992). Property-Rights Regimes and Natural Resources: A Conceptual Analysis. *Land Economics, 68*, 249-62.

Schmid, A. (1972). Analytical institutional economics: changing problems in the economics of resources for a new environment. *American Journal of Agricultural Economics, 54*(5), 893-901.

Schmoller, G. (1900). *Grundriss der allgemeinen Volkswirtschaftslehre.* Leipzig.

Schotter, A. (1981). *The Economic Theory of Social Institutions.* Cambridge: Cambridge University Press.

Scott, A. (1989). Evolution of Individual Transferable Quotas as a Distinct Class of Property Right. *Economics of Fishery Management in the Pacific Islands Region* (pp. 20-22). Hobart, AUS: Campbel, H; Menz, K and Waugh, G.

Scott, W. R. (1995). *Organizations: Rational, Natural, and Open Systems.* Englewood Cliffs: Prentice-Hall.

Scott, W. R. (1998). *Organizations: Rational, Natural, and Open Systems.* Englewood-Cliff: Prentice-Hall.

Seabright, P. (1993). Managing Local Commons: Theoretical Issues in Incentive Design. *Journal of Economic Perspectives, 7*(4), 113-134.

Selten, R., Abbink, K., & Cox, R. (2001). Learnin Direction Theory and the Winners Curse. *Discussion paper No.10/2001*.

Sened, I. (1997). *The Political Institutions of Private Property.* Cambridge: Cambridge University Press.

Shackle, G. L. (1972). *Epistemics and Economics: A Critique of Economic Doctrines.* Cambridge: Cambridge University Press.

Shepsle, K., & Weingast, B. (1987). The Institutional Foundations of Committee Power. *American Political Science Review, 81*, 85-104.

Shupe, S. J., Weatherford, G. D., & Checchio, E. (1989). Western Water Rights: The Era of Reallocation. *Natural Resources Journal, 29*, 413-434.

Simms, R. (1995). A Sketch of the Aimless Jurisprudence of Western Water Law. Dans M. Carr, & J. Crammond, *Water Law: Trends, Policies, and Practices* (pp. 320-329). Chicago: American Bar Association.

Simon, H. (1957). *Models of Man.* New York: Wiley.

Simon, H. A. (1971). Designing Organizations for an Information-Rich World. Dans M. Greenberger, *Computers, Communication, and the Public Interest.* Baltimore: The Johns Hopkins Press.

Simon, H. A. (1976). *Administrative Behavior.* New York: Macmillan.

Simon, H. A. (1991). Organizations and Markets. *Journal of Economic Perspectives, 5*(2), 25-44.

Simon, H. A. (1991). Organizations and Markets. *Journal of Economic Perspectives, 2*(25), 25-44.
Sinn, H. (1984). Common Property Resources, Storage Facilities and Ownership Structure: A Cournot Model of Oil Market. *Economica, 51*, 235-252.
Smith, A. (1776). *An Inquiry into the Nature and Cause of the Wealth of Nations.* Dublin: Printed for Messrs. Whitestone and others.
Smith, H. E. (2008). Governing Water: the Semicommons of Fluid Property Rights. *Arizona Law Review*, 445-478.
Smith, H. E. (2008). Governing Water: The Semicommons of Fluid Property Rights. *Arizona Law Review*, 445-478.
Smith, R. J. (1981). Resolving the Tragedy of the Commons by Creating Private Property Rights in Wildlife. *CATO journal, 1*, 439-468.
Stavins, R. N. (1995). Transaction Costs and Tradeable Permits. *Journal of Environmental Economics and Management, 29*(2), 133-148.
Stene, E. A. (1995). *All American Canal: Boulder Canyon Project.* Denver: Bureau of Reclamation.
Stevenson, G. G. (1991). *Common Property Economics: A General Theory and Land Use Application.* Cambridge: Cmabridge University Press.
Stigler, G. J. (1966). *The Theory of Price.* New York: Macmillan.
Stiglitz, J. E. (1987). The Causes and Consequences of the Dependence of Quality of Price. *Journal of Economic Literature, 25*, 1-48.
Stroebe, W., & Frey, S. (1980). In Defense of Economics Man: Towards an Integration of Economics and Psychology. *Zeitschrift für Volkswirtschaft and Statistik, 2*, 119-148.
Stroup, R. L., & Baden, J. A. (1983). *Natural Resources: Bureaucratic Myths and Environmental Management.* San Francisco US: Pacific Institute for Public Policy Research.
Stroup, R., & Baden, J. (1983). *Natural Resources: Bureaucratic Myths and Environmental Management.* New York: Ballinger Publishing Company for Pacific Institute for Public Policy Research. .
Sugden, R. (1989). Spontaneous Order. *Journal of Economic Perspectives, 3*(4), 85-97.
Sunding, D. L., Zilberman, D., Howitt, R. E., Dinar, A., & Macdougall, N. (2002). Measuring the costs of reallocating water from agriculture: A multi-model approach. *Natural Resource Modeling, 15*, 201-225.
Sunding, D., Ajami, N., Hatchet, S., Mitchell, D., & Zilberman, D. (2008). *Economic Impacts of the Wanger Interim Order for Delta Smelt.* Berkley: Berkley Economic Consulting.
Sutton, J. (1986). Non Cooperative Bargaining: An Introduction. *Review of Economic Studies, 53*, 709-724.
Takayama, T., & Judge, G. (1964). Equilibrium Among Spatially Separated Markets. *Econometrica*, 510-524.
Takayama, T., & Judge, G. G. (1964). Spatial Equilibrium and Quadratic Programming. *Journal of Farm Economics, 46*(1), 67-93.
Tellman, B. (2011). Why Has Integrated Management Succeeded in Some States But Not in Others? *Journal of Contemporary Water Research and Education*, 13-18. Récupéré sur http://opensiuc.lib.siu.edu/cgi/viewcontent.cgi?article=1295&context=jcwre

Thomas, G. (2001). *Designing Successful Groundwater Banking Programs in the Central Valley Lessons from Experience.* Berkeley, CA : Natural Heritage Institute.

Thompson, J. D. (1967). *Organizations in Action.* New York: McGray-Hill.

Thomson, B. H. (1993). Institutional Perspectives on Water Policy and Markets. *California Law Review, 81*(3), 671-764.

Tinbergen, J. (1962). Shaping the World Economy: Suggestions for an International Economic Policy. *Twentieth Century Fund, New-York.*

Tintner, G. (1941). The Theory of Choice under Risk and Uncertainty. *Econometrica, 9*, 298-304.

Tobin, J. (1956). The Interest-Elasticity of Transactions Demand for Cash. *Review of Economics and Statistics, 38*(3), 241-247.

Trefler, D. (1995). The Case of the Missing Trade and Other Mysteries. *American Economic Review, 85*(5), 1029-1046.

Trelease, F. J. (1957). A Model State Water Code for River Basin Development. *Law and Contemporary Problem, 22*, 301-322.

Trelease, F. J. (1961). Water Law and Economic Transfers of Water. *Journal of Farm Economics, 43*, 1147-1152.

Trelease, F. J. (1962). Water Law and Economic Transfers of Water: A Rejoinder. *Journal of Farm Economics, 44*, 435-443.

Tullock, G. (1967). The Welfare Cost of Tarrifs, Monopolies, and Theft. *Western Economic Journal, 5*, 224-232.

Turvey, R. (1963). On Divergences between Soial Costs and Private Costs. *Economica, 30*(119), 309-313.

Tversky, A., & Kahneman, D. (1981). The Framing of Decisions and the Psychology of Choice. *Science, 211*(4481), 453-458.

Umbeck, J. (1981). Might Makes Right: A Theory of the Formation and Initial Distributionof Property Rights. *Economic Inquiry*, 38-59.

Van Long, N., & Raff, H. S. (2011). Innovation and trade with heterogeneous firms. *Journal of International Economics, 84*, 149-159.

Vanberg, V. (1989). Carl Menger's Evolutionary and John R Commons' Collective Action Approach to Institutions: A Comparison. *Review of Political Economy, 1*(3), 334-360.

Vaux, H. J. (1986). Water Scarcity and Gains from Trade in Kern County, California. Dans K. Frederick, *Scarce Water and Institutional Change* (pp. 67-101). Washington, DC: Resources for the Future.

Vaux, H. J., & Howitt, R. (1984). Managing Water Scarcity: An Evaluation of Interregional Transfers. *Water Resources Research, 20*, 785-792.

Veblen, T. (1899). *The Theory of Leisure Class.* New York: Macmillan.

Veblen, T. B. (1919). *The Place of Science in Modern Civilisation and other essays.* New York: Huebsch.

Vincenty, T. (88-93). Direct and Inverse Solutions of Geodesics on the Ellipsoid with Application of Nested Equations. *Survey Review, 22*(176), 1975.

Viner, J. (1931). Cost Curves and Supply Curves. *Zeitschrift für Nationalökonomie, 3*, 23-46.

Wahl, R. W. (1989). *Markets for Federal Water: Subsidies, Property Rights, and the Bureau of Reclamation.* Washington DC: Resources for the Future.

Walker, W. R., & Skogerboe, G. V. (1975). An Implicit Approach to Pricing Agricultural Water Transfers to Urban Uses. *Journal of the American Water Resources Association, 11*, 751-758.

Walker, W. R., & Skogerboe, G. V. (1975). An Implicit Approach to Pricing Agricultural Water Transfers to Urban Uses. *Journal of the American Water Resources Association, vol. 11 (4)*, 751-758.

Walston, R. E. (2008). California Water Law: Historical Origins to the Present. *Whittier Law Review, 29*(4), 765-826.

Weber, M. (1947). *The Theory of Social and Economic Organization.* London: Routledge & Kegan Paul.

Weber, M. (1968). *Economy and Society: An Outline of Interpretative Sociology.* Berkley: University of Caifornia Press.

Weingast, B. R. (1996). Political Institutions: Rational Choice Perspectives. Dans R. Goodin, & H.-D. Klingemann, *New Handbook of Political Science* (pp. 167-190). New York: Oxford University Press.

Welch, W. P. (1983). The Political Feasibility of Full Ownership Property Rights: The Cases of Polution and Fisheries. *Policy Sciences, 16*(2), 165-180.

Wiel, S. C. (1928). Need of Unified Law for Surface and Underground Water. *California Law Review*, 358.

Williams, S. F. (1972). Optimizing Water Use: The Return Flow Issue. *Colorado Law Review, 44*, 301-321.

Williamson, O. (1981). The Economics of Organization: The Transaction Costs Approach. *American Journal of Soiciology, 87*(3), 548-577.

Williamson, O. (1985). *The Economic Institutions of Capitalism, Firms, Markets, Relational Contracting.* NY: The Free Press.

Williamson, O. (1994). Institutions and economic organization: the governance perspective. *annual bank conference on development economics.* Washington: World Bank.

Williamson, O. E. (1975). *Markets and Hierarchies: Analysis and Antitrust Implication: A Study in the Economics of Internal Organization.* New York: Free Press.

Williamson, O. E. (2000). The New Institutional Economics: Tacking Stock, Looking Ahead. *Journal of Economic Literature, 38*, 595-613.

Winter, S. G. (1964). Economic 'Natural Selection' and the Theory of the Firm. *Yale Economic Essays, 4*, 225-272.

Winter, S. G. (1971). Satisficing, Selection, and the Innovating Remnat. *Quaterly Journal of Economics, 85*, 237-262.

Winter, T., Harvey, J., Franke, O., & Alley, W. (1998). Groundwater and Surface Water: A Single Resource. *U.S. Geological Survey Circular 1139.*

Wood, R. (1973). *The Owens Valley and the Los Angeles Water Controversy, Owens Valley as I knew It.* Stockton: Pacific Center for Western Historical Studies, University of Pacific.

Young, H. P. (1998). *Individual Strategy and Social Structure.* Princeton: Princeton University Press.

Young, R. (1986). Why Are There so Few Transaction among Water Users. *American Journal of Agricultural Economics, 68*(5), 1143-1151.

Zerbe, R. O. (1976). The Problem of Social Cost: Fifteen Years Later. Dans S. A. Lin, *Theory and Measurement of Economic Rxternalities* (pp. 29-43). New York: Academic Press.

Zetland, D. (2008). *Conflict and Cooperation Within an Organization: A Case Study of the Metropolitan Water District of Southern California.* Davis: Ph.D. Dissertation, University of California, Davis. Consulté le August 26, 2016, sur http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1129046

Appendix: Water District Data

Y corresponds to the financial revenue in dollars net of treatment costs used in the econometric estimation. W is the estimated amount of water used by the district. Irrigation and Urban are respectively the share of the district revenue that comes from either water deliveries to irrigators or domestic use. All values have been averaged over the period 1995-2011.

Water District Name	Y	W	Irrigation	urban
4-M WD	76515.42	22887.59	.4778467	0
AMADOR WATER AGENCY	6182446	3599.934	.0180113	.4867156
Alameda Cty FCWCD	2.72e+07	47731	.0085982	0
Alpaugh ID	998191.5	26402.72	.7256773	.0607508
Alta ID	2168330	300241.7	.7291515	.0130506
Anderson-Cottonwood ID	1008422	72866.24	.4727781	.0020436
Antelope Valley-East Kern WA	3.09e+07	59301	.0326612	.3284261
Arvin-Edison WSD	1.93e+07	302946	.5623733	.010193
Atwell Island WD	100638.7	16200.45	.7603293	0
BEAUMONT-CHERRY VALLEY W.D.	7717487	8909.626	.0242744	.6141309
BIG BEAR CITY C.S.D.	2060985	1160.938	0	.780777
Banta-Carbona ID	3288820	33776.4	.7174334	0
Bella Vista WD	4062536	74795.31	.06156	.2773941
Broadview WD	1111619	20190.11	.757705	.0006053
Browns Valley ID	1398290	156723.2	.5222139	0
Buena Vista-Rosedale	5023655	174543.2	.2860637	0
Butte Valley Irrigation District	254555.3	201147.3	.7719929	0
Butte WD	553933.9	82170.15	.519312	.1127545
Byron-Bethany ID	2548212	75444.65	.4224589	.0024243
CAMBRIA C.S.D.	1754096	771.7792	0	.7601129
CAMP FAR WEST I.D.	28313.97	10708	.6728522	0
CARMICHAEL W.D.	5996550	12370	0	.9199587
CITRUS HEIGHTS WATER DISTRICT	5851825	19137.39	0	.640828
CORCORAN I.D.	3896815	106528.4	.938752	0
CRESCENTA VALLEY W.D.	4959849	4936.833	0	.9454221
Calaveras County Water District	5773240	5144.654	.0019655	.3828259
Carpinteria Valley Water District	6153746	5970.856	.2654716	.6104967
Casitas MWD	1.00e+07	17964.25	.1409885	.147172
Castaic Lake WA	5.10e+07	63600.54	.0002174	.0888927
Cawelo WD	1.03e+07	86091.43	.0645799	0
Centerville CSD	769256.9	3800	0	.5947815
Centinella WD	43914.34	2030.39	.6656709	0

Central California ID	1.02e+07	346053.2	.6058894	8.48e-06
Central San Joaquin WCD	978880.8	136194	.459752	0
Chowchilla WD	5942157	200031.7	.3190672	.2074324
Clear Creek CSD	1392089	45359.46	.1025978	.4529383
Coachella Valley WD	9.34e+07	391856	.1172949	.3104223
Colusa Cty WD	2341689	73034.22	.638385	.0674998
Contra Costa WD	9.98e+07	128019.4	.0075528	.5394891
Corning WD	584988	25814.49	.5649027	0
Cortina WD	31183.74	1533.008	.8920187	.0065826
Crestline Village Water District	2486033	775.1135	0	.8435982
Crestline-Lake Arrowhead WA	4565199	1485	0	.1084335
Cucamonga Valley WD	3.33e+07	50851.13	.1339633	.5642363
DIABLO WATER DISTRICT	5732656	4965.652	0	.7470462
Davis WD	91408.77	4404.044	.5074249	.2777778
Delano-Earlimart ID	7487395	126334.5	.505816	0
Desert WA	2.40e+07	41664.75	.0193996	.4977235
Dublin San Ramon SD	1.66e+07	8119.963	.0618518	.4381248
Dudley Ridge WD	3623742	56840.1	.5068806	0
Dunnigan WD	671053	23702.18	.5283864	0
EAST NILES C.S.D.	3833630	10408.71	.0850509	.762884
EAST ORANGE COUNTY W.D.	4394422	1285.132	0	.107041
EAST VALLEY WATER DISTRICT	9800203	26806.73	.0374022	.8380792
EL TORO WATER DISTRICT	9356779	11107.91	.2031237	.6080181
ELSINORE VALLEY M.W.D.	3.62e+07	26771.44	.0922739	.2537699
Eagle Field WD	124450.4	3060.599	.9478523	.05
East Bay MUD	2.05e+08	234125.7	0	.7998351
Eastern MWD	8.99e+07	85610	.0221079	.6104834
El Dorado Irrigation District	2.10e+07	70274	.010644	.4261077
Empire West Side ID	3093365	17068.19	.7634574	.01237
Exeter ID	1101030	33884.83	.6250426	0
FAIR OAKS W.D.	5864318	13960.1	.0006331	.8584685
FOOTHILL MUNICIPAL W.D.	6602879	10090	0	.0381944
Fallbrook PUD	1.27e+07	16583.08	.2600212	.5643533
Feather WD	720365.8	23462.89	.2921275	0
Firebaugh Canal WD	2863196	49257.92	.5313833	0
Foresthill Public Utility District	897775.4	40041.25	0	.7332034
Fresno Cty WW	719486.8	5969.451	0	.4540692
Fresno ID	8635219	519382	.0527138	0
Fresno Slough WD	144096.8	2757.388	.995192	0
GEORGETOWN DIVIDE P.U.D.	2281711	12200	.0458151	.353331
GOLDEN HILLS C.S.D.	1787325	1325.545	0	.6849461
GROVELAND COMMUNITY S.D.	1458842	4614	0	.5508765

Glenn Valley WD	19696.37	4941.639	.9795495	0
Glenn-Colusa ID	1.02e+07	438037.6	.6104238	0
Glide WD	548377.3	23728.09	.5693656	0
Goleta Water District	1.68e+07	10818.35	.0759275	.6820638
Gravelly Ford WD	317320.4	19139.17	.5595706	0
HELIX WATER DISTRICT	4.19e+07	40479.6	.0199385	.7826006
HUMBOLDT BAY M.W.D.	2954969	84000	0	.405394
HUMBOLDT C.S.D.	1889566	2795.018	0	.8533238
Hi-Desert WD	7581657	19713	.005941	.4910514
Hills Valley ID	783212.2	9282.087	.3955873	.1237404
Holthouse WD	36921.97	4984.153	.8726608	.0860358
INDIAN WELLS VALLEY W.D.	5909990	8623.917	0	.8418513
IRVINE RANCH WATER DISTRICT	6.51e+07	151751	.0323635	.2709619
Inland Empire Utilities Agency	1.43e+07	205925.1	.0001046	.0860426
International WD	118867.1	1516.982	.9681044	0
Ivanhoe ID	849962.6	24508.21	.4767348	0
JOSHUA BASIN WATER DISTRICT	3803198	1612.267	0	.5076355
James ID	3641408	55388.71	.7681712	0
Kanawha WD	1186447	42267.23	.619937	.0240114
Kaweah Delta WCD	2493823	755280.3	0	0
Kern Cty WA	7.80e+07	982730	0	0
Kern-Tulare WD	4521060	49488.32	.6792414	0
Kings Riv WAssn	175252.2	29681.73	.0306472	0
LAGUNA I.D.	678208.6	76758.46	.0836488	0
LAKE HEMET MUNICIPAL W.D.	8955077	9087.313	.1002899	.7091432
LAS VIRGENES MUNICIPAL W.D.	2.45e+07	22293.88	.1588442	.6550723
LINDA COUNTY W.D.	1242968	16470	0	.7383975
La Grande WD	163167.3	3678.72	.7879154	0
Lake Arrowhead Community Services District	3581286	2274.625	.0001845	.7830945
Lakeside Irrigation WD	1592334	5109.286	.4894793	.116394
Lewis Creek WD	100941.3	2894.213	.6725765	0
Lindmore ID	2597871	61744.7	.5550243	0
Lindsay-Strathmore ID	3364170	35915.46	.420791	.0928551
Lower Tule Riv ID	7509441	230450.3	.6042102	0
MARIN M.W.D.	4.06e+07	29224.62	.0482469	.6398101
MARINA COAST WATER DISTRICT	8712957	4419.813	0	.7150444
MCKINLEYVILLE C.S.D.	1125512	1707.991	0	.8103929
MISSION SPRINGS W.D.	6103856	8908.802	0	.5841476
MONTE VISTA WATER DISTRICT	9895355	21325	0	.8262814
MOULTON-NIGUEL WATER DISTRICT	3.06e+07	11865.68	.1715166	.391909
MWDSC	8.43e+08	3775750	0	.0377778
Madera ID	9565583	296706	.496719	.0003513

Maxwell ID	706662.9	17013.14	.496906	0
Merced ID	1.41e+07	267946.8	.6301059	0
Mercy Springs WD	183051.2	7519.958	.98777	0
Modesto	1.14e+07	153454	.3947309	0
Mojave WA	2.71e+07	171606.5	0	0
Montecito Water District	8245827	5426.9	.0031546	.8227318
Mountain Gate CSD	562207.8	8794.807	0	.6904184
Municipal Water District of Orange County	9.88e+07	489222.3	0	0
NEVADA I.D.	1.97e+07	86355.65	.1202362	.3133529
NEWHALL COUNTY WATER DISTRICT	7018862	9982	.0649738	.7233542
NORTH COAST COUNTY W.D.	5686837	3657.603	.0147502	.7533599
NORTH OF THE RIVER M.W.D.	3027021	10887	0	.3780323
NORTH TAHOE P.U.D.	2246738	1593.182	0	.9138479
Nipomo CSD	2175349	2419.067	0	.7230557
North Kern WSD	6904830	190445.6	.8178331	0
North Marin WD	7853442	10348.11	0	.7399056
OLIVEHURST P.U.D.	1496461	3035.558	0	.724964
ORCHARD DALE W.D.	2071112	2390.9	.0020296	.7945826
Oakdale ID	5730796	168724	.292095	.0208663
Olivenhain MWD	2.41e+07	19572.5	.0737657	.482346
Orange Cove ID	4461502	61722.74	.3887148	0
Orland-Artois WD	1876656	78587.32	.6012495	.0294738
Oro Loma WD	79965.25	2296.426	.9988061	0
Otay WD	3.99e+07	35277.37	.1500019	.5754943
PADRE DAM MUNICIPAL W.D.	2.22e+07	15637.88	0	.4705333
PARADISE IRRIGATION DISTRICT	4607330	26072	.003299	.7652364
PINE GROVE C.S.D.	221058.6	177.0667	0	.758213
Pacheco WD	1050527	11004.3	.7582006	.0051599
Pajaro Valley WMA	680384.5	155167.3	0	.7010089
Palmdale WD	1.68e+07	23255.9	0	.6192395
Palo Verde ID	4331907	417789.1	.7592128	.0037435
Panoche WD	7011108	83679.17	.5848085	.0545448
Patterson ID	2151112	31801.86	.6790955	0
Pico Water District	2223388	3602.181	0	.711174
Pixley ID	2069071	156153.6	.3164292	0
Placer Cty WA	3.74e+07	248972	.0430381	.3336254
Porterville ID	1233044	38013.05	.1785554	0
Princeton-Codora-Glenn ID	891931.3	30415.09	.7060878	0
Proberta WD	130700.6	6960.545	.5475476	.0447419
Provident ID	811222.9	42312.57	.8486934	0
QUARTZ HILL W.D.	3265618	5161.279	.0085688	.6422464
RAINBOW MUNICIPAL WATER DIST.	1.95e+07	120535.2	.5199111	.1801215

RAMONA MUNICIPAL W.D.	1.19e+07	9044.813	.1906957	.3324764
RD 1004	1400557	7202.388	.6683296	0
RD 108	1720218	147093.8	.9461774	0
RD 2068	816191.1	31371.38	.5418653	0
REDWOOD VALLEY COUNTY W.D.	533217.2	15844.38	.1179708	.7479222
RINCON DEL DIABLO M.W.D.	7764864	8202.066	.0593057	.7486157
RIVERDALE I.D.	227267.4	32252.63	.0598959	0
ROSAMOND C.S.D.	2047835	3259.62	0	.7119102
ROWLAND AREA COUNTY W.D.	1.03e+07	13679.03	.0053082	.6834164
RUBIDOUX C.S.D.	3201145	6210.182	0	.8494545
Rag Gulch WD	1522707	13384.34	.7621788	0
Rancho California WD	5.87e+07	43128.63	.1125584	.2727638
Richvale ID	790358.7	98352.4	.5162134	0
Rosedale-Rio Bravo WSD	3937872	65908.41	.0393481	0
SAN GABRIEL COUNTY W.D.	3698496	7396.8	0	.756046
SANTA FE IRRIGATION DISTRICT	9907318	13544.7	.0405923	.665994
SOQUEL CREEK W.D.	6549852	5015.5	.0052944	.6898518
SOUTH TAHOE P.U.D.	1.04e+07	4699.005	0	.652413
SPANISH FLAT W.D.	82478.19	892.3352	0	.90438
STALLION SPRINGS C.S.D.	716193.9	399	0	.5762657
STRATFORD I.D.	206836.3	19925.8	.8825845	0
STRATFORD PUBLIC UTILITY DIST.	103304.6	801.2819	.0013424	.8154086
SUNNY SLOPE WATER CO.	2130251	4522.636	0	.8342794
SWEETWATER AUTHORITY	2.68e+07	22957.54	.0011937	.8212997
Sacramento Cty WA	3.27e+07	54320	.0212015	.4494223
Sacramento Suburban WD	2.43e+07	43355.38	.0130022	.8499737
San Benito Cty WD	7090196	61096.65	.2008801	.0445633
San Bernardino Valley MWD	4.15e+07	49406	0	0
San Diego Cty WAuth	2.71e+08	644512.2	0	0
San Gabriel Valley MWD	6522652	35226.33	0	0
San Joaquin Riv Exchange Contractors WAuth	1.21e+07	548043.5	.8836873	0
San Luis Obispo Cty FCWCD	1.11e+07	8730	0	.0002319
San Luis WD	2.09e+07	71500.2	.6448263	.0044131
Santa Clara Valley WD	9.81e+07	371470.6	.0052156	.0387664
Santa Margarita WD	4.74e+07	27487.63	.1153392	.2794647
Saucelito ID	1747057	44227.68	.8129885	0
Semitropic WSD	2.70e+07	310015.8	.3119003	0
Shafter-Wasco ID	3702465	88926.17	.6990159	.0419318
Shasta CSD	341554.7	15487.37	0	.799342
South San Joaquin ID	1.60e+07	122716	.1813412	0
Southern San Joaquin MUD	6832193	140535.4	.6319764	0
Stevinson WD	406651.7	8380.266	.8652835	0

Stone Corral ID	742170.8	15370.35	.7637314	0
Stony Creek WD	11898.38	5665.018	.7265263	.1754235
Sutter Extension WD	670265.7	47015.55	.7400026	0
TAHOE CITY P.U.D.	2007904	1971.454	0	.740473
TRABUCO CANYON WATER DISTRICT	5293601	3126.293	.124818	.3757159
TRUCKEE-DONNER P.U.D.	6508354	5679.831	0	.7993155
TUOLUMNE UTILITIES DISTRICT	4876866	5589.979	.0158772	.7369369
TWENTYNINE PALMS W.D.	3629334	2819.438	0	.668533
Tea Pot Dome WD	740995.3	7990.884	.7745562	0
Tehachapi-Cummings County Water District	5701923	9650	.1070909	.0970967
Terra Bella ID	3882229	31046.4	.4437857	.0811751
Thomes Creek WD	119949.8	5622.982	.5397898	0
Tranquility ID	2048381	22341.96	.8061063	.0634643
Tri-Valley WD	158163.6	5988.308	.5488741	0
Tulare ID	6286364	164037.4	.3775647	0
Tulare Lake Basin WSD	6443179	424570.1	.8410958	0
Tulelake Irrigation District	2821821	180119.5	.7818331	0
VALLECITOS WATER DISTRICT	1.57e+07	14588.47	.1302336	.444758
VALLEY CENTER MUNICIPAL W.D.	2.75e+07	151264.6	.5951257	.2443041
VALLEY COUNTY W.D.	4778762	38657.39	0	.7250811
VALLEY OF THE MOON W.D.	2851743	3416.438	0	.9324348
VISTA IRRIGATION DISTRICT	2.17e+07	19098.44	.0821752	.4932871
WALNUT VALLEY W.D.	2.17e+07	23143.13	.0212653	.7335376
WESTBOROUGH WATER DISTRICT	1367515	827.19	0	.6853823
West Kern WD	1.18e+07	3612.839	0	.8981557
West Side ID	1016192	11554.29	.7033852	0
West Stanislaus ID	3131954	51194.41	.708288	0
West Valley WD	9605904	20946.69	.0080955	.6550974
Western Canal WD	2067380	161560.2	.3825931	0
Western MWD	5.52e+07	151778	.0465257	.1241256
Westlands WD	6.91e+07	1181620	.796982	.0154527
Westside Districts	1475325	40826.04	.9001436	0
Widren WD	19658.64	1845.941	.4768079	.0769231
YORBA LINDA SERVICE AREA	1.53e+07	22706.01	.0040798	.7243758
YUCAIPA VALLEY WATER DISTRICT	6969357	12488.04	.0123099	.5607631
Yuba Cty WA	3857908	343112	.4106759	0
del puerto WD	3453317	126125.4	.863786	0

Ecole doctorale :
École doctorale Sciences Sociales et Humanités (481)
Laboratoire :
Centre d'Analyse Théorique et de Traitement des données économiques
Contact :
charles.regnacq@univ-pau.fr

Transaction Costs in Water Markets: The Case of California

Abstract

This dissertation aims at contributing to the ongoing debate about the potential effectiveness of water markets. With the ongoing economic changes and the growing versatility of water resources due to climate changes, many arid regions around the world need to reconsider their strategy of managing their hydrological resources. Interests among policy makers are leaning toward flexible reallocation mechanisms such as water markets to cope with water shortages. While efficient in theory, such instruments are also very costly to establish and to maintain because of the potential externalities that transferring water may cause. These so-called transaction costs limit the effectiveness of water markets in comparison to the situation of perfect competition and can induce a more detrimental outcome than a centralized management. Therefore, any decentralized solutions to manage the scarce water resources must account for the transaction costs of running such alternatives. In that respect, this work focuses on studying the underlying causes of these transaction costs and adapts a tool widely used in the international trade economics: the gravity equations. Through that way, importance of these transaction costs for the development of effective water markets is reasserted. More importantly, a theoretical and empirical model is developed to measure the magnitude of the different frictions in reallocating water through decentralized managements in the case of California.

Key words: Water markets, Transaction costs, Externalities, Property rights, Gravity Equations, Water institutions, California

Résumé

Cette thèse s'attache à contribuer aux débats actuels quant aux possibles avantages des marchés de l'eau. De par les changements économiques et une croissante instabilité climatique, bon nombre de régions arides à travers le monde doivent reconsidérer leur stratégie de gestion de leurs ressources hydrologiques. Une préférence substantielle envers des mécanismes de réallocation plus flexibles telle que les marchés de l'eau y est portée pour limiter le stress hydrique. Bien qu'efficients en théorie, ces instruments sont aussi très coûteux, autant dans leurs mises en place que dans leur maintenance, à cause principalement des possibles externalités que des transferts d'eau peuvent induire. Ces coûts de transaction limitent l'efficacité des marchés de l'eau en comparaison à une situation de concurrence pure et parfaite et peuvent être plus dommageables qu'une gestion centralisée. Ainsi, toutes analyses d'une décentralisation de la gestion des ressources en eau doivent prendre en compte ces coûts de transaction. A ce titre, le travail présenté ici étudie les causes sous-jacentes à ces coûts de transactions et adapte un outil déjà largement utilisé dans le cadre du commerce international : les équations de gravité. L'application de ce modèle aux marchés de l'eau en Californie permet de mettre en évidence et de mesurer l'importance de ces coûts de transaction dans le développement de tels instruments de gestion de l'eau.

Mots clés : Marchés de l'eau, Coûts de transaction, Externalités, Droits de propriété, Equations de gravité, Institutions de l'eau, Californie