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Imperfect competition and Liability Rules for Indivisible Harm

Concurrence Imparfaite et Règles de Responsabilité pour les Dommages Indivisibles

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Short abstract - Court résumé

Abstract

This dissertation studies the economic efficiency of different collective liability designs when firms pertaining to the same industry generate an (expected) indivisible harm to a third party victim, such as environmental good.

The first chapter studies the influence of different liability regimes on firms' choices regarding care spending and output level, in a context where firms compete *à la Cournot*. Two main results emerge from the analysis. First, none of the liability allows to decentralize the socially optimal level of care. Second, we find that with a liability regime based on strict liability augmented with an equal sharing and an optimal damages multiplier, "conventional" competition policy induces a convergence towards the social optimum. By opposition, other liability regimes (negligence, strict liability augmented with a market share apportionment) justify the use of unconventional competition policy consisting in a restriction of the number of participants on the market.

The second chapter studies the influence of different sharing rules (equal apportionment, apportionment based on market share) on the likelihood of tacit collusion among firms subject to strict liability and competing *à la Cournot*. The sharing rule used has an influence on both the gains and losses from the deviation and the severity of the punishment. Yet, the overall effect on the collusion sustainability depends on the harm's modelization. If the harm is linear in the aggregate production, then the sharing rule used has no influence on the collusion sustainability. On the contrary, if harm is cumulative in the aggregate production, then collusion among firms is less likely to occur if damages are shared in proportion of the market share.

The third chapter studies the implications for environmental liability laws of two legal doctrines, Joint and Several Liability and Joint Liability, which provide solutions for settling cases where multidefendants are jointly involved in the harm to a victim. None of the liability regimes allow to decentralize the social optimum - irrespective of the legal doctrine used. Furthermore, none of these doctrines strictly dominate the other. Coupled with a strict liability, the use of optimal damages multipliers adapted to each liability regime lead firms to choose the same equilibrium outputs - care level being socially optimal given the level of output. Negligence appears to be unstable, meaning that depending on the model's parameters, it might exist two, one or zero Nash equilibrium.

Keywords: Strict liability; negligence; damages apportionment rules;liability sharing rules ; market share liability; environmental liability; Cournot oligopoly; competition policy ; imperfect competition ; market collusion ; Joint and Several Liability ; Joint liability.

Résumé

Cette thèse étudie l'efficience économique de différentes formes de responsabilités collectives lorsque des firmes appartenant à un même branche d'industrie génèrent un dommage (espéré) indivisible envers une tierce partie, tel un bien environnemental.

Le premier chapitre étudie l'impact de différents régimes de responsabilité sur les choix en quantités produites et en investissement en précaution de firmes en concurrence à la Cournot. Deux résultats ressortent de cette analyse. D'abord, aucun des régimes de responsabilité ne permet de décentraliser le niveau de précaution optimal. Ensuite, nous trouvons que sous un régime de responsabilité basé sur une règle de responsabilité stricte, couplée à un partage par parts égales et augmentée d'un multiplicateur de dommage optimal, l'application d'une politique de concurrence "conventionnelle" permet de converger vers l'optimum social, tandis que les autres régimes de responsabilité (négligence, responsabilité stricte avec une règle de partage basée sur les parts de marché) justifient au contraire l'application de politiques de la concurrence peu conventionnelles, visant à restreindre le nombre de firmes sur le marché.

Le deuxième chapitre étudie l'influence de différentes règles de partage de l'indemnisation du dommage joint (partage par parts égales, partage au prorata des parts de marché) sur la soutenabilité des collusions entre des firmes soumises à une responsabilité stricte et en concurrence à la Cournot. Nous déterminons que si la règle de partage utilisée a une influence tant sur les gains associés à une déviation unilatéral d'un des membres du cartel que sur la sévérité de la punition des autres membres, son influence sur la soutenabilité de la collusion dépend de la forme du dommage. Lorsque le dommage est linéaire, les différentes règles de partage sont sans influence sur la soutenabilité de la collusion. À l'inverse, lorsque le dommage est cumulatif, la collusion est moins soutenable sous une répartition par parts de marché que sous une répartition par parts égales.

Le troisième chapitre étudie l'impact de deux doctrine juridiques, la *joint liability* et la *joint and several liability*, sur l'efficacité des régimes de responsabilité. Ces deux doctrines fournissent des solutions pour régler les affaires où plusieurs firmes sont conjointement impliquées dans la création d'un dommage. Aucun des régimes de responsabilité étudiés - quelle que soit la doctrine utilisée - ne permet de décentraliser les niveaux d'output et de précaution socialement optimaux. Mais surtout, aucune des doctrines ne domine strictement l'autre. Sous une responsabilité stricte, l'utilisation de multiplicateurs de dommages optimaux adaptés à chaque régime de responsabilité conduit les firmes à mettre en œuvre les même décisions output/précaution et donc induit le même équilibre, équilibre dans lequel les firmes adoptent un niveau de précaution socialement optimal étant donné le niveau d'output. La négligence apparaît en revanche comme instable : en fonction des paramètres du modèle, il peut exister deux équilibres de Nash, un seul, ou aucun.

Mots-clés: Responsabilité stricte ; responsabilité pour faute ; règles de répartion des dommages et intérêts ;responsabilité environnementale ; oligopole à la Cournot, Collusion ; Joint and Several Liability ; Joint liability.

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General Introduction

0.1 Context

Le 10 avril 2014, le Tribunal de Grande Instance de Nanterre a appliqué une règle peu conventionnelle de répartition d'un préjudice. La répartition n'était pas basée sur le nombre de co-auteurs du dommage, ni même sur la gravité de la faute, mais sur les parts de marché détenues par chacun des co-auteurs. La reconnaissance de cette nouvelle règle de partage, la *Market share liability*, a clos un épisode juridique connu en France sous le nom de "l'affaire Distilbène" en même temps qu'elle a ravivé un débat plus profond sur l'objectif poursuivi par la responsabilité, et par conséquent, sur les modalité d'application de ce mécanisme de droit.

Le Distilbène est un médicament qui fut commercialisé par deux laboratoires pharmaceutiques et délivré à plus de 200 000 femmes en France des années 1940 à la fin des années 1970. Il est à l'origine de nombreuses pathologies auprès des enfants exposés *in utero*, dont cancers, infertilités et malformations congénitales. On estime à 160 000 le nombre de victimes potentielles du Distilbène sur le seul territoire français. Du fait de la longue période (plusieurs décennies) entre la vente du médicament et la survenance des dommages causés par celui-ci, il est impossible pour les cours comme pour les victimes de déterminer lequel des laboratoires est à l'origine du préjudice subi par chacune des victimes. Pour surmonter cet obstacle probatoire et garantir aux victimes un droit à indemnisation, la Cour de cassation décida en 2009 de condamner solidairement les deux laboratoires à indemniser les victimes[1]. Ce faisant, les juges durent déterminer comment, dans ce contexte, répartir l'indemnisation du dommage entre chacun des laboratoires. Dans un premier temps les juges décidèrent d'appliquer les règles traditionnelles en matière de répartition de l'indemnisation, impliquant en

[1]Voir Cass. 1er civ., 24 septembre 2009, n 14-23.909

l'espèce que le l'indemnisation était supportée à parts égales entre chacun des laboratoires[2] . Mais cette décision fut fortement critiquée par la doctrine au regard de l'écart entre les parts de marché de chacun des laboratoires – l'un d'eux détenant plus de 97 % de ces parts au moment des faits. En réponse à ces critiques, le Tribunal de Grande Instance de Nanterre opéra en 2014 un revirement de jurisprudence – confirmé en appel[3] - en décidant de répartir l'indemnisation du préjudice subi par les victimes entre les laboratoires au prorata de leurs parts de marché au moment des faits. De nombreux doctrinaires du droit virent dans ce revirement l'application concrète de la théorie économique de la responsabilité, la décision n'étant pas motivée par la simple volonté d'assurer aux victimes l'indemnisation de leur préjudice, mais d'inciter également les laboratoires à réguler le risque généré par leur activité.

Point de départ de cette thèse, cette affaire constitue un exemple emblématique des évolutions des dommages industriels et des transformations en cours qu'ils engendrent dans le droit de la responsabilité. Le Distilbène est en effet un des nombreux exemples d'activités dans lesquelles c'est l'ensemble de l'industrie qui génère un dommage et dont il est impossible de déterminer la contribution individuelle de chacune des firmes appartenant à cette industrie. Ce genre d'activité ne se limite évidemment pas au domaine pharmaceutique. La simple évocation des problèmes sanitaires et environnementaux associés au diesel, aux peintures au plomb, aux matériaux de construction en amiante ou même, de façon plus originale, aux débris spatiaux suffit à percevoir cette réalité. Ces nouveaux risques industriels collectivement générés par des firmes appartenant à une même branche d'industrie – constructeurs automobiles, industries pétrochimiques, laboratoires pharmaceutiques, etc. - obligent les acteurs publics, législateurs comme juges, à faire évoluer en profondeur les règles de responsabilité.

Cette évolution porte d'abord sur l'objectif de la règle de responsabilité. Le risque industriel devenant ainsi toujours plus complexe, les acteurs publics doivent déterminer de nouvelles façons de le réguler. Or la règle de responsabilité offre de nombreux avantages, notamment lorsque le risque industriel est collectivement généré par des firmes appartenant à une même branche d'industrie. Mais pour que cet objectif incitatif soit atteint, et que les firmes adoptent un contrôle socialement optimal du

[2]Voir CA Paris, 26 oct. 2012, n 10/18297

[3]Voir TGI Nanterre, 10 avr. 2014, n 12/12349 et n 12/13064, CA Versailles - 3ème ch, 30 juin 2016, n 14/04397

risque qu'elles génèrent collectivement, encore faut-il que ces règles de droit soient correctement conçues.

Lorsque le dommage est indivisible au sein d'une même industrie, le design de la responsabilité ne se limite pas au régime utilisé (responsabilité stricte, responsabilité pour faute ou absence de responsabilité) mais intègre également d'autres éléments fondamentaux au regard des effets incitatifs qu'elle produit, notamment la règle de partage du dommage utilisée (partage par parts égales c. partage au prorata des parts de marché) ou la procédure appliquée (*Joint and several liability* c. *Several liability*). Corollaire du changement d'objectif, les règles de responsabilité évoluent donc également dans leurs formes. Enfin, si la règle de responsabilité est conçue comme un mécanisme de régulation des dommages collectivement créés par un groupe de firmes en concurrence au sein d'une même industrie, s'ajoute à cela une nouvelle problématique. La règle de responsabilité, en régulant le risque associé à une industrie, modifie la structure des coûts des entreprises appartenant à cette industrie. Ce faisant, elle peut générer des effets anti-concurrentiels et rentrer en opposition avec l'objectif poursuivi par le droit de la concurrence. Il apparaît donc indispensable d'adapter les outils des autorités de concurrence au régime de responsabilité et inversement, afin que l'objectif des autorités de concurrence – la promotion de l'intérêt des consommateurs – ne s'oppose pas aux objectifs des cours de justice – la régulation du risque industriel.

Pour percevoir ces évolutions, encore faut-il au préalable définir cette notion de risque industriel indivisible au sein d'une même branche d'activité.

0.2 La notion de risque industriel au sein d'une même branche d'activité

Le risque inscrit dans une relation probabiliste une action et ses diverses conséquences. Le risque industriel se distingue du risque naturel par le contrôle qu'exerce l'homme dessus. Alors que le risque naturel est indépendant de la volonté humaine, de sorte que l'homme ne peut exercer de contrôle dessus (bien qu'il puisse prévenir certaines de ses conséquences), le risque industriel émane des activités humaines. Dès lors, l'homme peut exercer un contrôle sur son intensité.

Traditionnellement, la littérature de l'analyse économique du droit a adopté une approche individuelle du risque industriel. Ce dernier est généré par un agent économique, l'offenseur, qui est le plus à même d'en contrôler l'amplitude et l'intensité. Comme le souligne Faure (2016) "*The traditional approach to torts, both legal and economic, has always started from a simple premise, which assumes one tortfeasor, one victim, and a clear causal relationship between the tortious conduct of the tortfeasor and the damage suffered by the victim*". Cette approche individuelle du risque industriel est séduisante pour les économistes, car elle offre un cadre d'analyse simple duquel émergent des résultats robustes, mais elle écarte dans le même temps de l'analyse un grand nombre de situations dans lesquelles le risque est collectivement généré par une pluralité d'offenseurs. Par conséquent, de nombreux auteurs ont élargi l'analyse du risque industriel aux situations dans lesquelles plusieurs offenseurs sont à l'origine de celui-ci. Cela nécessite alors de préciser comment chacun des offenseurs contribue à la création du risque industriel, et quelles interactions ont entre eux les offenseurs.

Dans cette perspective, Kornhauser and Revesz (1989) distinguent deux types de dommages : divisible et indivisible. Un dommage divisible se caractérise par le fait que les coûts dommageables associés au niveau d'activité ou les bénéfices associés aux investissements en precaution d'un offenseur sont indépendants des choix des autres offenseurs. Le dommage généré collectivement par les offenseurs - et donc, d'un point de vue *ex ante*, la création du risque industriel - est alors divisible entre chacun au prorata de leur contribution individuelle, de sorte que la part que doit indemniser chacun des offenseurs ne dépend que de ses propres choix et correspond au montant des dommages qui résulte de ceux-ci. À l'inverse un dommage est dit indivisible si les coûts dommageables associés au niveau d'activité ou les bénéfices associés aux investissements en precaution d'un offenseur dépendent non seulement de ses propres choix, mais également de ceux des autres offenseurs. Dans cette situation d'interaction stratégique, il est impossible de diviser le dommage entre les offenseurs de sorte que la part relative de chacun corresponde aux dommages causés par ses propres choix. Le dommage est indivisible[4].

Tietenberg (1989) adopte une approche similaire de la notion de dommage indivisible. Il remarque qu'à l'origine le droit du *common law*, et plus particulièrement le droit anglais, restreignait la notion de dommage indivisible aux situations dans lesquelles les auteurs de celui-ci agissaient de concert - c'est à dire qu'ils exerçaient conjointement une activité à l'origine du préjudice. Toutefois, la notion d'indivisibilité s'est considerablement élargie, en particulier dans la jurisprudence américaine. Dépassant cette exigence, les cours américaines ont inclus dans la notion de dommage indivisible des situations dans lesquelles il était impossible d'identifier la contribution relative et l'identité des auteurs d'un dommage au sein d'un groupe d'individus. En ce sens, un dommage causé par l'accumulation de pollutions diffuses au cours du temps et générées par différentes activités industrielles peut être considéré comme indivisible dès lors qu'il est possible de déterminer un groupe de responsables potentiels, sans qu'il soit possible de déterminer la contribution individuelle de chacun des membres de ce groupe. Se fondant sur cette jurisprudence des cours américaines, Tietenberg élargit donc cette notion d'indivisibilité aux situations dans lesquelles il est impossible de déterminer la contribution individuelle de chacun des offenseurs dans la réalisation d'un dommage, de sorte que toute répartition du dommage entre les offenseurs ne peut se faire que sur des critères arbitraires[5].

C'est cette définition que nous retiendrons dans le cadre de cette thèse. Un dommage est indivisible - et *a fortiori* le risque industriel à l'origine de celui-ci – lorsqu' il est impossible de déterminer la contribution individuelle de chacun des offenseurs. Cette définition inclut l'ensemble des dommage qui sont créés par l'actions conjointe

[4]Kornhauser et Revesz (1989) définissent ainsi cette distinction : *"a harm is distinct if the damage caused by one actor is independent of the harm caused by other actors. In contrast, where the damage caused by one actor increases the damage caused by another actor, the harm is non-distinct."*

[5]Tietenberg relève que *" In the key case, United States v. Chem-Dyne Corp, Judge Rubin stated that the imposition of the doctrine of joint and several liability was possible if the harm was caused by two or more parties and if their respective contributions were indivisible. Indivisibility in this context means that it is difficult or impossible to apportion the responsibility among the respective parties on anything but an arbitrary basis."*

de plusieurs agents économiques, mais aussi celles où il est impossible pour les cours comme pour les parties d'identifier *ex post* l'identité ou les actions d'offenseurs potentiels, comme l'illustre l'affaire Distilbène.

Au-delà de l'interdépendance des contributions au risque des offenseurs, un deuxième aspect est essentiel aux risques industriels analysés dans le cadre de cette thèse. Il s'agit des interactions stratégiques qu'ont entre eux les offenseurs. Une hypothèse classique est que les offenseurs sont des étrangers, et n'ont d'interactions stratégiques que dans le cadre d'un litige les impliquant. Les décisions que prend un offenseur n'a d'influence sur les gains des autres offenseurs qu'à travers le mécanisme de responsabilité, la compensation que doit verser chacun des offenseurs en cas d'accident étant dépendante non seulement de ses propres décisions (quantité de biens produite, dépenses en mesure de précaution, etc ...) mais également de celles des autres offenseurs. C'est l'hypothèse que retiennent par exemple Landes and Posner (1980), Kornhauser and Revesz (1989), ou encore Young (2007).

Toutefois, les offenseurs peuvent avoir entre eux des interactions stratégiques au-delà de celles générées par le mécanisme de responsabilité. À titre d'exemple, Feess and Hege (1998) analysent les interactions entre plusieurs offenseurs collectivement responsables d'un même dommage et des compagnies d'assurances. Jacob and Lovat (2016) se focalisent sur les cas dans lesquels les offenseurs sont dans une relation de production " verticale ", où le risque associé à un produit final dépend à la fois d'un opérateur industriel, qui produit le bien final, mais également d'un fournisseur qui vend en amont un input de production à cet opérateur. Marino (1991), Daughety and Reinganum (2014) ou encore Li (2019) se concentrent au contraire sur des dommages conjointement causés par des firmes étant dans une relation "horizontale", c'est à dire appartenant à une même branche d'industrie et en concurrence sur un même marché. C'est dans ce dernier scenario que s'inscrit cette thèse. Nous nous focalisons en effet sur les risques industriels créés par les entreprises appartenant à une même branche d'industrie, et opérant donc sur le même marché. Dès lors, les recettes générées par les firmes sur le marché comme le montant de la compensation qu'elles doivent verser en cas d'accident dépendent de l'ensemble des choix stratégiques réalisés par les firmes appartenant à la même industrie.

Plusieurs jurisprudences nous permettent d'illustrer des situations dans lesquelles l'ensemble des firmes appartenant à une même industrie génèrent un risque indivisible. Utilisé aux États-Unis dans le processus de raffinage de l'essence, le Méthyl tert-butyl éther (MTBE) constitue l'une des principales sources de pollution des nappes phréatiques. Ce composé chimique, même présent en petites quantités, donne un goût et une odeur qui rendent l'eau inutilisable et impropre à la consommation humaine. Il est également un cancérigène probable. De nombreuses victimes de cette pollution – personnes privées comme collectivités publiques- ont porté plainte devant les tribunaux pour exiger des raffineurs qu'ils indemnisent les dommages causés par le MTBE. Dès 2005, dans la jurisprudence In re Methyl Tertiary Butyl Ether ("MTBE') Products Liability Litigation, la cour de New York relevait que le processus de transport et de distribution, au cours duquel le MTBE présent dans l'essence fuit des infrastructures et contamine l'environnement, implique que les essences des différents raffineurs sont mélangées. Il est alors impossible de déterminer la proportion dans laquelle chacun des raffineurs contribue aux dommages causés, et donc ces dommages doivent être considérés comme indivisibles[6].

La peinture au plomb est un autre exemple illustratif. Dans les années 2000, on estimait que dans le seul Etat du Wisconsin, 3 300 enfants âgés de moins de 6 ans souffraient d'empoisonnement du fait du plomb contenu dans la peinture, engendrant notamment une baisse du quotient intellectuel, des troubles de l'attention ou encore des retards de croissance. De nombreuses habitations ayant été construites des décennies avant les empoisonnements, il est souvent impossible de déterminer le fabricant à l'origine de la peinture litigieuse, ni même de garantir qu'une seule marque de peinture a été utilisée au cours du temps. Dans la jurisprudence *Thomas v. Mallet*[7], la cour suprême du Wisconsin a ainsi obligé les fabricants de peintures au plomb à indemniser l'une des victimes, ouvrant la voie à de multiples recours[8].

Au-delà de ces jurisprudences, la littérature offre des exemples plus originaux de ces risques industriels indivisibles. En témoigne l'article de Sundahl (2000) qui propose d'appliquer à l'industrie aérospatiale une responsabilité collective concernant les débris spatiaux. En effet, l'exploitation de l'espace génère de plus en plus de débris, ce

[6]La cour de New York relève ainsi que *"certain gaseous or liquid products (e.g., gasoline, liquid propane,alcohol) of many suppliers were present in a completely commingled or blended state at the time and place that the risk of harm occurred, and the commingled product caused a single indivisible injury"* - In re Methyl Tertiary Butyl Ether ("MTBE") Prods. Liab. Litig. (MTBE 1), 379 F. Supp. 2d 348, 377-78 (S.D.N.Y. 2005).

[7]2005 WI 129, 285 Wis. 2d236, 701 N.W.2d 523

[8]Voir également Laura Worley, The Iceberg Emerged: Wisconsin's Extension of Risk Contribution Theory Beyond DES, 90 Marq. L. Rev. 383 (2006)

qui accroît les risques de collision. Or l'une des principales difficultés est qu'il est impossible de tracer les débris inférieurs à 10 centimètres, et donc de déterminer l'origine d'un dommage causés par l'un de ces débris. De plus, la multiplication des débris spatiaux peut entraîner ce que les scientifiques appellent "l'effet Kessler", c'est-à-dire une chaîne de collision perpétuelle qui rendrait l'exploitation de l'espace impossible. Là encore, les dommages générés par l'industrie aérospatiale s'apparentent à des dommages indivisibles.

La simple évocation de ces exemples où une industrie produit des risques industriels indivisibles permet d'illustrer une autre réalité : dans de nombreux cas, la responsabilité est utilisée comme outil de régulation de ces risques.

0.3 La responsabilité, nouvel outil de régulation des risques indivisibles

La règle de responsabilité se caractérise par le fait qu'elle constitue un instrument de contrôle *ex post*. Mécanisme d'indemnisation, la responsabilité n'intervient qu'une fois le dommage réalisé – s'il se réalise.

Le premier avantage donc de la responsabilité civile réside dans le fait qu'il n'implique de faire peser sur les agents économiques aucune contrainte *ex ante*, à l'inverse notamment des réglementations. Le deuxième avantage est qu'elle réduit considérablement les coûts de surveillance, puisque ne s'appliquant que lorsque survient le dommage. Elle est en principe un mécanisme de private enforcement, c'est-à-dire qu'il revient aux victimes, subissant un dommage, de porter plainte devant les tribunaux et d'apporter les preuves nécessaires pour obtenir réparation, et non à une autorité publique de contrôler l'activité des firmes litigieuses. Par ailleurs, même lorsque l'initiative d'un recours est laissée à une personne publique (État ou collectivité territoriale), comme c'est le cas de certaines responsabilités environnementales, il suffit simplement à l'État d'observer les dommages causés par l'industrie et non directement et de façon continue l'activité et les mesures de précautions adoptées par les firmes appartenant à cette industrie. Droit essentiellement prétorien – en ce sens que les règles de responsabilité s'énoncent et se modifient au cours des jurisprudences – le mécanisme de responsabilité est très facilement adaptable aux différentes évolutions de notre société. Un simple revirement de jurisprudence suffit à modifier en profondeur ses règles là où la réglementation exige un important niveau de formalisme.

Ainsi, comme le soulignent Kolstad et al. (1990) , *"From its beginnings the literature has focused on alternative forms of what may be called ex ante policies (for example, safety standards, Pigouvian taxes, and transferable discharge permits) that affect an activity before the externality is generated. But in the past decade researchers have analyzed the ability of what may be called ex post policies (for example, exposure to tort liability) to control externalities.' These latter policies regulate the externality only after it has been generated and harm has occurred. The threat of suit causes the potential injurer to internalize the expected social damages and thus to take optimal precaution."* .

Les différents régimes de responsabilité environnementale développés entre les années 1980 et 2000 se fondent directement sur le principe du polleur payeur. Aux États-Unis, l*e Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) , promulgué en 1980 et amendé en 1986, consacre l'obligation pour les responsables potentiels de sites pollués par des substances toxiques de réparer les atteintes portées à l'environnement. Ce faisant, le CERCLA dépasse le simple objectif indemnitaire de la responsabilité pour en faire un outil de régulation des activités à risque pour l'environnement. En Europe, la directive 2004/35/CE est encore plus explicite sur l'objectif de la responsabilité environnementale qu'elle consacre. Se fondant explicitement sur le principe du "pollueur-payeur", la directive établit dans son préambule que *"le principe fondamental de la [...] directive devrait donc être que l'exploitant dont l'activité a causé un dommage environnemental ou une menace imminente d'un tel dommage soit tenu pour financièrement responsable, afin d'inciter les exploitants à adopter des mesures et à développer des pratiques propres à minimiser les risques de dommages environnementaux, de façon à réduire leur exposition aux risques financiers associés "*. Cette évolution dans les objectifs de la responsabilité s'étend même au principes fondamentaux de la responsabilité civile. Ainsi le projet de réforme français de la responsabilité civile propose d'introduire au sein de la responsabilité civile français des dommages punitifs au travers du mécanisme de l'amende civile[9], ce qui illustre la volonté du législateur de dépasser l'objectif indemnitaire de la responsabilité civile pour en faire un outil de régulation des risques.

Si les règles de responsabilité semblent converger – au moins en partie - vers un objectif commun, leurs designs diffèrent fortement d'une responsabilité à une autre, et leur application d'une cour à l'autre. En témoignent à nouveau les différences entre les responsabilités environnementales sous le CERCLA et la directive européenne 2004/35/CE. Ces deux régimes de responsabilité diffèrent en effet en trois points fondamentaux. Tout d'abord, le CERCLA établit un régime de responsabilité stricte. À l'inverse, la directive européenne introduit une distinction entre les activités les plus dangereuses - listées en annexe III de la directive - pour lesquelles les firmes sont soumises à une responsabilité stricte, et les autres activités, pour lesquelles les firmes sont soumises à une responsabilité pour faute. Ensuite, sous le CERCLA, les compensations que versent les firmes en cas de dommage environnemental peuvent être augmentées de dommages punitifs, tandis que sous la directive européenne, il est impossible pour les cours d'exiger plus que la réparation des dommages causés. Enfin sous le CERCLA, la *joint and several liability* s'applique (les firmes sont condamnées *in solidum*), tandis que sous la directive européenne, il revient aux droits nationaux de déterminer les règles de répartition de l'indemnisation du dommage.

Cette pluralité n'est évidemment pas unique à la responsabilité environnementale. Il est à cet égard frappant de remarquer que l'essentiel des règles de répartition des dommages indivisibles sont forgées par les cours au gré des cas, et évoluent régulièrement avec les particularités de ceux-ci, et notamment sous l'émergence de dommages indivisibles générés par les industries. En témoigne la théorie de la *market share liability*, forgée par la cour suprême des États-Unis en 1980 à l'occasion de l'indemnisation de victimes du Distilbène dans l'affaire *Sindell vs. Abott*, et qui a connu en 40 années de nombreuses évolutions et modifications. Ainsi, si à l'origine la théorie de la *market share liabiility* consistait à répartir au prorata des parts de marché entre les firmes l'indemnisation d'un dommage dont il était impossible d'identifier l'auteur parmi un groupe de firmes potentiellement responsables – les firmes appartenant à une même industrie – les cours ont largement fait évoluer celles-ci. Ainsi la cour du Wisconsin a

[9] Le projet de réforme de responsabilité extracontractuelle de mars 2017 prévoit ainsi d'insérer dans le code civil l'article L 1266-1, qui dispose qu'" *en matière extracontractuelle, lorsque l'auteur du dommage a délibérément commis une faute en vue d'obtenir un gain ou une économie, le juge peut le condamner, à la demande de la victime ou du ministère public et par une décision spécialement motivée, au paiement d'une amende civile.*"

forgé au cours de la jurisprudence *Thomas v. Mallet* la *Risk-contribution theory*, une théorie qui élargit l'application de la market share liability à des produits pour lesquels le risque créé n'est pas uniforme, tout en proposant de répartir l'indemnisation entre les firmes au prorata du risque généré par chacune des firmes au sein de l'industrie, la part de marché étant un des éléments permettant d'évaluer ce risque. De même, l'affaire MTBE a été l'occasion pour la cour de New York de forger la *Commingled Product Theory*, qui là encore étend l'application d'une répartition au prorata des parts de marché de l'indemnisation d'un dommage aux situations dans lesquelles les produits mélangés de plusieurs firmes causent un dommage.

0.4 Problématique de la thèse et principaux résultats

Cette thèse propose donc d'étudier l'efficience économique des différents régimes de responsabilité lorsque des firmes appartenant à une même industrie génèrent collectivement un dommage indivisible.

D'un point de vue positif, et dans un contexte où il est impossible d'individualiser le dommage produit collectivement par les firmes en concurrence imparfaite, quels effets incitatifs produisent les différents régimes de responsabilité et les règles de partage associées sur les stratégies de chacune des firmes ? Quels impacts in fine ces régimes ont-ils non seulement sur les choix de précaution des firmes, mais aussi sur les performances de marché ?

D'un point de vue normatif, existe-t-il un ou des régimes de responsabilité qui permettent d'atteindre l'optimum de premier rang, ou du moins, qui dominent les autres formes de responsabilité ?

Pour répondre à ces questions, la thèse ici présentée se décompose en trois chapitres. Le premier chapitre, *" Should environment be a concern for competition policy when firms face environmental liability ? "* se concentre sur l'impact de trois régimes de responsabilité (responsabilité sans faute, responsabilité pour faute et absence de responsabilité) sous deux règles de répartition des dommages (répartition au prorata des parts de marché, répartition par parts égales). Il permet d'étudier, dans le contexte d'une concurrence imparfaite où chaque firme dispose d'un pouvoir de marché, comment le design des différents régimes de responsabilité et des règles de répartition associés influencent non seulement les choix de précaution, mais également les performances de marché.

Le deuxième chapitre, *"Market collusion with joint harm and liability sharing"*, interroge l'influence des différents régimes de responsabilité sur les incitations des firmes à adopter des comportements collusifs. Plus précisément, ce chapitre illustre le fait que, sous un régime de responsabilité sans faute, les différentes règles de répartition du dommage peuvent inciter les firmes à adopter des comportements collusifs, qui influencent les performances de marché.

Enfin, le troisième chapitre *"Apportioning indivisible environmental harm, and the joint and several liability doctrine"* étudie le design des régimes de responsabilité qui découle de la mise en oeuvre de doctrines juridiques de répartition du dommage : la *Joint Liability* et la *Joint and Several Liability.* Ce chapitre permet d'illustrer l'importance – au-delà du simple critère de répartition du dommage (parts de marchés ou parts égales) – des modalités de répartition du dommage et comment ceux-ci peuvent conduire à des résultats différents, tant en termes de performance de marché que de choix de précaution – en fonction des stratégies formées par les firmes.

Les trois prochaines sections détaillent chacun de ces chapitres.

0.4.1 Chapitre 1 : Should environment be a concern for competition policy when firms face environmental liability ?

Problématique et méthode

Le premier chapitre, publié en 2021 dans l'*International Review of Law and Economics*, étudie l'impact de différents régimes de responsabilité environnementale sur les choix de firmes (quantités produites, investissement en mesures de précaution) en concurrence au sein d'une même industrie. De cette problématique, il découle deux questions précises. Tout d'abord, quel régime de responsabilité permet d'inciter les firmes à adopter un niveau de précaution socialement efficient, ou du moins, domine les autres ? Ensuite, quels impacts ont ces différents régimes de responsabilité sur les politiques visant à accroître la concurrence au sein de l'industrie étudiée en encourageant de nouvelles firme à entrer sur le marché ?
Le modèle de ce chapitre est un oligopole à la Cournot symétrique, où chaque firme produit un bien homogène à un coût de production nul. Le modèle s'écarte toutefois d'un modèle à la Cournot classique par le fait que la production agrégée des firmes génère un dommage indivisible à l'environnement. Ce caractère indivisible se traduit dans notre modélisation par un dommage qui croît plus que proportionnellement par rapport à la production jointe des firmes. De plus, nous supposons que chacune des

firmes peut investir dans des mesures de précaution. Ces dernières sont assimilables à des contributions à un bien public – la sécurité - puisque réduisant le dommage généré par l'ensemble des membres de l'industrie. Elles bénéficient non seulement à la firme qui les réalise, mais également à ses concurrentes. De plus, le coût de ces mesures est fixe (indépendant des quantités produites par chacune des firmes), ce qui traduit ici des dépenses d'infrastructure réalisées par les firmes.

Enfin les firmes sont soumises à différents régimes de responsabilité environnementale. Ces derniers se distinguent en fonction de trois critères : la règle de responsabilité utilisée (responsabilité stricte ou responsabilité pour faute), le critère de partage utilisé (partage égal entre les firmes ou partage au prorata des parts de marché) et l'utilisation ou non de multiplicateurs de dommages (ou dommages punitifs).

Résultats

Deux résultats principaux ressortent de notre analyse. Au regard de notre première question, nous montrons que les régimes de responsabilité environnementale ne permettent pas de décentraliser, dans un contexte de concurrence imparfaite, un niveau de précaution socialement optimal, ni même une réponse socialement optimale à un niveau d'output donné. Au regard de notre seconde question, nous trouvons que sous un régime de responsabilité environnementale basé sur une règle de responsabilité stricte, couplée à un partage par parts égales et augmentée d'un multiplicateur de dommage optimal, l'application d'une politique de concurrence "conventionnelle" - qui vise à réduire le pouvoir de marché des firmes – permet non seulement d'accroître le surplus des consommateurs, mais également d'inciter les firmes à adopter des mesures de préservation de l'environnement, améliorant ainsi le bien-être social. À l'inverse, sous un régime de responsabilité stricte couplé à un partage par parts de marché, ou bien sous une responsabilité pour faute – réduire le pouvoir de marché des firmes peut au contraire inciter les firmes à réduire leurs dépenses en mesures de précaution, résultant en une dégradation de l'environnement, et donc, du bien-être social. Ces situations peuvent alors justifier l'usage de politiques de concurrence peu conventionnelles qui limitent le nombre de firmes sur un marché.

En premier lieu donc, ce chapitre illustre que les régimes de responsabilités ne permettent pas de décentraliser un niveau de précaution optimal. Sous un régime de responsabilité stricte, les niveaux de précaution et d'outputs d'équilibre peuvent être excessifs comme insuffisants. L'introduction d'un multiplicateur de dommage optimal permet d'obtenir un niveau optimal de précaution pour un niveau d'output donné. Toutefois, le multiplicateur de dommage ne permet pas d'inciter les firmes à également adopter un niveau d'output efficient. Il en résulte donc, étant donné l'interdépendance entre chacune des variables, que les niveaux de précaution et d'output sont inefficaces. Les incitations générées par un régime de responsabilité pour faute ne permettent non plus pas de décentraliser l'optimum social. Si les firmes sont incitées à adopter un niveau de précaution optimal pour un niveau d'output donné, la réduction des coûts induits par le régime de responsabilité pour faute comme les perturbations introduites par la structure de marché imparfaite induisent que les firmes adoptent un niveau de production excessif. De sorte qu'in fine, les niveaux de précaution comme de production sont excessifs à l'équilibre. Quels que soient les régimes de responsabilité utilisés, aucun ne permet, dans le cadre d'une structure de marché imparfaite, d'inciter les firmes à minimiser les coûts associés aux risques d'accidents environnementaux. Il apparaît donc indispensable d'utiliser conjointement un régime de responsabilité et une politique de régulation de la concurrence.

Mais la forme optimale de ce *policy mix* dépend du design du régime de responsabilité, justifiant parfois le recours à des politiques de concurrence peu conventionnelles.

Ainsi nous trouvons que sous un régime de responsabilité stricte augmenté d'une règle de partage par parts égales et d'un multiplicateur de dommage optimal, les politiques classiques menées par les autorités de concurrence ne sont pas perturbées par le régime de responsabilité. Plus particulièrement, une politique qui consiste à accroître la pression concurrentielle sur le marché en incitant de nouveaux concurrents à entrer sur le marché permet d'accroître non seulement le surplus des consommateurs, mais également d'inciter les firmes à accroître leurs dépenses en précaution, augmentant ainsi le bien-être social. Lorsque le nombre de firmes tend vers l'infini (hypothèse d'atomicité du marché), les niveaux de précautions et d'output d'équilibres convergent vers l'optimum social. Ce résultat ne tient plus sous d'autres designs de la responsabilité environnementale. En particulier, lorsque, sous un régime de responsabilité stricte, la répartition du dommage est réalisée au prorata des parts de marché, ou lorsque la responsabilité environnementale se fonde sur une responsabilité pour faute, il peut être préférable de limiter le nombre de concurrents au sein de l'industrie. Sous ses designs, l'entrée de nouvelles firmes peut induire une réduction tant du niveau d'output agrégé que des dépenses agrégées en précaution. Plus encore, sous ses différentes formes de responsabilité, le bien-être social est maximisé pour un nombre fini de firmes. Dès lors, les autorités de concurrence doivent prendre en compte dans la conception des politiques de concurrence le design de la responsabilité environnementale, et adopter en conséquence des politiques non conventionnelles, et notamment des politiques qui limitent la pression concurrentielle sur les marchés compte tenu de l'impact environnementale de celles-ci.

0.4.2 Chapitre 2 : Market collusion with joint harm and liability sharing

Problématique et méthode

Le deuxième chapitre, publié en 2020 dans l'*International Review of Law and Economics*, interroge l'influence des différents régimes de responsabilité sur les incitations des firmes à adopter des comportements collusifs lorsqu'elles génèrent conjointement un risque d'accident. En particulier, nous analysons l'influence de deux règles de partage de l'indemnisation (partage par parts égales c. partage par parts de marché) sur le comportement des firmes, et plus particulièrement sur les incitations à adopter des stratégies de collusion.

Pour ce faire, nous supposons que plusieurs firmes se font concurrence un nombre infinie de période. À chaque période, les firmes doivent choisir leur niveau d'output (contrairement au premier chapitre, la seule variable stratégique à la disposition des firmes est le niveau d'output). Pour modéliser les interactions stratégiques entre les firmes, nous utilisons un modèle de concurrence à la Cournot linéaire et symétrique, où la production agrégée des firmes génère un risque d'accident envers une tierce partie, que l'on peut interpréter comme un bien environmental ou un groupe d'individus n'ayant pas de relations commerciales avec les firmes. En cas d'accident, les firmes sont collectivement tenues d'indemniser le dommage. Nous supposons donc que la responsabilité est une responsabilité stricte. Élément clef de ce modèle, la répartition de cette indemnisation peut se faire selon deux règles de partage : répartition par parts égales ou répartition au prorata des parts de marché. Plus précisément, nous utilisons une combinaison linéaire des deux règles. Cette combinaison linéaire nous permet d'examiner dans quelle mesure la proportionnalité de la règle de partage à la production des firmes incite celles-ci à adopter des stratégies coopératives.

Le dommage (espéré) est également modélisé sous deux formes : soit sous une forme linéaire, auquel cas le dommage espéré croit proportionnellement avec le niveau agrégé d'output, soit une forme quadratique, auquel cas le dommage espéré croit plus que proportionnellement avec la production. Ces deux modélisations du dommage permettent in fine d'avoir soit un coût marginal de production constant, soit linéaire avec la production de chacune des firmes, ce qui joue un rôle clef dans les résultats du modèle.

Enfin, nous supposons que les firmes adoptent des stratégies du déclic (*grim strategies*). Elles commencent par être coopératives. Toutefois, si l'une des firmes dévie à la période $n - 1$, chacune des autres firmes "punit" ce comportement déviant par un retour à l'équilibre de Cournot-Nash durant les périodes suivantes. Ce cadre d'analyse nous permet d'étudier l'influence des règles de partage sur les comportements collusifs.

Résultats

Dans ce cadre d'analyse, nous déterminons deux résultats principaux. Premier resultat, les règles de partage ont une influence sur les gains associés à la déviation unilatérale d'une firme de la collusion comme sur la sévérité de la punition imposée par les autres firmes. Deuxième résultat, cela n'implique pas nécessairement que la soutenabilité de la collusion soit affectée par la règle de partage utilisée : lorsque le dommage (espéré) est linéaire, les règles de partage n'ont pas d'influence sur la soutenabilité de la collusion, mais lorsque le dommage est quadratique, la soutenabilité d'une collusion est plus faible lorsque le dommage est réparti au prorata des parts de marché.

Le premier résultat réside dans le fait que le passage d'un partage égal à un partage au prorata des parts de marché induit une baisse du gain associé à une déviation de la collusion, mais également une réduction du pouvoir de punition des firmes. En effet, les profits de court terme comme les perte de long terme associés à une déviation sont tous deux affectés par deux externalités qu'exercent les firmes entre elles. L'une est due à la structure imparfaite de la concurrence et l'autre à la répartition du dommage entre les firmes. Une évolution de la règle de partage vers une réparation par parts de marché accroît le coût marginal de production des firmes, puisque chaque unité supplémentaire produite accroît pour une firme non seulement le dommage espéré, mais également la part de la compensation de ce dommage qu'elle doit indemniser. L'introduction de ce coût marginal supplémentaire associé à la répartition par part de marché induit une baisse du profit de déviation, la firme déviante étant plus exposée à la responsabilité. Mais il induit également une baisse des perte associées à la sanction de ce comportement. En effet, le coût marginal de responsabilité étant supérieur sous une répartition au prorata des parts de marché que sous un partage par parts égales, les firmes produisent moins sous la première règle de partage, ce qui accroît le prix du marché. In fine, le profit sous une concurrence à la Cournot est supérieur avec un partage par parts de marché, ce qui réduit la sévérité de la punition exercée par les membres du cartel à l'égard de la firme déviante. Le second résultat tient au fait que l'impact de ces deux effets contraires sur la soutenabilité de la collusion dépend de la forme du dommage. Lorsque la demande de marché et les coûts auxquels font face les firmes, incluant le coût de responsabilité, sont linéaires, ces deux effets s'annulent, de sorte que la soutenabilité de la collusion n'est pas impactée. En revanche, dès lors que l'on sort de ce cadre parfaitement linéaire, ce que nous faisons en supposant que le dommage (espéré) est quadratique, alors la soutenabilité de la collusion est influencée par la règle de partage utilisée : le passage d'une répartition par parts égales à une répartition par parts de marché réduit le pouvoir de punition des membres du cartels de façon relativement plus importante que ne baisse le gain de déviation, ce qui rend ainsi la formation de collusion moins probable sur les marchés. De plus, lorsque l'on compare les deux scenarii – dommage linéaire et dommage cumulatif – l'on observe que les collusions sont plus soutenables lorsque le dommage est cumulatif.

Ainsi, ce chapitre met en évidence deux résultats fondamentaux. D'une part, l'influence des règles de partage sur la soutenabilité des collusions dépend de la forme linéaire ou quadratique du dommage espéré. Si dans un cadre parfaitement linéaire, celles-ci sont sans influence, ce résultat ne vaut plus lorsque le dommage est cumulatif. Ensuite, les collusions sont plus soutenables lorsque le dommage est cumulatif.

Aussi et par conséquent, ce chapitre invite les autorités de concurrence à focaliser leurs investigations sur les dommages non-linéaires, plus susceptibles d'inciter les firmes à former des comportements collusifs. Dans cette situation, les autorités doivent également être vigilantes quant à la structure de la règle de responsabilité et de la règle de partage associée, une répartition proportionnelle aux parts de marché incitant moins les firmes à adopter des stratégies coopératives qu'un partage par parts égales.

0.4.3 Chapitre 3 : Apportioning indivisible environmental harm, and the joint and several liability doctrine

Problématique et méthode

Ce troisième chapitre se concentre sur l'étude de deux doctrines juridiques, la *Joint and Several Liability* (JSL) et la *Joint Liability* (JL), dans le cadre de dommages environnementaux indivisibles. Plus précisément, nous étudions l'impact des différents designs de responsabilité environnementale sur les choix de production et d'investissement en précautions de firmes en concurrence à la Cournot et dont la production agrégée génère un dommage à l'environnement. Comme dans le premier chapitre, nous supposons que les mesures de précaution adoptées par les firmes ont des propriétés équivalentes à des contributions à un bien public – la préservation de l'environnement – puisque l'ensemble des firmes appartenant à une même industrie profitent des bénéfices associés aux mesures de précaution de chacune d'entre elles. Les différents designs de la responsabilité environnementale reposent sur 3 piliers : la règle de responsabilité utilisée (responsabilité stricte c. responsabilité pour faute), la présence de dommage punitifs (optimaux ou non) et la doctrine juridique utilisée (JL c. JSL). Nous developpons l'analyse en supposant que les cours appliquent toujours un partage par parts égales (s'il est nécessaire de réaliser un tel partage). En annexe, nous étendons les résultats dans le cas d'un partage par parts de marché.

La JL est une doctrine qui permet à une victime de poursuivre l'intégralité des offenseurs dans un seul et même procès. À l'inverse, sous la doctrine de la JSL, la victime peut exiger de chacun des offenseurs la réparation de l'intégralité de son dommage, chacun des offenseurs étant responsable in solidum des dommages causés. De plus, nous étendons l'analyse aux situations où un recours en contribution est intégré à la JSL. Dans cette hypothèse, l'offenseur est obligé d'indemniser l'intégralité du dommage. Le défenseur principal, peut, dans un second procès, exiger des autres offenseurs de contribuer à l'indemnisation.

Résultats

De ce cadre d'analyse, nous déduisons quatre résultats originaux.

Le premier résultat concerne le fait que, lorsque l'ensemble des firmes ont une probabilité strictement positive de contribuer à l'indemnisation d'une part du dommage collectivement généré, les niveaux de précaution et d'output à l'équilibre sous chacune des doctrines, JL ou JSL, peuvent être supérieurs comme inférieurs aux niveaux socialement optimaux. Mais surtout, aucune des doctrines étudiée n'est, dans l'absolu, socialement préférable à une autre. En fonction des valeurs des paramètres du modèle, les niveaux de précaution des firmes peuvent être supérieurs sous une doctrine que sous une autre, mais les niveaux en output inférieurs, sans qu'il soit possible de déterminer in fine sous lequel de ces régimes le bien-être social est le plus élevé. Ce résultat est dû à l'interdépendance stratégique entre les choix de précaution et d'output à laquelle sont confrontées les firmes. Toutefois, si nous supposons que le plaignant désigne de façon purement aléatoire le défendeur principal (restriction des paramètres), alors nous trouvons une équivalence de résultat entre chacune des doctrines : les niveaux de précaution et d'output à l'équilibre sont les mêmes sous une JL ou sous une JSL – avec ou sans recours en contribution – et ces niveaux sont sous-optimaux.

Nous retrouvons un deuxième résultat lorsque la victime cible un défenseur principal auprès duquel elle exige une indemnisation sous la doctrine de la JSL de façon déterministe. Dans cette situation, les firmes se retrouvent face à des coûts de responsabilité asymétriques. Il est alors possible de déterminer les fonctions de meilleures réponses de chacune des firmes en terme de précaution et d'output, en fonction de son type et de la doctrine utilisée. Elles nous permettent de déduire notamment que pour un niveau d'output exogène, les firmes qui ne sont pas ciblées comme défendeurs principaux ne prennent aucune mesures de précaution sous une JSL sans recours en contribution, tandis qu'elles adoptent un niveau de précaution supérieur sous une JL que sous une JSL avec un recours en contribution. À l'inverse, la firme ciblée comme défendeur principal adopte, pour un niveau d'output exogène, un niveau de précaution supérieur sous une JSL sans recours en contribution que sous une JSL avec recours en contribution, le niveau de précaution sous une JSL avec recours en contribution étant lui-même supérieur à celui sous une JL. Ces résultats sont cohérents avec la littérature (voir notamment Tietenberg (1989)). L'apport de ce chapitre au regard de la littérature existante tient au fait que lorsque le niveau d'output est endogène, il ne nous est pas possible de déterminer les outcomes à l'équilibre sous chacune de ces doctrines – et donc de les comparer et de déterminer les effets que produisent chacune de ces doctrines. Là encore, on ne peut déterminer si l'une des doctrine est socialement préférable à une autre.

Troisième résultat, l'utilisation d'un multiplicateur de dommage optimal ne permet pas de résoudre les distorsions induites à la fois par la structure de marché imparfaite et par le partage par parts égales du dommage. Toutefois, ce multiplicateur incite les firmes à adopter un niveau de précaution socialement optimal étant donné le niveau de production, ce qui rapproche in fine l'équilibre de l'optimum social. Il permet de plus de rendre les différentes stratégies du plaignant inopérantes, puisque nous montrons que l'utilisation de multiplicateurs de dommages optimaux adaptés à chaque régime de responsabilité conduit les firmes à mettre en œuvre les même décisions output/précaution et donc induit le même équilibre.

Quatrième résultat, nous trouvons que la responsabilité pour faute ne permet pas d'inciter les firmes à adopter un niveau de précaution efficient. La responsabilité pour faute apparaît comme une règle instable : en fonction des paramètres du modèle, il peut exister deux équilibres de Nash, un seul, ou aucun. À l'inverse, la règle de responsabilité stricte est stable, en ce sens que sous des hypothèses basiques, la responsabilité stricte conduit à un seul équilibre. Là encore, ces résultats s'écartent de ceux déterminés par la littérature lorsque le niveau d'output/activité est exogène. Dans ce cadre d'analyse, plusieurs auteurs (Tietenberg (1989), Kornhauser and Revesz (1989)) déterminent que le régime de négligence complété des doctrines de JL ou de JSL permet d'inciter les firmes à adopter un niveau de précaution socialement optimal. Ce résultat permet aux auteurs de conclure qu'un régime de négligence est préférable à un régime de responsabilité stricte. À rebours de ces recommandations, l'endogénéisation du niveau d'activité montre que la négligence est un régime instable. À ce titre, la responsabilité stricte apparaît comme plus prévisible, et donc préférable.

Chapter 1

Should environment be a concern for competition policy when firms face environmental liability

This chapter is a joint work with Eric LANGLAIS.

Abstract

In the recent period, more and more voices have called for unconventional competition policies as a way to achieve higher environmental investments from firms. This chapter shows that this objective may come into conflict with those of environmental liability laws. We introduce a basic oligopoly model where firms produce a joint and indivisible environmental harm as a by-product of their output. We first analyze the effects on the equilibrium of alternative designs in environmental liability law, secondly, we discuss the rationale for "non-conventional" competition policies, i.e. more concerned with public interest such as the preservation of environment (as well as human health and so on). We study firms decisions of care and output under various liability regimes (strict liability vs negligence) associated with alternative damages apportionment rules (per capita vs market share rule), and in some cases with damages multipliers. We find that basing an environmental liability law on the combination of strict liability, the per capita rule, and an "optimal" damages multiplier, is consistent with a conservative competition policy, focused on consumers surplus, since, weakening firms' market power also increases aggregate expenditures in environment preservation and social welfare. In contrast, a shift to the market share rule, or to a negligence regime, may be consistent with a restriction of competition, since firms' entry may instead lead to a decrease in aggregate environmental expenditures and losses of social welfare. Nevertheless the fine tuning of the policy requires specific information from a Competition Authority, which we discuss as well.

Keywords: Strict liability; negligence; damages apportionment rules; market share liability; environmental liability; Cournot oligopoly; competition policy.

JEL codes: K13, K32, L13, L49.

This chapter is published. See Charreire, M. and Langlais, E. (2021). Should environment be a concern for competition policy when firms face environmental liability. *International Review of Law and Economics*, 67:105990.

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Chapter 2

Market collusion with joint harm and liability sharing

This chapter is a joint work with Florian BAUMANN and Andreea COSNITA-LANGLAIS

Abstract

When it is impossible to identify ex post the producer of a product causing harm, or the damage caused is indivisible although caused by multiple injurers, courts must apportion the total damage among tortfeasors. In this chapter we examine how such liability sharing rules affect the likelihood of tacit collusion. For this we use a standard Cournot oligopoly model where firms are collectively held liable for joint harm inflicted on third parties. With repeated market interaction and grim strategies, we investigate the sustainability of collusion to derive some policy implications.

Keywords: Cournot oligopoly, liability sharing rules, market collusion

This chapter is published. See Baumann, F., Charreire, M., and Cosnita-Langlais, A. (2020). Market collusion with joint harm and liability sharing. *International Review of Law and Economics*, 62:105885

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Chapter 3

Apportioning indivisible environmental harm, and the Joint and Several Liability Doctrine

This chapter is a joint work with Eric LANGLAIS

Abstract

In this chapter we analyze the implications for environmental liability laws of two legal doctrines, Joint and Several Liability and Joint Liability, which provide solutions for settling cases where multidefendants are jointly involved in the harm to a victim. We consider a situation where offenders are firms pertaining to an oligopoly, and produce a homogeneous good and, as a by-product, an indivisible environment harm. We compare the effects on preservation measures and output decisions that result from alternative designs for the environmental liability law based on three pillars : a legal doctrine (Joint Liability vs Joint and Several Liability), a liability rule (strict liability vs negligence), a damages multiplier (optimal vs suboptimal multiplier).

Keywords: Joint and Several Liability; Strict liability; damages apportionment; market share liability; environmental liability; imperfect competition.

3.1 Introduction

The protection of environmental and natural resources is a major stake for public policies today. However regarding the implementation of their environmental policies, governments are often strongly constrained by the political and social acceptability of the tools they wish to use. In contrast to *ex ante* instruments such as regulations, taxes[1] or permits[2], environmental liability laws provide *ex post* tools for implementing the polluter-payer principle that usually have a better social acceptability.

Nevertheless the settlement of environmental cases by Courts is challenging for judicial systems. Environmental harm is often the result of joint actions by individuals, and specifically by firms in an industry. Many industrial activities entail potential harmful consequences for the environment and/or human health, as a by-product of their production, with diffuse, large-scale and long-term standing effects that result in indivisible harm to the environment or human health. The point is that establishing facts in separate trials for each offender or determining separate causations is not achievable when indivisibility exists. Hence if plaintiffs (public environmental agencies, or private associations) can not sue the different firms involved in the harm unless through individual trials, there is a risk that liability laws fall down *de facto* into a no liability regime, and that environmental harm never be compensated. Legal doctrines, such as Joint Liability or Joint and Several Liability, provide solutions for settling cases where multidefendants are jointly involved in the harm to a victim, and have been adopted in several environmental laws in Europe as well in the USA.

The Comprehensive Environmental Response, Compensation, and Liability Act, for example was adopted by the US Congress in 1980 (and amended by the Superfund Amendments and Reauthorization Act of 1986) to cleaning up uncontrolled or abandoned hazardous-waste sites which exist throughout the United States, as well as those resulting of accidents, spills, and other emergency releases of pollutants and contaminants into the environment. Two decades after, the European Union adopted

[1] Green taxes face protestations on a regular basis, either from industrials or from citizens. See for example the reaction of the companies of trucks for road transportation in France in 2014: https://www.europe1.fr/economie/Royal-enterre-encore-l-ecotaxe-les-routiers-arretent-leur-greve-683018 . See more recently the so-called revolt of "yellow vests" from October 2018 to January 2020 : https://en.wikipedia.org/wiki/Yellow_vests_movement .

[2] Ecological associations and the Green Party are usually strong opponents to markets for pollution permits. See for example https://npa2009.org/content/droits-%C3%A0-polluer-un-syst%C3%A8me-injuste-et-contre-productif-par-g%C3%A9rard-vaysse.

the directive 2004/35/CE on environmental liability with regard to the prevention and remedying of environmental damage. While both laws follow similar objectives, they diverge on three fundamental points.[3] First of all, under CERCLA all responsible parties are subject to strict liability. On the contrary, the European Directive introduces a distinction between operations and activities that are subject to strict liability all being listed in its Annex III,5 and those (not listed) that are subject to negligence.[4] Secondly, in case where the Superfund is activated, the government is allowed under CERCLA to use punitive damages, while the European directive only provides for compensatory damage. Finally, under CERCLA courts traditionally use joint-and-several liability (all parties have full responsibility) while the European directive states that liability apportionment should be determined in accordance with national law. [5] Even if few state members have prefered to adopt proportionate/several liability, the vast majority also choose joint-and-several liability[6]. In this regard, The Principles of European Tort Law proposed by the European Group on Tort Law, which constitutes a compilation of guidelines for the national authorities and represents "a common denominator among various European legal system" Faure (2016), opts for the doctrine of joint and several liability in case of indivisible harm[7].

Although the adoption of such environmental liability laws has been motivated mainly on the grounds of the "deep-pocket" argument, it is important to understand the incentives driven by the different designs adopted, and their effects on environmental preservation measures. The purpose of this paper is to provide an analysis of Joint

[3]For an overview of the distinctions between CERCLA and the EU directive, see Tabatabai (2012)

[4]Activities listed in its Annex III,5 include for instance the waste management operations, the release of pollutants into the water or air, the manufacture, use, storage, processing, filling, release into the environment and on site transport of dangerous substances as defined by european directives. Note also that a number of Member States included further activities not mentioned in Annex III in the scope of strict liability (Belgium, Denmark, Finland, Greece, Hungary, Latvia, Lithuania, Netherlands and Sweden).

[5]Article 9 of the directive states that "This Directive is without prejudice to any provisions of national regulations concerning cost allocation in cases of multiple party causation"

[6]The commission observes that "for rules on multi-party causation, most Member States opted for a system of joint and several liability, whilst a minority chose proportionate liability (Denmark, Finland France, Slovakia and Slovenia)." See European Commission, report from the commission to the council, the European parliament, the European economic and social committee and the committee of the regions under Article 14(2) of Directive 2004/35/CE on the environmental liability with regard to the prevention and remedying of environmental damage. Article 162-18 of the French environmental code states that "Lorsqu'un dommage à l'environnement a plusieurs causes, le coût des mesures de prévention ou de réparation est réparti par l'autorité visée au §2 de l'article L. 165-2 entre les exploitants, à concurrence de la participation de leur activité au dommage ou à la menace imminente de dommage. "

[7]Article 3 : 102 of the *Principles of European Tort Law* states that *"In case of multiple activities, where each of them alone would have caused the damage at the same time, each activity is regarded as a cause of the victims damage. "*

Liability, and Joint and Several Liability, in the important case of indivisible environmental harms. Our analysis deals explicitly with interdependencies existing at a firm level between care and output decisions, and at the same time, considering the existence of strategic interactions between firms in imperfect competitive environments. Our paper adds to the literature in several respects. Firstly, to our knowledge, this is the first paper to analyze the effects of Joint and Several Liability taking explicitly into account market interactions, and imperfect (quantity) competition. Secondly, we also provide a first (comparative) analysis of the implications of simple, basic apportionment damages rules, when combined with either the Joint Liability doctrine or the Joint and Several Liability doctrine in a multitortfeasors context. Finally, our paper also innovates with respect to the focus made on the case for (joint) indivisible harms to the environment, where the issue of damages sharing is still a matter of debate.

Section 2 provides a survey of the literature. Section 3 introduces our model, based on an oligopoly producing a homogeneous good, but also as a by-product, an indivisible environmental harm; we solve for the social optimum. Section 4 analyzes the implications of Joint and Several Liability on the industry equilibrium with Cournot competition, considering that a strict liability regime prevails. Section 5 considers instead a regime of negligence. Section 6 concludes.

3.2 Literature review

Our paper builds on the pioneering literature dedicated to liability with multiple tortfeasors (for a survey of several liability, joint and several liability, see Kornhauser and Revesz (2000)), focused on care incentives. Landes and Posner (1980) and Shavell (1984) have first considered the standard question of the comparative advantages of strict liability vs negligence for care decisions, finding that neither rule is efficient to induce tortfeasors to undertake efficient decision in care activity. Miceli and Segerson (1991) turn to the issue of firms entry, but do not explicitly consider the strategic interactions between firms. Hansen and Thomas (1999) analyze the issue of liability sharing between generators and disposable sites of hazardous wastes in competitive economies, while Watabe (1999) deals with the issue of delegating a dangerous activity. The specific case of indivisible harm has motived less studies to our knowledge. Tietenberg (1989) and Li (2019) address the issue of damages sharing in cases of indivisible torts to the environment (contaminated waste sites, aquatic pollutions and so on) produced by several firms, but Tietenberg does not introduce firms production decisions, while Li introduces *ad hoc* apportionment rules based on (exogenously) fixed shares.

In this perspective, Tietenberg (1989) has provided a comparative analysis of the performances of standard liability regimes (negligence vs strict liability) under the doctrines of Joint Liability and Joint and Several Liability, when firms produce joint indivisible environmental harm (such as for toxic torts cases, wastes disposables and so on), and his analysis has obvious implications for CERCLA. He concludes that although simple negligence is a weak revenue raiser compared with strict liability, negligence associated either with Joint Liability or with Joint and Several Liability is effective in achieving efficient preservation measures: in every case, negligence will induce from any of the firms to abide with the due level of care when (close enough) set to the first best level. In contrast, strict liability always induces inefficient care expenditures, despite it being an effective tool for collecting damages for environmental harms. Some authors have commented on specific dimensions of the European Directive, such as the articulation between liability and insurance (for example Fluet (2016)), but to the best of our knowledge no formal analysis of the general design of the European Directive in the line of Tietenberg analysis.

An important issue concerns the properties of specific rules in lawsuit cases with multidefendants. Feess and Muehlheusser (2000) introduce informational asymmetries and deal explicitly with pretrial negotiations for the purpose of comparing the effects of a proportional rule, and an (un-)conditional pro tanto rule, in a context where the plaintiff sues each defendant in separate trials. The two rules we consider in this paper, the market share rule and the per capita rule, have motivated a debate among US scholars focusing its consistency on basic causation requirements, as well as its moral/ethical roots (see Dillbary (2011), Kornhauser and Revesz (1989), Priest (2010)). The debate has acknowledged a revival in France with the 2014 *Distilbène litigation*, several French scholars arguing in favor of traditional solutions adopted for damages apportionment (Molfessis (2015), Quézel-Ambrunaz (2010)). In contrast, Ferey and G'sell (2013) suggest new foundations for the market share rule arguing that market shares may be a proxy for the likelihood of individual liability at the stage of damages apportionment, in contexts of joint liability characterized by hard uncertainty and ambiguous causation. More recently, Leshem (2017) analyses how the use of composite rules (weighting of a proportional contribution rule with the equal allocation one) may improve the injurer's incentives to take care. Dehez and Ferey (2013), Ferey and Dehez (2016), or Kim and Lee (2019) rely on cooperative game tools and the Shapley value, in order to identify apportionment rules that are both efficient and fair, in context of multiple causation.

Finally, our paper is obviously connected to the vast literature on the performances of product liability in alternative competitive environments (for a survey, see Daughety and Reinganum (2013b), and more specifically two papers that introduce Joint Liability here. Marino (1991) considers a case of an oligopoly producing a joint but divisible harm as a by-product of its marketed output, and shows that strict liability with the market share rule provides inefficient incentives in care decisions, and arrives at an industry equilibrium which is suboptimal. Daughety and Reinganum (2014) instead discuss (among others) a case with correlated and cumulative individual harm , and show that when strict liability is combined with a modified market share rule and an optimal damages multiplier, then firms face efficient incentives in care activities, allowing that firms entry on the market moves the oligopoly equilibrium closer to the social optimum.

3.3 The framework

3.3.1 Assumptions

We consider a symmetric oligopoly *à la Cournot* where $n > 2$ firms compete for a homogenous product. Both consumers and firms are risk neutral. The quantity of goods produced by firm i is denoted q_i ($\forall i = 1, ..., n$), and $Q = \sum_{i=1}^{n} q_i$ represents the industry output. The inverse market demand is denoted $P(Q)$, and is supposed to be decreasing and concave: $P'(Q) < 0$ and $P''(Q) < 0$.

We assume that each firm i $(= 1, ..., n)$ operates at a cost given by $C(q_i, x_i) = c(x_i)q_i$, where x_i represents the level of care of firm i, satisfying: $c(0) = 0$, $c'(0) = 0$, and $\forall x_i > 0$: $c'(x_i) > 0$ and $c''(x_i) > 0$. This means that the marginal cost corresponding to the use of all productive inputs (care expenditures aside) is constant and equal to the cost of care, while the marginal cost of care increases with a firm output – referring to the terminology used by Nussim and Tabbach (2009), this corresponds to the case with non durable care.

Finally, the product may cause a joint harm to society (third party victims, not consuming the good), such that the individual contribution by each firm cannot be disentangled[8]; thus, the expected harm is supposed to be $H(Q,X) = h(X).Q^2$, $h(X)$ is the joint probability of harm – satisfying $h(0) > 0$ and $h(X) < 1$ for any $X \geq 0$ – and $X = \sum_{i=1}^{n} x_i$ is the aggregate care expenditure.

Finally, most of the central results of the paper have been obtained thanks to a set of very simple assumptions, namely:

H1a. $-P'(q) > h(0)$. **H1b.** $h'(X) < 0 < h''(X)$ for any $X \geq 0$; **H1c:** $H(Q,X)$ is convex in (Q,X).

H1a puts a lower bound for the slope of the inverse market demand. H1b is usual in the literature on liability rules, saying that the probability function is decreasing and convex with care expenditures. H1c has sound economic motivations, since it establishes that the expected external harm to society is supposed to be a convex function, which is a very natural and reasonable assumption for a cost function. H1c implies that the next condition holds:

$$\text{For any } (Q,X) > 0 : \left[h(X)h''(X) - 2\left(h'(X)\right)^2\right] > 0 \qquad (3.C1)$$

Under (3.C1), second order conditions, as well as the uniqueness and stability of Nash equilibrium are satisfied for the social optimum, as well as the different market equilibria and liability regimes we consider below (See in Appendix). Hence, we do not insist on these issues in the sequel (excepted when mentioned).

3.3.2 The benchmark : social welfare maximization

Social welfare is the sum of consumers' total utility minus the sum of firms operating costs (cost of care), minus the expected harm: $SW = \int_0^Q P(z)dz - \sum_{i=1}^{n} c(x_i).q_i - H(Q,X)$. We will directly use firms symmetry in order to reduce the dimension of the optimization problem, allowing the benevolent planner to focus on a symmetric optimum where $q_1 = ... = q_n = q$ and $x_1 = ... = x_n = x$, with the aggregate output and care levels

[8]For example, in the case of the Orly Airport litigation for noise pollution (1988, Cass. 2e civ, No 86-12.543), the individual contribution of each plane and/or company cannot be easily assessed, at least at a reasonable economic or social cost - neither instantaneously, nor across periods.

given by respectively $Q = nq$ and $X = nx$. As a result, social welfare may be written as a function of (q, x):

$$SW = \int_0^{nq} P(z)dz - n.c(x).q - h(nx)\,(nq)^2 \tag{3.3.1}$$

The first-order conditions for an interior solution (q^{sw}, x^{sw}) are written:

$$P(nq) = c(x) + 2h(nx)nq \tag{3.3.2}$$

$$-h'(nx).n^2q = c'(x) \tag{3.3.3}$$

meaning that the optimal output level (see condition (3.3.2)) must be pushed up to the point where the average market proceeds (LHS) are equal to the marginal cost associated with expected harm (RHS); similarly (condition (3.3.3)), optimal care expenditures are such that the marginal cost of care (RHS) is equal to the social marginal benefits associated with the decrease in the expected harm (LHS). It can be verified that under (3.C1), output and care decisions defined according to (3.3.2))-(3.3.3) are strategic complements (see in Appendix).

3.4 Joint and Several Liability with the Strict Liability rule

We assume in this section that the liability regime is based on strict liability according to which Courts do not rely on a negligence test, and need only causation to establish the responsibility of firms. We discuss the case for negligence in section 5.

Remark 1: Several legal doctrines are concerned with the settlement of cases where multidefendants are involved in the harm a victim is suffering from (Landes and Posner (1980), Kornhauser and Revesz (1989)). One is Several Liability, according to which the Plaintiff is entitled to the right to sue each one of the firms in separate trials. Several Liability is not relevant in our context since the environmental harm is indivisible: thus establishing facts on individual basis, and/or determining separate causations for each defendant is not achievable, and would leave the Plaintiff with the impossibility to be compensated for the harm borne. Instead, the doctrine of Joint Liability affords the Plaintiff with the opportunity to sue in a single trial the different defendants involved in its harm. Given Joint Liability, the main issue when defendants are strictly liable is the way total damages will be apportioned between them. An alternative doctrine is Joint and Several Liability which may give rise to two sequential trials. Under Joint and Several Liability each defendant successfully sued by the Plaintiff is responsible *in solidum* for the joint harm they cause, and the Plaintiff is entitled to obtain the payment of total damages from any one of the defendants. Given the obvious unfair implications of this outcome, and depending on specific traditions or jurisdictions (Tietenberg (1989), Smith (1989)), a right ofcontribution may have been created, that allows Defendants that have been sentenced to pay a compensation to the Plaintiff, to seek reimbursement in a second trial from other parties that have not.

Remark 2: In the context of CERCLA for example, the "joint and several liability" doctrine has proven to be an effective means of financing the restoration of contaminated waste sites, and to secure the reimbursement of clean-up expenditures. In practice, Joint and Several Liability has enabled Public Environmental Agencies to focus on solvable firms and activities involved in the pollution of these sites, thus avoiding issues such as the "judgment-proof problem" or the "disappearing defendant" problem. In our set up, firms in the industry are symmetric, and such issues are not relevant. Nevertheless, the choice between Joint Liability and Joint and Several Liability instead, may be motivated by the existence of litigation costs (see Kornhauser and Revesz (1989, 2000),Landes and Posner (1980); Tietenberg (1989)) although they are not directly captured by the model. In case of a unique trial where the Plaintiff sues the set of all potential defendants (alike under Joint Liability), there are several litigation costs that will be duplicated for the Plaintiff during the pre-trial stage (investigations, scientific expertise, testimonies) in order to establish facts and causation for each defendant/firm. Litigations in the context of environmental harm (or health) often raise technical issues, and motivate methodological controversies between scientific experts. One of the implications is that such cases require long delays before being settled, the greater the number of defendants, the longer the delays. As a result, this raises both the direct costs associated with the litigation, such as pleading costs, as well as the indirect costs (generally speaking "the value of time"). From this point of view, "Joint and Several Liability", may help the plaintiff in saving on such costs, since she is entitled to the right to sue a subset of potentially responsible parties in order to obtain the payment of total damages. In the current paper, as a result of firms symmetry, we assume that under Joint and Several Liability, the Plaintiff sues a single firm.

Remark 3: Tietenberg (1989) observes that most of sharing arrangements could appear as arbitrary in cases with joint and indivisible harm. However case law shows us that traditional solutions have emerged. Accordingly, Courts' decisions are founded on the seriousness of each defendant's misconduct to establish how the damages to victims will be shared between the different injurers. We focus the analysis hereon the *per capita rule*.[9] In the Appendix, we show that should Courts consider the market share rule, then the equilibrium would correspond to a lower output and a lower care than under the per capita rule – i.e. proposition 1 of chapter 1 extends to Joint and Several Liability: the market share rule still aggravates the problem of output underprovision created by the distortion due to imperfect competition.

Remark 4: We are not very specific with procedural rules, and generally speaking we ignore the existence of litigation costs, as well as strategic aspects of settlements and litigations (pretrial negotiations). Similarly, we are not specific with Plaintiff type/identity. It may be a (public) environmental agency – in this case, the trial will come to an administrative jurisdiction/Court; or it may be a private association involved in the protection of environment, or generally speaking a third-party victim (the Plaintiff is an individual who has neither an economic nor contractual relationship with the Defendants) – hence, the case will be settled in front of a civil Court. The way total damages are shared between multidefendants may have strategic aspects, since the choice of a sharing rule is either in the hands of Courts, or a decision of the Plaintiff. This corresponds to reality,[10] and depends on legal tradition specific to national jurisdictions or legal doctrinal issues. Indeed, this is neutral here since

[9] Basic causation requirements imply that the contribution of each defendant, among the pool of identified tortfeasors, should be proportional to its contribution to the harm of the victims. Thus, if no fault is established for any defendant, then no one is liable (no liability rule); if all the defendants committed a fault with the same intensity, then the damages are equally shared between them (per capita rule). In France, for example, Article L. 162-18 of Code de l'environnement, states that: *Lorsqu'un dommage à l'environnement a plusieurs causes, le coût des mesures de prévention ou de réparation est réparti par l'autorité visée au 2 de l'article L. 165-2 entre les exploitants, à concurrence de la participation de leur activité au dommage ou à la menace imminente de dommage.*

[10] In the Distilbène litigation in France, the Court implemented the market share rule to solve the issue raised by the lack of evidence. In case of the implementation of CERCLA, Environmental Agencies are entitled to choose the apportionment of damages between the potential defendants, and thus may avoid issues raised by the insolvability of some defendants.

we assume complete information, we rule out the insolvability problem, and do not consider the Plaintiff costs. Rather we focus on firms/defendants liability costs.

3.4.1 A simple model of Joint and Several Liability

Here we capture the essence of Joint and Several Liability, adopting a simple structure with two potential sequential trials. To keep simple, we assume that information is complete, and there is no negotiation (either between the victim and the Principal Defendant, or between this last one and the other firms).

The model has two periods. In period 1, any of the n firms has a probability $p \in]0,1[$ to be designated as the Principal Defendant in the first trial, and be sentenced for total damages $D = Q^2$. In period 2, either a firm has been sentenced in the first trial and sues its $n-1$ opponents with probability $\theta \in]0,1[$; the purpose of the second trial for the Principal Defendant is to obtain the sharing of D, or equivalently the reimbursement of $(1-s_i).D$. Or a firm has not been sued initially, but she will be sued by the Principal Defendant with probability $\theta \in]0,1[$; the outcome of this second period trial is that the firm has to reimburse $s_i.D$ to the Principal Defendant. This implies that $L_i^{JSL}(q_i, x_i)$, the expected liability cost of firm i, e.g. the amount of compensation accruing ex ante to firm i, may be written as:

$$\begin{aligned} L_i^{JSL}(q_i, x_i) =& p.\alpha h(X).\left[D - \theta\left((1-s_i).D\right)\right] + (1-p)\theta.\alpha h(X).\left(s_i.D\right) \\ =& \left[\theta.s_i + (1-\theta).p\right].\alpha h(X) Q^2 \end{aligned}$$

where $\alpha \geq 1$ is a damages multiplier used by Courts to inflate total damages paid by responsible parties. Finally, let us assume that at the stage of the second trial, Courts divide total expected damages in equal share between all firms pertaining to the industry, i.e. $s_i = \frac{1}{n}$, $\forall i = 1, ..., n$. Remark that H1c guarantees the convexity of the individual liability cost function $L_i^{JSL}(q_i, x_i) = \left[\theta.\frac{1}{n} + (1-\theta).p\right] \alpha h(X) Q^2$ with respect to (q_i, x_i).

Remark 5: This way the model focuses the attention on the risk structure that a liability regime puts on firms. As long as the strategy of the Plaintiff is not made explicit yet, the model captures different situations depending on the way we interpret the probability p. Since Joint and Several Liability makes each successfully sued defendant potentially liable for the entire damage caused, it enables the Plaintiff who sues several defendants to demand that only one among them pays total damages. Hence a first possible interpretation of the model states that for recovering the payment of total damages, the Plaintiff's strategy consists of picking up the Principal Defendant among the n firms with probability p; one specific case we discuss below is when the Plaintiff makes a pure random draw i.e. $p = \frac{1}{n}$. A second interpretation is that the Plaintiff does not designate a single Principal Defendant but focuses at the first trial on a subset of $k < n$ firms (see Tietenberg (1989)) and demands a sharing of total damages in proportion $\frac{1}{k}$ between them (formally this yields the same liability cost substituting p with $p.\frac{1}{k}$).[11] Anyway, the different interpretations yields the same outcome regarding firms' liability cost – this is the main point. However, we return to the issue of Plaintiff's objective and the choice of a strategy in paragraph 3. In the meanwhile, one is allowed to understand the different results we discuss in propositions 1 to 3 as corresponding to interim equilibrium situations for a given Plaintiff's strategy (i.e. Nash equilibria associated to firms' strategy in any subgame following a given strategy for the Plaintiff).

Under this liability cost, each firm $i(= 1, ..., n)$ chooses a level of output and a level of care in order to maximize its profit:

$$\Pi^{JSL}(q_i, x_i) = [P(Q) - c(x_i)]\, q_i - \left[\theta.\frac{1}{n} + (1-\theta).p\right].\alpha h(X)Q^2 \tag{3.4.1}$$

It is easy to verify using the first order conditions that the symmetric Cournot-Nash equilibrium where $q_1 = ... = q_n = q^{JSL}$ and $x_1 = ... = x_n = x^{JSL}$ solves the system (see in Appendix):

$$P(nq) + P'(nq)q = c(x) + 2\left[\theta.\frac{1}{n} + (1-\theta).p\right].\alpha h(nx).nq \tag{3.4.2}$$

$$-h'(nx).\alpha\left[\theta.\frac{1}{n} + (1-\theta).p\right].n^2 q = c'(x) \tag{3.4.3}$$

meaning that the output level (see condition (3.4.2)) must be pushed up to the point

[11] In this case, we have:
$L_i^{JSL}(q_i, x_i)$
$= p.\alpha h(X).\left[\frac{1}{k}D - \theta\left(\left(\frac{1}{k} - s_i\right).D\right)\right] + (1-p)\theta.\alpha h(X).(s_i.D)$
$= \left[\theta s_i + (1-\theta)\frac{p}{k}\right].\alpha h(X)D$

where marginal market proceeds are equal to the marginal cost of liability (RHS); similarly (condition (3.4.3)), care expenditures are such that the marginal cost of care (RHS) is equal to their marginal benefits, defined as the decrease in the expected liability cost (LHS). We can remark more specifically that the LHS in (3.4.2) exhibits the standard distortion due to imperfect competition according to which the marginal markets proceeds are smaller than the market demand price (RHS in (3.3.2)). It is easy to verify under (3.C1) that output and care levels defined by (3.4.2) - (3.4.3) are strategic complements (see in Appendix).

Condition (3.4.3) shows that firms' private marginal benefits associated with care under strict liability are smaller than their socially optimal value, implying that firms have inefficient incentives to take care at any output level. Strict liability (whatever the damage sharing rule) also leads to an inefficient rule for output choice since (3.4.2) shows that the furniture of the output is driven by two opposite effects. On the one hand, firms' marginal market benefits under strict liability fall short of their socially optimal value: this is nothing else but the standard output distortion of output that reflects firms' market power under imperfect competition. On the other hand, the marginal cost of liability is lower than its optimal value. As a result, strict liability also exerts inefficient incentives to produce at any level of care, but this is the result of two countervailing influences and the net effect is ambiguous: firms may produce either too much or not enough at any care level. Hence the comparison between the equilibrium values for output and care under strict liability (for any damages sharing rule) and their optimal values is also generally ambiguous.[12] As a consequence of the two stages structure of litigations and the possibility to avoid liability with a positive probability at each stage, firms face a marginal cost for output and a marginal benefit for care that are generally lower than at the social optimum ($\theta.\frac{1}{n}+(1-\theta).p<1$ for any $\theta, p>0$). The equilibrium (q^{JSL}, x^{JSL}) is thus inefficient, both in terms of responses and levels; but (q^{JSL}, x^{JSL}) may correspond to levels of output and care smaller as well as larger than (q^{sw}, x^{sw}).

Let us consider now that there may exist no legal opportunity for the Principal Defendant to sue her competitors after the first trial (a second trial is forbidden). Then under Joint and Several Liability, either the Plaintiff still randomly picks one of

[12]It can be understood as the result of the comparison between the slope of two curves: the slope of the marginal market proceeds (mainly driven by the value of the (inverse of the) price elasticity of market demand $P'(Q).\frac{Q}{P(Q)}$), and the slope of the marginal cost of liability; the proof is omitted.

the firms to be the Principal Defendant - this corresponds to the case labelled below Joint and Several Liability with no right of contribution; or the Plaintiff chooses to sue jointly all the industry in a single trial, and a sharing of total damages is proposed – this situation is equivalent to the one implied by the Joint Liability doctrine. Formally, we obtain the next outcome:

Joint and Several Liability with no right of contribution. If the Principal Defendant is not entitled to a right of contribution (setting $\theta = 0$ in $L_i^{JSL}(q_i, x_i)$ for any $p < 1$), then the individual expected liability cost for any firm is given by $L_i^{NRC}(q_i, x_i) = p\alpha h(X)Q^2$. Thus the individual ex ante profit for firm i is written as:

$$\Pi^{NRC}(q_i, x_i) = [P(Q) - c(x_i)]\, q_i - p\alpha h(X)Q^2 \tag{3.4.4}$$

Then, the symmetric Cournot-Nash equilibrium where $q_1 = ... = q_n = q^{NRC}$ and $x_1 = ... = x_n = x^{NRC}$ solves the system:

$$P(nq) + P'(nq)q = c(x) + 2p\alpha h(nx)nq \tag{3.4.5}$$

$$-h'(nx).p\alpha n^2 q = c'(x) \tag{3.4.6}$$

It is self-evident that the equilibrium under Joint and Several Liability with no right of contribution is socially inefficient, and may lead to output and care levels larger as well as smaller than the socially optimal ones. As long as $\alpha p < 1$, the RHS in (3.4.5) is smaller than the RHS in (3.3.2), whereas the LHS in (3.4.6) is smaller than the one in (3.3.3) – thus the equilibrium in (3.4.5) - (3.4.6) is not directly comparable with the social optimum. This reflects that under Joint and Several Liability with no right of contribution. Each firm of the industry has a positive probability to avoid any liability cost; nevertheless, this affects in the same way both the marginal cost of production, and the marginal benefit of care (both are reduced), leading both to decrease: hence, output and care decisions are not set according to efficient rule, but the net effect on the equilibrium levels of output and care is ambiguous.

Joint Liability. If the Plaintiff's suite encompasses all firms in the first trial, and the Plaintiff asks for an equal sharing of total damages between firms, then the expected liability cost is given by $L_i^{JL}(q_i, x_i) = \frac{\alpha}{n}.h(X)Q^2$ (as in chapter 1). Hence the individual profit is defined as follows:

$$\Pi^{JL}(q_i, x_i) = [P(Q) - c(x_i)]\, q_i - \left(\frac{\alpha}{n}\right) h(X)Q^2 \tag{3.4.7}$$

Using the first order conditions (second order conditions are met under (3.C1), the symmetric Cournot-Nash equilibrium where $q_1 = ... = q_n = q^{JL}$ and $x_1 = ... = x_n = x^{JL}$ solves the system:

$$P(nq) + P'(nq)q = c(x) + 2\alpha h(nx)q \tag{3.4.8}$$

$$-h'(nx).\alpha nq = c'(x) \tag{3.4.9}$$

Indeed, we have a simple equivalence result which may be framed according to Plaintiff's strategies:

Proposition 1. *Assume α is exogenously set. Joint and Several Liability (with or without a right of contribution) when Plaintiff's strategy is based on a pure random designation of the Principal Defendant reaches the same equilibrium as Joint Liability* $\left[p = \frac{1}{n} \Rightarrow q^{JL} = q^{NRC} = q^{JSL} \text{ and } x^{JL} = x^{NRC} = x^{JSL}\right]$.

Proof: Straightforward since for $p = \frac{1}{n}$, then $L_i^{JSL}(q_i, x_i) = L_i^{NRC}(q_i, x_i) = L_i^{JL}(q_i, x_i) = \frac{\alpha}{n}h(X)Q^2$. Thus (3.4.2) - (3.4.3), (3.4.5) - (3.4.6) and (3.4.8) - (3.4.9) are identical. ■

Such a kind of equivalence is also discussed by Miceli and Segerson (1991) in a single decision model with no market interactions. Proposition 12 implies that if the Plaintiff's strategy is to make a pure random draw among the n firms of the industry in order to designate the Principal Defendant, then in some sense it does not matter whether a right of contribution exists or does not exist: the outcome will be similar. Moreover, when a right of contribution exists, if the Planitiff's strategy is to sue all firms at trial and ask for an equal sharing of total damages between them, then the equilibrium outcome will be similar to a pure random draw after which a unique firm bears the full cost of liability. In the next paragraph, we focus on a situation where in contrast $p >$ *or* $< \frac{1}{n}$.

Proposition 2. *Assume α is exogenously set. i) If $p > \frac{1}{n}$, then $q^{JL}(x) > q^{JSL}(x) > q^{NRC}(x)$ $\forall x$ and $x^{JL}(q) < x^{JSL}(q) < x^{NRC}(q)$ $\forall q$; to the converse if $p < \frac{1}{n}$, then $q^{JL}(x) < q^{JSL}(x) < q^{NRC}(x)$ $\forall x$ and $x^{JL}(q) > x^{JSL}(q) > x^{NRC}(q)$ $\forall q$. ii) If $p > \frac{1}{n}$, then at equilibrium Joint and Several Liability with a right of contribution yields a level of output larger than without a right of contribution but smaller than Joint Liability; and a level of care smaller than without a right of contribution, but larger than Joint Liability $\left[p > \frac{1}{n} \Rightarrow q^{JL} > q^{JSL} > q^{NRC} \text{ and } x^{JL} < x^{JSL} < x^{NRC}\right]$. To the converse if $p < \frac{1}{n}$, then at equilibrium, Joint and Several Liability with a right of contribution yields a level of output smaller than without a right of contribution but larger than Joint Liability; and a level of care larger than without a right of contribution, but smaller than Joint Liability $\left[p < \frac{1}{n} \Rightarrow q^{JL} < q^{JSL} < q^{NRC} \text{ and } x^{JL} > x^{JSL} > x^{NRC}\right]$.*

Proof. Consider any α exogenously given. A/ Alike before, let us denote as $q^{NRC}(x)$ ($q^{JL}(x)$) the output level that solves (3.4.5) (respectively (3.4.8)) for any given value of care; while $x^{NRC}(q)$ ($x^{JL}(q)$) is the care level that solves (3.4.6) (respectively (3.4.9)) for any given value of the output. When $\theta < 1$ and $p \neq \frac{1}{n}$, then it comes that $p > \frac{1}{n} \Rightarrow p > \left[\theta.\frac{1}{n} + (1-\theta).p\right] > \frac{1}{n}$, and vice versa $p < \frac{1}{n} \Rightarrow p < \left[\theta.\frac{1}{n} + (1-\theta).p\right] < \frac{1}{n}$. For $p > (<)\frac{1}{n}$, the RHS in (3.4.5) is larger (respectively, smaller) than the RHS in (3.4.2), which is also larger (smaller) than the RHS in (3.4.8); similarly, the LHS in (3.4.6) is larger (respectively, smaller) than the LHS in (3.4.3), which is also larger (smaller) than the LHS in (3.4.9). Hence the result. For both $p > \frac{1}{n}$ and $p < \frac{1}{n}$, the comparison of equilibrium output and care levels is ambiguous; basic comparative statics allow to solve the ambiguity (see in Appendix). ■

The main implication of proposition 13 is that when all firms have a positive probability to contribute to the sharing of total damages according to the per capita rule, then the equilibrium levels of care and output may be smaller as well as larger than the optimal level, and generally, they are not comparable between the Joint Liability and Joint and Several Liability. This is the result of the interdependency existing between the choice of the output and the choice of care at a firm level. However, when firms face a risk that the Principal Defendant is designated thanks to a pure random draw at first trial, or when they face the certainty of a second trial, the per capita rule yields the same effects on care and output under Joint Liability and Joint and Several Liability.

We have found that whatever the doctrine that supports the liability regime, firms choose at equilibrium a rule of care that is not an efficient response at any level of output. Courts have thus the opportunity to choose the specific value of the damage multiplier $\alpha > 1$ in order to correct firms' incentives to take care. We focus here on the optimal value of this damages multiplier, i.e. the value required in order that firms undertake an efficient care response at any level of output.

Proposition 3. *When Courts apply (ad hoc) optimal damages multipliers. i) Then Joint and Several Liability with or without a right of contribution as well as Joint Liability, reach the same equilibrium. ii) This equilibrium is inefficient, with insufficient levels of output and care, compared with the social optimum* [$q^{sw} > q^{JL} = q^{JSL} = q^{NRC}$ *and* $x^{sw} > x^{JL} = x^{JSL} = x^{NRC}$].

Proof: By definition, the (ad hoc) optimal damages multiplier associated with each liability regime is constructed for the next relationship to hold: $x^{sw}(q) = x^{JL}(q) = x^{JSL}(q) = x^{NRC}(q)$, $\forall q > 0$ under the per capita rule. Hence: i) a) Under Joint Liability, the optimal damages multiplier is $\alpha^* = n$, since comparing the LHS in (3.4.9) and (3.3.3), it comes that $\alpha^* = n \Rightarrow -h'(nx).\alpha^* nq = -h'(nx).n^2q$, in which case $x^{sw}(q) = x^{JL}(q)$, $\forall q > 0$. b) the optimal damages multiplier under Joint and Several Liability with a right of contribution is $\alpha^{**} = \frac{n}{\theta+(1-\theta)np}$, since condition (3.4.3) and (3.3.3) are identical, meaning $x^{JSL}(q) = x^{sw}(q)$ $\forall q$, when $\alpha\left[\theta.\frac{1}{n} + (1-\theta).p\right] = 1 \Leftrightarrow \alpha^{**} = \frac{n}{\theta+(1-\theta)np}(> 1 \text{ since } \theta.\frac{1}{n}+(1-\theta).p < 1)$. As a result, if either $\theta = 1$ or $p = \frac{1}{n}$, then $\alpha^{**} = \alpha^*$; otherwise for any $\theta < 1$, then $\alpha^{**} > (<)\alpha^*$ if $p < (>)\frac{1}{n}$. c) Finally, the optimal damages multiplier associated with Joint and Several Liability and no right of contribution is $\hat{\alpha} = \frac{1}{p}$: setting $\hat{\alpha} = \frac{1}{p}$ in (3.4.6), implies that it is identical to (3.3.3). Hence the result $x^{sw}(q) = x^{NRC}(q)$, $\forall q > 0$. Finally according to the RHS of (3.4.2), (3.4.5) and (3.4.8), $2\alpha^* h(nx)q = 2\alpha^{**}h(nx)nq = 2\hat{\alpha}ph(nx)nq$ implying that $q^{JL}(x) = q^{JSL}(x) = q^{NRC}(x)$, $\forall x > 0$. Given that $x^{JL}(q) = x^{JSL}(q) = x^{NRC}(q)$, $\forall q > 0$, we obtain that: $q^{JL} = q^{JSL} = q^{NRC}$ and $x^{JL} = x^{JSL} = x^{NRC}$. ii) According to the RHS of (3.3.2), and (3.4.2), (3.4.5) and (3.4.8), $2\alpha^* h(nx)q = 2\alpha^{**}h(nx)nq = 2\hat{\alpha}ph(nx)nq = 2h(nx)nq$ but given that according to the LHS we have $P(nq) + P'(nq)q < P(nq)$, it comes that $q^{sw}(x) > q^{JL}(x) = q^{JSL}(x) = q^{NRC}(x)$, $\forall x > 0$. Hence using i), we obtain that: $q^{sw} > q^{JL} = q^{JSL} = q^{NRC}$ and $x^{sw} > x^{JL} = x^{JSL} = x^{NRC}$. ∎

Proposition 14 displays that Joint Liability and Joint and Several Liability with a right of contribution yields the same equilibrium levels of output and care in a second noticeable case, i.e. when Courts use optimal damages multipliers. In this set up, the purpose of a damages multiplier, above the general objective of Courts use optimal damages multipliers for aligning firms incentives in care taking with socially optimal ones, and at the same time in Joint and Several Liability, for compensating for the specific risk structure associated with the two sequential trials: with probability, $p.(1-\theta)$ any firm may be selected as the Principal Defendant and will bear total damages D after two sequential trials (in case where the second trial leads to no damages sharing with the opponents); on the other hand, with probability θ any firm will finally ends in sharing liability in proportion $s_i.D$ after the second trial.

Part i) of proposition 14 suggests that an optimal damages multiplier may be quite easy to assess for Courts, since it corresponds to industry size $\alpha^* = n$. Part ii) illustrates that when the per capita rule is combined with a damages multiplier optimally chosen, firms face an individual cost of liability equal to its social value. Hence an optimal damages multiplier solves the issue of care incentives (firms face efficient incentives to take care at any level of output), and also part of the distortion on production, i.e. the tendency to overproduce created by a cost of liability smaller than its optimal value. However, this is not sufficient to reach optimal levels of care and output at equilibrium, since the distortion coming from imperfect competition still holds. A single instrument such as a damages multiplier is obviously not enough to solve two distortions; nevertheless, under the capita rule, the optimal damages multiplier allows to improve both the incentives to take care and the incentives to produce.

3.4.2 Joint and Several Liability with a Targeted Principal Defendant

We consider here situations where the Plaintiff chooses the Principal Defendant among the n firms of the industry in a deterministic way (Tietenberg (1989)). Despite our context of a symmetric oligopoly, there may exist obvious reasons explaining that one firm be specially designated: for example, it may be a firm historically engaged in the industry (maybe initially having a monopoly position).

The point being that the Principal Defendant knows ex ante that she will be targeted by the Plantiff, and at the same time the $n-1$ other firms know ex ante that they will not be targeted. The implications of such a strategy where the Plaintiff more specifically targets one firm to be the Principal Defendant are easy to describe. If the Targeted Principal Defendant (be it unique to be designated[13]) has a right of contribution ($\theta > 0$), then her liability cost is defined as $L_i^{TPD}(q_i, x_i) = \left[\theta.\frac{1}{n} + (1-\theta)\right] \alpha h(X) Q^2$. She chooses a level of output and a level of care in order to maximize the profit (for any $\theta, p \in]0,1[$):

$$\Pi^{TPD}(q_i, x_i) = \left[P(Q) - c(x_i)\right] q_i - \left[\theta.\frac{1}{n} + (1-\theta)\right].\alpha h(X) Q^2 \tag{3.4.10}$$

Using the first order conditions of profit maximization, the Principal Defendant's equilibrium decisions (q^{TPD}, x^{TPD}) solve the system:[14]

$$P(Q) + P'(Q).q = c(x) + 2\left[\theta.\frac{1}{n} + (1-\theta)\right].\alpha h(X).Q \tag{3.4.11}$$

$$-h'(X).\alpha\left[\theta.\frac{1}{n} + (1-\theta)\right].Q^2 = c'(x).q \tag{3.4.12}$$

Instead, for each of the $n-1$ Non Targeted Firms, the individual liability cost is defined for any $\theta > 0$ as $L_i^{NTF}(q_i, x_i) = \left[\theta.\frac{1}{n}\right] \alpha h(X) Q^2$. Then, any one of these firms chooses a level of output and a level of care in order to maximize its profit (for any $\theta \in]0,1[$):

$$\Pi^{NTF}(q_i, x_i) = \left[P(Q) - c(x_i)\right] q_i - \frac{\theta}{n}.\alpha h(X) Q^2 \tag{3.4.13}$$

Using the first order conditions, the Non Targeted Firms' decisions (q^{NTF}, x^{NTF}) at equilibrium for each of the $n-1$ Non Targeted Firms solve the system:[15]

$$P(Q) + P'(Q).q = c(x) + 2\frac{\theta}{n}.\alpha h(X).Q \tag{3.4.14}$$

$$-h'(X).\alpha\frac{\theta}{n}.Q^2 = c'(x).q \tag{3.4.15}$$

It is straightforward (since, for any $\theta, p \in]0,1[$: $\left[\theta.\frac{1}{n} + (1-\theta)\right] > \theta.\frac{1}{n}$) that all else equal, the Targeted Principal Defendant faces both a marginal cost of liability and a

[13]Obviously, the argument extends to any number of targeted firms $k < n$.
[14]Equivalently, setting $p = 1$ in (3.4.2) - (3.4.3) gives (3.4.11) - (3.4.12).
[15]Equivalently, setting $p = 0$ in (3.4.2) - (3.4.3) gives (3.4.14) - (3.4.15).

marginal benefit of care which are larger than the Non Targeted Firms; as a result, the Targeted Principal Defendant produces a lower level of output at any level of care, but realizes a larger level of care at any level of output, than Non Targeted Firms (using the same conventions of notation as before: $q^{TPD}(x) < q^{NTF}(x)$ at any x, and $x^{TPD}(q) > x^{NTF}(q)$ at any q).

The next proposition compares this situation to the case where all firms face an equal probability of being designated as the Principal Defendant, and also considers some limit cases regarding the occurrence of a second trial.

Proposition 4. *Assume Courts α is exogenously set and any $p \in]0,1[$. i) For any $\theta \in]0,1[$, then $q^{NTF}(x) > q^{JSL}(x) > q^{TPD}(x)$ $\forall x$ and $x^{NTF}(q) < x^{JSL}(q) < x^{TPD}(q)$ $\forall q$. ii) For $\theta = 0$, then $q^{NTF}(x) = q^{NTF} > q^{NRC}(x) > q^{TF}(x)$ $\forall x$ and $x^{NTF}(q) = 0 < x^{NRC}(q) < x^{TPD}(q)$ $\forall q$. iii) For $\theta = 1$: if $p > \frac{1}{n}$ then $q^{TPD}(x) = q^{NTF}(x) = q^{JSL}(x) < q^{NRC}(x)$ $\forall x$ and $x^{TPD}(q) = x^{NTF}(q) = x^{JSL}(q) > x^{NRC}(q)$ $\forall q$; but if $p < \frac{1}{n}$, then $q^{TPD}(x) = q^{NTF}(x) = q^{JSL}(x) > q^{NRC}(x)$ $\forall x$ and $x^{TPD}(q) = x^{NTF}(q) = x^{JSL}(q) < x^{NRC}(q)$ $\forall q$.*

Proof. i) Straightforward since for any $\theta, p \in]0,1[$: $\theta.\frac{1}{n}+(1-\theta) > \theta.\frac{1}{n}+(1-\theta).p > \theta.\frac{1}{n}$; hence on the one hand, comparing the RHS in (3.4.11), (3.4.14) and (3.4.8) for the output, and on the other hand the LHS in (3.4.12), (3.4.15) and (3.4.9) for care expenditures, yields the result. ii) As $\theta \to 0$ then $\theta.\frac{1}{n} + (1-\theta) \to 1 > p$; hence at $\theta = 0$, we have: $L_i^{TPD}(q_i, x_i) = \alpha h(X) Q^2$ and $L_i^{NTF}(q_i, x_i) = 0$. Thus comparing the RHS in (3.4.5) and (3.4.11), and the LHS (3.4.6) and (3.4.12), the result is obvious for the Principal Defendant decisions. In contrast, the Non Targeted Firms face a "pure" no liability regime, choosing a level of output and a level of care in order to maximize the profit: $\Pi^{NTF}(q_i, x_i) = [P(Q) - c(x_i)]\, q_i = \Pi^{nl}(q_i, x_i)$. Thus, Non Targeted Firms do not invest in care $x^{NTF} = 0$, and choose a level of output alike under a pure no liability regime, q^{NTF} that satisfies $P(Q) + P'(Q)q^{NTF} = 0$. Hence the result. iii) As $\theta \to 1$ then $\theta.\frac{1}{n} + (1-\theta) \to \frac{1}{n}$, such that at $\theta = 1$ we obtain: $L_i^{TPD}(q_i, x_i) = \frac{\alpha}{n} h(X) Q^2 = L_i^{NTF}(q_i, x_i) = L_i^{JSL}(q_i, x_i)$; hence the result is straightforward. ■

Despite all firms in the industry being symmetric, the Plaintiff's strategy which targets one firm as being the Principal Defendant breaks off the symmetry since firms face a different liability cost according to their status targeted/not targeted and, as a response, undertake different output and care decisions. This implies that the associated equilibrium is asymmetric. However, at the aggregate level, both the equilibrium output and care with a Targeted Principal Defendant are generally not comparable to those that emerged under the other liability regimes.

3.4.3 Discussion

We return now to the issue of Plaintiff's strategy under the doctrine of Joint and Several Liability. We have in mind the situations where the Plaintiff is a Government, or at least a Public Agency, the domain of which is the preservation of environment.

Comments 1: To begin with, it is worth noticing that the model of Joint and Several Liability we have developed here provides an additional robustness check for the analysis of chapter 1, given that Joint Liability appears as a specific case of Joint and Several Liability. While we assume here that care has a non durable nature in contrast to chapter 1, we have shown that this is neutral for the comparison of the performances of the per capita and market share rules. Indeed the same results extend in a natural way to Joint and Several Liability.

Comments 2: Tietenberg (1989) discusses the case for Joint and Several Liability under strict liability assuming asymmetric defendants. These are partitioned in a group of solvable defendants, who are targeted by the Plaintiff for the first trial; and a group of defendants having a high risk of bankruptcy that the Plaintiff foreseen as potentially insolvable if sentenced to pay total damages (judgment-proofness problem); the latter are not targeted in the first trial, but may be sued in a second trial under Joint and Several Liability by those targeted as Principal Defendants. Tietenberg does not consider the defendant's activity level. He shows that in a regime of strict liability, defendants that are not targeted undertake zero care expenditures under Joint and Several Liability without a right of contribution, and more care under Joint Liability than under Joint and Several Liability with a right of contribution. Symmetrically, Principal Defendants invest more in care under Joint and Several Liability with a right of contribution than under Joint Liability, but no more than under Joint and Several Liability without a right of contribution. These findings are consistent with proposition

15 part i) and ii), at least regarding care decisions for any level of output exogenously given. In our set-up where firms are otherwise identical in every respect, an asymmetric behavior soon arise as the Plaintiff targets a (set of) Principal Defendant(s) in a deterministic way and leaves other firms free of liability costs, as we remarked earlier. However, whether this outcome still holds at equilibrium is not determinated.

On the other hand, the results of propositions 12 to 14 provide a more contrasted picture than those of Tietenberg (1989) in several respects. When symmetric Defendants all face a positive probability of being the Principal Defendant, and a positive probability of being sued by the Principal Defendant, we do not recover the ranking of Tietenberg, but generally speaking, we find that different rankings are possible depending on the probabilities of suits at both periods (apart from the choice of damages multipliers). More interesting, we have considered different possible strategies for the Plaintiff, that yield a set of possible equilibrium outcomes we discuss now, relying on different objectives the Plaintiff as a public party may wish to pursue.

Comments 3: The following table collects the equilibrium value of expected harm under the different liability regimes, for some specific values of p or α. Let us remember (see proposition 13) that the same inequalities also apply to equilibrium levels of aggregate output, while the reverse inequalities hold for equilibrium levels of care associated with the different liability regimes (for example, $H^{JSL} = H(Q^{JSL}, X^{JSL})$ denotes the equilibrium expected harm under Joint and Several Liability with a right of contribution):

$p = \frac{1}{n}$	$H^{JL} = H^{JSL} = H^{NRC}$ $q^{JL} = q^{JSL} = q^{NRC}$ $x^{JL} = x^{JSL} = x^{NRC}$
$p > \frac{1}{n}$	$H^{JL} > H^{JSL} > H^{NRC}$ $q^{JL} > q^{JSL} > q^{NRC}$ $x^{JL} < x^{JSL} < x^{NRC}$
$\alpha^*, \alpha^{**}, \hat{\alpha}$	$H^{JL} = H^{JSL} = H^{NRC}$ $q^{JL} = q^{JSL} = q^{NRC}$ $x^{JL} = x^{JSL} = x^{NRC}$

Our results illustrate the kind of bias that an analysis based on unidimensional decision models (only care decisions, as in Kornhauser and Revesz (1989), Tietenberg

(1989); or activity level, as in Miceli and Segerson (1991)), or focused on some limited strategy for Plaintiff under Joint and Several Liability, may introduce.

For example, consider that the objective of the Plaintiff is to maximize the damages collected. It can be easily assessed that given the Plaintiff's strategy whether there exists a liability regime that allows to reach this goal. Indeed, whether the Plaintiff focuses on ex ante (expected) damages or *ex post* (realised) damages, any liability regime leads to the same equilibrium, with the same aggregate expected harm in two cases, as long as the Plaintiff's strategy consists in selecting the Principal Defendant through a pure random draw ($p = \frac{1}{n}$). The same outcome occurs if Courts apply a damages multiplier optimally set according to the liability regime, which has the power to make the Plaintiff strategy irrelevant. In contrast, if the Plaintiff 's strategy is rather to sue a subset of firms randomly selected (i.e. $p\frac{1}{k} > \frac{1}{n}$), Joint Liability is preferable.

However, the liability regime that maximizes the damages collected is at the same time as the one for which equilibrium care expenditures are the lowest. As a consequence, if the objective of the Plaintiff is the preservation of the environment and if her strategy is rather to sue a subset of firms randomly seleted ($p > \frac{1}{n}$), Joint and Several Liability with no right of contribution is preferable.

Finally, one of the main consequence of our analysis is unfortunately that the comparison of the different strategies for the Plaintiff that we consider here is not meaningful, to the extent that the different equilibria are not comparable. As a result, performing a welfare analysis may be useful.

Comment 4: Let us start with a reference point, corresponding to a situation where all liability regimes and Plaintiff's strategies yield an equivalent equilibrium outcome $(Q^{JL}, X^{JL}) = (Q^{JSL}, X^{JSL}) = (Q^{NRC}, X^{NRC}) = (Q^*, X^*)$ and thus more specifically the same expected environmental harm $H^{JL} = H^{JSL} = H^{NRC} = H^*$; this requires that $p = \frac{1}{n}$ – moreover, for the sake of simplicity, we set $\alpha = 1$. Hence, evaluating (3.3.1) at (Q^*, X^*) gives $SW(Q^*, X^*) = \int_0^{Q^*} P(z)dz - c(x^*).Q^* - H^*$. Differentiating with respect to p yields the next effect:

$$
\begin{aligned}
&\left(\frac{dSW}{dp}(Q^*,X^*)\right)_{p=\frac{1}{n}}\\
&=\left((P(Q^*)-c(x^*)-2h(X^*)Q^*)\frac{dQ^*}{dp}-(c'(x^*)+h'(X^*)nQ^*)\,Q^*.\frac{dx^*}{dp}\right)_{p=\frac{1}{n}}\\
&=\left(\left(-P(Q^*)\left(\frac{1}{n}\right)-(1-\Delta)\,2h(X^*)\right)Q^*\frac{dQ^*}{dp}+(1-\Delta)\,(-h'(X^*))\,n\,(Q^*)^2\,\frac{dx^*}{dp}\right)_{p=\frac{1}{n}}\\
&=\left(-P(Q^*)\left(\frac{1}{n}\right)-\left(1-\frac{1}{n}\right)2h(X^*)\right)Q^*\left(\frac{dQ^*}{dp}\right)_{p=\frac{1}{n}}+\left(1-\frac{1}{n}\right)(-h'(X^*))\,n\,(Q^*)^2\left(\frac{dx^*}{dp}\right)_{p=\frac{1}{n}}
\end{aligned}
$$

with $\Delta=\theta\frac{1}{n}+(1-\theta)p<1$, and where we use (3.4.2)-(3.4.3) for $\alpha=1$ to obtain the second line. Thus on the one hand: $\frac{1}{n}<1-\frac{1}{n}$ (since $n>2$), and on the other hand, by H1a: $-P(Q^*)>2h(X^*)$. As a result the sign of $\left(-P(Q^*)\left(\frac{1}{n}\right)-\left(1-\frac{1}{n}\right)2h(X^*)\right)$ is generally ambiguous.

3.5 Joint and Several Liability with the Negligence rule

We assume now that Courts consider the negligence rule associated with a due care level x^{sw}. According to a negligence test, a firm will be released from any liability cost as soon as she complies with the rule of care (thus she faces the same profit as in a no liability regime, minus the cost of the due care); in contrast, when a firm does not comply, she has to bear some liability cost reflecting the damages paid (and thus faces the same profit as under strict liability) above the cost of care.

We start the analysis with the two specific cases where the Principal Defendant is not entitled to the right of contribution. As seen before, either the Plaintiff sues all the firms as potential responsible parties in a single trial (the case called "Joint Liability"); or the Plaintiff sues a unique firm (the case called Joint and Several Liability without a right of contribution).

Remark 6 (a "pure" No liability regime): Before that, let us consider the effects of a "pure" no liability regime, such that firms are not constrained with regard to their choice of care. In this case, each firm i chooses a level of output and a level of care in order to maximize its profit: $\Pi^{nl}(q_i, x_i) = [P(Q) - c(x_i)]\, q_i$. Thus, firms do not invest in care $x^{nl} = 0$, and we obtain the standard symmetric Cournot-Nash equilibrium where firms choose a level of output q^{nl} such that $P(nq) + P'(nq)q = 0$. It is straightforward that compared with the other equilibrias obtained under liability, the no liability regime yields the highest level of output and the lowest level of care expenditures x^{nl}. In contrast, the comparison with the social optimum yields an ambiguous result; it can be verified that $c(x^{sw}) + 2h(nx^{sw})nq < (>) - P'(nq)q \Rightarrow q^{sw} > (<)q^{nl}$.

3.5.1 Joint Liability

Let us start with the case where a right of contribution is not recognized to the Principal Defendant, and the Plaintiff sues all the firms in the industry. With Joint Liability, the individual liability cost for any firm i can be defined under the negligence rule as:

$$L_i^{JL}(q_i, x_i) = \begin{cases} 0 & if\ x_i \geq x^{sw} \\ s_i.\alpha h(X)Q^2 & if\ x_i < x^{sw} \text{ and } \exists\ k \neq i \text{ s.t. } x_k < x^{sw} \\ \alpha h(X)Q^2 & if\ x_i < x^{sw} \text{ and } x_k \geq x^{sw}\ \forall k \neq i \end{cases}$$

with $s_i < 1$ (that depends on the number of non compliant firms and the sharing rule). Thus the individual profit may be written as:

$$\hat{\Pi}^{neg}(q, x) = [P(Q) - c(x_i)]\, q_i - \begin{cases} 0 & if\ x_i \geq x^{sw} \\ s_i.\alpha h(X)Q^2 & if\ x_i < x^{sw} \text{ and } \exists\ k \neq i \text{ s.t. } x_k < x^{sw} \\ \alpha h(X)Q^2 & if\ x_i < x^{sw} \text{ and } x_k \geq x^{sw}\ \forall k \neq i \end{cases} \tag{3.5.1}$$

To begin with, remark that when all firms are compliant, i.e. choose to abide x^{sw}, then each one produces the output $\tilde{q}^{nl} = q^{nl}(x^{sw}) = \arg\max_{q_i} [P(Q) - c(x^{sw})]\, q_i$, and earns the profit: $\Pi^{nl}(\tilde{q}^{nl}) - c(x^{sw})\tilde{q}^{nl} = \left[P(n\tilde{q}^{nl}) - c(x^{sw})\right] \tilde{q}^{nl}$. Hence, compliance to the due care level leads firms to a no liability regime where they are constrained on their care decision, and choose a output level that is the best response to this constraint. Several preliminary remarks are then useful. Given that $\tilde{q}^{nl} = q^{nl}(x^{sw})$ is satisfying the condition $P(nq) + P'(nq)q = c(x^{sw})$, it is straightforward to see that compared with the ("pure") no liability regime above, we verify that $\tilde{q}^{nl} < q^{nl}$. As a result:

- i) If $q^{nl} < q^{sw}$ then it is still true that $\tilde{q}^{nl} < q^{sw}$, but ii) if $q^{nl} > q^{sw}$ then we may obtain either $\tilde{q}^{nl} < q^{sw}$ or $\tilde{q}^{nl} > q^{sw}$.
- By the same token, consider Joint Liability; one observes that there exists a threshold for the damage multiplier, $\bar{\alpha}$, defined by the condition $c(x^{sw}) = c(x^{JL}) + 2h(nx^{JL})\bar{\alpha}q^{JL}$, such that: i) $\alpha > \bar{\alpha} \Rightarrow \tilde{q}^{nl} > q^{JL}$; ii) $\alpha < \bar{\alpha} \Rightarrow \tilde{q}^{nl} < q^{JL}$. A similar result can be established for the market share rule. Hence, it turns out that the comparison between $\tilde{q}^{nl} = q^{nl}(x^{sw})$ and both q^{sw} and q^{JL} is ambiguous.

Proposition 5. ***(Joint Liability and negligence)*** *i) If $\tilde{q}^{nl} > q^{sw}$ and $x^{JL} > x^{sw}$, the negligence rule induces all firms to abide with the due care level and to produce an excessive level of output (i.e. $(\tilde{q}^{nl}, x^{sw})$ is the unique Nash equilibrium). ii) Otherwise, the negligence rule yields any outcome (there may exist no Nash equilibrium, or a unique Nash equilibrium given either by $(\tilde{q}^{nl}, x^{sw})$ or by (q^{JL}, x^{JL}), or both are Nash equilibria).*

Proof. a) Consider a situation where all firms choose $(\tilde{q}^{nl}, x^{sw})$. Assume that (while its $n-1$ competitors are still choosing $(\tilde{q}^{nl}, x^{sw})$) one firm deviates (with the same output $\tilde{q}^{nl}$) from x^{sw} to the level of care denoted as $\hat{x}^{neg} = x(\tilde{q}^{nl}, x^{sw})$ that maximizes its profit. On the one hand, $\tilde{q}^{nl}$ being given, it is immediate that $\hat{x}^{neg} = \arg\min_x \left[c(x)\tilde{q}^{nl} + \alpha h(x + (n-1)x^{sw}) \left(n\tilde{q}^{nl}\right)^2\right]$ and the following inequality necessarily holds:

$$[c(x^{sw}) - c(\hat{x}^{neg})]\,\tilde{q}^{nl} > L^{JL}(\hat{x}^{neg}) - h(nx^{sw})\left(n\tilde{q}^{nl}\right)^2 \tag{3.5.2}$$

where we denote $L^{JL}(\hat{x}^{neg}) \equiv \alpha h(\hat{x}^{neg} + (n-1)x^{sw})\left(n\tilde{q}^{nl}\right)^2$ the expected cost of liability borne by the firm be it the unique non compliant one. On the other hand, the unilateral deviation is profitable only if $\hat{\Pi}^{neg}(\tilde{q}^{nl}, \hat{x}^{neg}) > \left[P(n\tilde{q}^{nl}) - c(x^{sw})\right]\tilde{q}^{nl}$, or equivalently, it must be (simplifying with the market proceeds) that:

$$[c(x^{sw}) - c(\hat{x}^{neg})]\,\tilde{q}^{nl} > L^{JL}(\hat{x}^{neg}) \tag{3.5.3}$$

However, it is straightforward that when $\tilde{q}^{nl} > q^{sw}$ then $\hat{x}^{neg}(\tilde{q}^{nl}) > x^{sw} = x(q^{sw})$, and indeed the inverse inequality holds: $c(x^{sw})\tilde{q}^{nl} < c(\hat{x}^{neg})\tilde{q}^{nl} + L^{JL}(\hat{x}^{neg})$. Hence a unilateral deviation to $\hat{x}^{neg} = x(\tilde{q}^{nl}, x^{sw})$ is never profitable if $\tilde{q}^{nl} > q^{sw}$. When $\tilde{q}^{nl} < q^{sw}$, note that (3.5.2) will be satisfied only for some specifications of the function $h(x)$ and/or values of parameters of the model (for example, it is more likely that (3.5.2) holds for small value of α); but the opposite may still hold.

b) In cases where a unilateral deviation is profitable, $(\tilde{q}^{nl}, \hat{x}^{neg})$ is not an equilibrium (since all firms deviate from x^{sw}, choosing both care and output levels that maximize their profit). Consider a situation where all firms choose (q^{JL}, x^{JL}), earning the profit $\Pi^{JL}(q^{JL}, x^{JL}) = \left[P(nq^{JL}) - c(x^{JL})\right] q^{JL} - L^{JL}(q^{JL}, x^{JL})$. Assume that one firm unilaterally deviates to (q^{JL}, x^{sw}) (shifts to the due care level for the same output q^{JL}, while its $n-1$ opponents still choose (q^{JL}, x^{JL})). The profit of deviation is $\Pi^{d}(q^{JL}, x^{sw}) = \left[P(nq^{JL}) - c(x^{sw})\right] q^{JL}$, and deviating is profitable now if $\Pi^{d}(q^{JL}, x^{sw}) > \Pi^{JL}(q^{JL}, x^{JL})$, or:

$$\left[c(x^{sw}) - c(x^{JL})\right] q^{JL} < L^{JL}(q^{JL}, x^{JL})(\textbf{??}) \tag{3.5.4}$$

It is immediate that: either A) $x^{JL} > x^{sw} \Rightarrow c(x^{JL}) > c(x^{sw})$ and thus (3.5.3) is always satisfied; but (q^{JL}, x^{sw}) is not a Nash equilibrium (if a Nash equilibrium exists, it is given by $(\tilde{q}^{nl}, x^{sw})$). Or B) (for example if $\alpha^* = n$) $x^{JL} < x^{sw} \Rightarrow c(x^{JL}) < c(x^{sw})$ and thus (3.5.3) may hold, but it may also not hold.

To sum up at this stage: if $\tilde{q}^{nl} > q^{sw}$ then a unilateral deviation from the standard x^{sw} (holding $\tilde{q}^{nl}$) is never profitable (stage a)), and if $x^{JL} > x^{sw}$ then a unilateral deviation from x^{JL} (holding q^{JL}) is always profitable (stage b)).

- if $\tilde{q}^{nl} > q^{sw}$ and if $x^{JL} > x^{sw}$, the Nash equilibrium is $(\tilde{q}^{nl}, x^{sw})$. This proves Part i).

- if a deviation from $\tilde{q}^{nl}(< q^{sw})$ is profitable and if a deviation from $x^{JL}(< x^{sw})$ is not profitable, the Nash equilibrium is (q^{JL}, x^{JL}).

- if $\tilde{q}^{nl} > q^{sw}$ and if a deviation from $x^{JL}(< x^{sw})$ is not profitable, there exists two Nash equilibria – both $(\tilde{q}^{nl}, x^{sw})$ and (q^{JL}, x^{JL}) are Nash equilibria.

- if a deviation from $\tilde{q}^{nl}(< q^{sw})$ is profitable and if a deviation from $x^{JL}(< x^{sw})$ is profitable, there is no Nash equilibrium – neither $(\tilde{q}^{nl}, x^{sw})$ nor (q^{JL}, x^{JL}) is a Nash equilibrium.

This proves Part ii). ■

A unilateral deviation from the due care level may be profitable if a firm reduces its level of care in a significant way and despite the burden of the liability cost, obtains a large cut on its total cost – the proof establishes that this depends on whether $\tilde{q}^{nl} \lesseqgtr q^{sw}$ – and if $\tilde{q}^{nl} > q^{sw}$, then deviating from x^{sw} is never profitable. In turn, a deviation from strict liability with the per capita rule may be profitable if a firm reduces its liability cost in a sufficient way to compensate for the increase in the cost of care – the proof shows that this depends on whether $x^{JL} \gtrless x^{sw}$ – and if $x^{JL} > x^{sw}$, deviating from x^{JL} is always profitable.

The general conclusion that proposition 16 affords is that firms behavior under the negligence rule is hardly predictable. The equilibrium may end up in a no liability equilibrium with firms abiding to the efficient care level, or a strict liability equilibrium with firms furnishing an inefficient level of care. In both cases, the equilibrium outcome is socially inefficient. Moreover, there may exist no Nash equilibrium (at least in pure strategies). In any case, the conditions that help to qualify one result or the other are generally complex.

These results contrast first with the findings by Tietenberg (1989) who shows that firms (always) abide with the due care level under negligence under Joint Liability; Tietenberg considers a situation where tortfeasors produce a joint and indivisible harm but he does not introduce production aside care taking. Daughety and Reinganum (2014) also obtain a different outcome for the analysis of product liability, showing that negligence always ends up in a no liability regime; in their set-up, firms in an oligopoly produce a joint but divisible harm.

3.5.2 Joint and Several Liability with no right of contribution

Let us consider now that a right of contribution is not recognized for the Principal Defendant, and the Plaintiff sues one of the firms in the industry only. As a consequence the ex ante individual profit for any of the n firms in the industry is defined under a negligence rule by (for any $p < 1$):

$$\hat{\Pi}^{neg}(q,x) = [P(Q) - c(x_i)]\, q_i - \begin{cases} 0 & if\ x_i \geq x^{sw} \\ \alpha ph(X)Q^2 & otherwise \end{cases} \tag{3.5.5}$$

The output that maximizes individual profits when a firm abides with x^{sw} is still $\tilde{q}^{nl} = q^{nl}(x^{sw})$, and the firm earns: $\left[P(n\tilde{q}^{nl}) - c(x^{sw})\right]\tilde{q}^{nl}$.

One observes that there exists a threshold level of damages multiplier (for any $p > 0$) $\alpha(p) = \tilde{\alpha}$, defined as $c(x^{sw}) = c(x^{NRC}) + 2\alpha ph(nx^{NRC})q^{NRC}$, such that: i) $\alpha < \tilde{\alpha} \Rightarrow \tilde{q}^{nl} > q^{NRC}$; ii) $\alpha > \tilde{\alpha} \Rightarrow \tilde{q}^{nl} < q^{NRC}$. Again, we provide sufficient conditions to show that negligence induces firms to abide with the due care level.

Proposition 6. ***(Joint and Several Liability without a right of contribution and negligence)*** *i) If $\alpha p\tilde{q}^{nl} > q^{sw}$ and $x^{NRC} > x^{sw}$, negligence induces all firms to abide with the due care level and to produce an excessive level of output (i.e. $(\tilde{q}^{nl}, x^{sw})$ is the unique Nash equilibrium). ii) Otherwise, negligence yields any outcome (there may exist no Nash equilibrium, or a unique Nash equilibrium given either by $(\tilde{q}^{nl}, x^{sw})$ or by (q^{NRC}, x^{NRC}), or both are Nash equilibria).*

Proof: a) Consider a situation where all firms choose $(\tilde{q}^{nl}, x^{sw})$. Assume that for the same output $\tilde{q}^{nl}$, a firm unilaterally deviates (while its $n-1$ competitors are still choosing $(x^{sw}, \tilde{q}^{nl})$) to the level of care denoted as:

$$\bar{x}^{neg}(p) \equiv x(\tilde{q}^{nl}, x^{sw}; p) = \arg\min_x \left[c(x)\tilde{q}^{nl} + \alpha ph(x + (n-1)x^{sw})\left(n\tilde{q}^{nl}\right)^2\right]$$

The deviation is profitable if the condition $\hat{\Pi}^{neg}(\tilde{q}^{nl}, \bar{x}^{neg}(p)) > \Pi^{nl}(\tilde{q}^{nl}, x^{sw}) - c(x^{sw})\tilde{q}^{nl}$ holds, or equivalently if:

$$\left[c(x^{sw}) - c(\bar{x}^{neg}(p))\right]\tilde{q}^{nl} > L^{JL}(\bar{x}^{neg}(p)) \tag{3.5.6}$$

where $L^{JSL}_{NRC}(\bar{x}^{neg}(p)) \equiv \alpha p.h(\bar{x}^{neg}(p) + (n-1)x^{sw})\left(n\tilde{q}^{nl}\right)^2$ still denotes the expected cost of liability borne by a firm be it the unique non compliant one. It comes that when $\alpha p\tilde{q}^{nl} > q^{sw}$ then $\bar{x}^{neg}(p) > x^{sw} = x(q^{sw})$, and indeed the reverse inequality holds: $c(x^{sw})\tilde{q}^{nl} < \bar{x}^{neg}(p)\tilde{q}^{nl} + L^{JL}(\bar{x}^{neg}(p))$. Thus when $\alpha p\tilde{q}^{nl} > q^{sw}$ the deviation is never profitable. Instead when $\alpha p\tilde{q}^{nl} < q^{sw}$, (3.5.6) will be satisfied again only for some specifications of the function $h(x)$ and/or values of parameters of the model (for example, it is more likely that (3.5.6) holds for small value of αp; but the reverse may hold).

b) Consider a situation where all firms choose (q^{NRC}, x^{NRC}), earning the profit $\Pi^{NRC}(q^{NRC}, x^{NRC}) = \left[P(nq^{NRC}) - c(x^{NRC})\right] q^{NRC} - L^{JSL}_{NRC}(q^{NRC}, x^{NRC})$, with $L^{JSL}_{NRC}(q^{NRC}, x^{NRC}) \equiv \alpha p.h(nx^{NRC}))\left(nq^{NRC}\right)^2$. Assume that one firm unilaterally deviates to (q^{NRC}, x^{sw}) (shifts to the due care level for the same output q^{NRC}, while its $n-1$ opponents still choose (q^{NRC}, x^{NRC})). The profit of deviation is $\Pi^d(q^{NRC}, x^{sw}) = \left[P(nq^{NRC}) - c(x^{sw})\right] q^{NRC}$, and deviating is profitable now if $\Pi^d(q^{NRC}, x^{sw}) > \Pi^{NRC}(q^{NRC}, x^{NRC})$, or:

$$\left[c(x^{sw}) - c(x^{NRC})\right] q^{NRC} < L^{JSL}_{NRC}(q^{NRC}, x^{NRC}) \tag{3.5.7}$$

It is immediate that: either A) $x^{NRC} > x^{sw} \Rightarrow c(x^{NRC}) > c(x^{sw})$ and thus (3.5.7) is always satisfied; but (q^{NRC}, x^{sw}) is not a Nash equilibrium (if a Nash equilibrium exists, it is given by $(\tilde{q}^{nl}, x^{sw})$). Or B) $x^{NRC} < x^{sw} \Rightarrow c(x^{NRC}) < c(x^{sw})$ and thus (3.5.7) may hold; but the reverse may also occur.

To sum up: if $\alpha p\tilde{q}^{nl} > q^{sw}$ then a unilateral deviation from the standard x^{sw} (holding $\tilde{q}^{nl}$) is never profitable (stage a)), and if $x^{NRC} > x^{sw}$ then a unilateral deviation from x^{NRC} (holding q^{NRC}) is always profitable (stage b)).

- if $\alpha p\tilde{q}^{nl} > q^{sw}$ and if $x^{NRC} > x^{sw}$, the Nash equilibrium is $(\tilde{q}^{nl}, x^{sw})$. This proves Part i).

- if a deviation from $\alpha p\tilde{q}^{nl}(< q^{sw})$ is profitable and if a deviation from $x^{NRC}(< x^{sw})$ is not profitable, the Nash equilibrium is (q^{NRC}, x^{NRC}).

- if $\alpha p\tilde{q}^{nl} > q^{sw}$ and if a deviation from $x^{JL}(< x^{sw})$ is not profitable, there exist two Nash equilibria – both $(\tilde{q}^{nl}, x^{sw})$ and (q^{NRC}, x^{NRC}) are a Nash equilibrium.

- if a deviation from $\alpha p\tilde{q}^{nl}(< q^{sw})$ is profitable and if a deviation from $x^{NRC}(< x^{sw})$ is profitable, there is no Nash equilibrium – neither $(\tilde{q}^{nl}, x^{sw})$ nor (q^{NRC}, x^{NRC}) is a Nash equilibrium.

This proves Part ii). ■

Nonetheless, the issue is whether Joint and Several Liability without a right of contribution achieves more deterrence than Joint Liability, i.e. whether non compliant behaviors under Joint and Several Liability with no right of contribution are less likely than under Joint Liability? The intuition relies on the fact that Joint and Several Liability without a right of contribution represents the risk for any one of the n firms to bear the full cost of expected damages, whereas under Joint Liability there is a possible sharing of total damages between the n firms. As far as a Nash equilibrium argument (and thus the profitability of a deviation) is concerned, it turns out that the result is less clear-cut. The LHS in (3.5.2) and (3.5.6) are easy to compare: given that $\bar{x}^{neg}(p)$ is increasing in p, and thus $\forall p < 1$: $\bar{x}^{neg}(p) < \hat{x}^{neg}$, this implies: $c(x^{sw}) - c(\bar{x}^{neg}(p)) > c(x^{sw}) - c(\hat{x}^{neg})$ for any $p < 1$ (and obviously $\bar{x}^{neg}(1) = \hat{x}^{neg}$), although $c(x^{sw}) - c(\bar{x}^{neg}(p))$ decreases with p. But on the other hand, the RHS in (3.5.2) and (3.5.6) are generally not comparable; at least it turns out that more restrictions are needed to qualify the result, since $L^{JSL}_{nc}(\bar{x}^{neg}(p))$ may be increasing as well as decreasing in p, since the restrictions on $h(x)$ are weak.[16] We obtain the following results:

Proposition 7. *Under a negligence rule, there exists a set of probabilities $p < 1$ such that: i) If the deviation is profitable under Joint Liability, it is also profitable under Joint and Several Liability without a right of contribution. ii) If the deviation is not profitable under Joint and Several Liability without a right of contribution, it is also not profitable under Joint Liability.*

Proof: Let us remind ourselves that we denote $L^{JL}(\hat{x}^{neg}) \equiv \alpha h(\hat{x}^{neg} + (n-1)x^{sw}) \left(n\tilde{q}^{nl}\right)^2$ and $L^{JSL}_{NRC}(\bar{x}^{neg}(p)) \equiv \alpha p h(\bar{x}^{neg}(p) + (n-1)x^{sw}) \left(n\tilde{q}^{nl}\right)^2$. We can remark that for any $\alpha > 0$ exogenously given, by continuity (since $h(x)$ is decreasing in x, and $\bar{x}^{neg}(p)$ is increasing in p), there exists a probability $\bar{p} < 1$ such that the expected cost of liability for the non compliant firm in both liability regimes is equal : $L^{JSL}_{NRC}(\bar{x}^{neg}(\bar{p})) = L^{JL}(\hat{x}^{neg})$. Given that $\forall p < 1$: $c(x^{sw}) - c(\bar{x}^{neg}(p)) > c(x^{sw}) - c(\hat{x}^{neg})$, we have by construction of $\bar{p}$:

- $[c(x^{sw}) - c(\hat{x}^{neg})]\, \tilde{q}^{nl} > L^{JL}(\hat{x}^{neg}) \Rightarrow [c(x^{sw}) - c(\bar{x}^{neg}(\bar{p}))]\, \tilde{q}^{nl} > L^{JSL}_{NRC}(\bar{x}^{neg}(\bar{p}))$;
- $[c(x^{sw}) - c(\bar{x}^{neg}(\bar{p}))]\, \tilde{q}^{nl} < L^{JSL}_{NRC}(\bar{x}^{neg}(\bar{p})) \Rightarrow [c(x^{sw}) - c(\hat{x}^{neg})]\, \tilde{q}^{nl} < L^{JL}(\hat{x}^{neg})$.

[16] Of course, $ph(x + (n-1)x^{sw})$ the expected liability cost for exogenous care x increases with p; nonetheless the key point for the the comparison of the profitability of deviation between JL and JSL is whether the expected liability cost for an adjusted care $ph(x(p)+(n-1)x^{sw})$ under JSL increases or decreases with p. Simplifying the notation, we have $\frac{d}{dp}(ph(x(p)++(n-1)x^{sw}) = h(.)+ph'(.).x'(p) \lesseqgtr 0$.

On the other hand, the inequality $L^{JSL}_{NRC}(\bar{x}^{neg}(\bar{p})) = L^{JL}(\hat{x}^{neg}) > L^{JSL}_{NRC}(\bar{x}^{neg}(p))$ holds for any $p \neq \bar{p}$ for two different sets of conditions, either: (A) for any $p > \bar{p}$ if $L^{JSL}_{NRC}(\bar{x}^{neg}(p))$ is decreasing in p, or: (B) for any $p < \bar{p}$ if $L^{JSL}_{NRC}(\bar{x}^{neg}(p))$ is increasing in p. Hence, in any case assuming that $L^{JL}(\hat{x}^{neg}) > L^{JSL}_{NRC}(\bar{x}^{neg}(p))$ holds, we have:

i) $[c(x^{sw}) - c(\hat{x}^{neg})]\,\tilde{q}^{nl} > L^{JL}(\hat{x}^{neg}) \Rightarrow c(x^{sw}) - c(\bar{x}^{neg}(p)) > L^{JSL}_{NRC}(\bar{x}^{neg}(p))$;

ii) $[c(x^{sw}) - c(\bar{x}^{neg}(p))]\,\tilde{q}^{nl} < L^{JSL}_{NRC}(\bar{x}^{neg}(p)) \Rightarrow [c(x^{sw}) - c(\hat{x}^{neg})]\,\tilde{q}^{nl} < L^{JL}(\hat{x}^{neg})$.

Hence the result. ■

The intuition of proposition 18 is as follows. The deviation to the due care level saves on precaution costs, and Joint and Several Liability without a right of contribution allows to save more on these costs compared with Joint Liability all else equal as long as $p < 1$, although these advantages decrease with p. On the other hand, there exists a probability threshold for any firm to be selected as the Principal Defendant under Joint and Several Liability, and for which the non compliant firm will bear exactly the same expected cost of liability under Joint and Several Liability and Joint Liability, be it alone to deviate. At this threshold, if deviating from the due level of care is a dominant strategy under Joint Liability, this will be also the case under Joint and Several Liability without a right of contribution. Above or below this threshold, this is still true to the extent that the expected cost of liability borne by the deviant firm be lower (than at the threshold); remark that this may occur both for a low(er) probability of being the Principal Defendant (if $L^{JSL}_{NRC}(\bar{x}^{neg}(p))$ is increasing with p), as well as a high(er) probability (if $L^{JSL}_{NRC}(\bar{x}^{neg}(p))$ is decreasing with p). The point of proposition 18 is that the advantage to Joint and Several Liability is preserved if departing from the probability threshold, the expected cost of liability under Joint and Several Liability is decreasing.

The reverse is generally not true, and in this sense, Joint and Several Liability without a right of contribution make a profitable deviation more likely than Joint Liability: a profitable deviation under Joint and Several Liability without a right of contribution may not necessarily be also profitable under Joint Liability.

In turn, if at this probability threshold, abiding with the due care level is a dominant strategy under Joint and Several Liability without a right of contribution, this will also arise under Joint Liability. Above or below this threshold, this continues to hold with our restriction that the expected cost of liability under Joint and Several Liability is decreasing. The reverse again is generally not true: when the Nash equilibrium under Joint Liability consists of abiding with the socially optimal level of care, the same outcome will not necessarily be true under Joint and Several Liability without a right of contribution. In this sense, a Nash equilibrium where firms abide to the socially optimal level of care may be less easy to achieve under Joint and Several Liability without a right of contribution, than with Joint Liability.

3.5.3 Joint and Several Liability with a right of contribution

When a right of contribution is recognized to the Principal Defendant, then this leads to the possibility of two sequential trials; under negligence the likelihood that the second trial occurs must be defined conditionally on which firms was the Principal Defendant at the first trial, and what is the outcome of this trial. Considering any one of the firms, i) either a firm i has been selected in first period as the Principal Defendant, and thus a second trial may arise only if she did not take enough care, ii) or she was not selected in first period as the Principal Defendant, and thus a second trial may occur only if a firm $k \neq i$ selected as the Principal Defendant did not take enough care. Let $\theta.\gamma$ denotes the likelihood of a second trial when i is the Principal Defendant, where $\gamma = \begin{cases} 0 & if\ x_i \geq x^{sw} \\ 1 & otherwise \end{cases}$; and $\theta.\mu$ the likelihood of a second trial when $k \neq i$ is the Principal Defendant, where $\mu = \begin{cases} 1 & if\ x_k < x^{sw} \\ 0 & otherwise \end{cases}$. The individual expected liability cost for any firm i can be written as (detailing for firm i the outcome of the different relevant events):

$$\begin{aligned} L_i^{JSL}(q_i, x_i) = & p \times \left(\begin{cases} 0 & if\ x_i \geq x^{sw} \\ \alpha h(X) Q^2 & if\ x_i < x^{sw} \end{cases} \right) \\ & + p.\theta.\gamma \times \left(\begin{cases} 0 & if\ x_i < x^{sw} \text{ and } x_k \geq x^{sw}\ \forall k \neq i \\ (s_i - 1).\alpha h(X) Q^2 & if\ x_i < x^{sw} \text{ and } \exists\ k \neq i \text{ s.t. } x_k < x^{sw} \end{cases} \right) \\ & + (1-p).\theta.\mu \times \left(\begin{cases} 0 & if\ x_i \geq x^{sw} \\ s_i.\alpha h(X) Q^2 & if\ x_i < x^{sw} \end{cases} \right) \end{aligned}$$

with as usual $s_i < 1$. Rearranging terms, individual profits under a negligence rule may be written as:

$$\hat{\Pi}^{neg}(q,x) = [P(Q) - c(x_i)]\, q_i - \begin{cases} 0 & if\ x_i \geq x^{sw} \text{ and } x_k \geq x^{sw}\ \forall\ k \neq i \\ [\theta.s_i + (1-\theta)p]\,.\alpha h(X)Q^2 & if\ x_i < x^{sw} \text{ and } \exists\ k \neq i \text{ s.t. } x_k < x^{sw} \\ p\alpha h(X)Q^2 & if\ x_i < x^{sw} \text{ and } x_k \geq x^{sw}\ \forall k \neq i \end{cases} \tag{3.5.8}$$

A brief look at the structure of liability costs under Joint Liability and Joint and Several Liability with a right of contribution shows that they are very similar. However, the Nash reasoning implies that the clue point is the deviation profitability away from the socially optimal level of care, and the associated jump in the cost of liability from zero to the full burden of expected damages. Once again, when all firms abide with x^{sw}, then $L_i^{JSL}(q_i, x_i) = 0$ for each one, and the equilibrium output that maximizes individual profits is still given by $\tilde{q}^{nl} = q^{nl}(x^{sw})$, and is associated with the profit: $(P(n\tilde{q}^{nl}) - c(x^{sw}))\tilde{q}^{nl}$ – this is still the same outcome as before, and this outcome may not be a Nash equilibrium.

Proposition 8. ***(Joint and Several Liability with a right of contribution and negligence)*** *i) If $\tilde{q}^{nl} > q^{sw}$ and $x^{JSL} > x^{sw}$, negligence induces all firms to abide with the due care level and to produce an excessive level of output (i.e. $(\tilde{q}^{nl}, x^{sw})$ is the unique Nash equilibrium). ii) Otherwise, negligence yields any outcome (there may exist no Nash equilibrium, or a unique Nash equilibrium given either by $(\tilde{q}^{nl}, x^{sw})$ or by (q^{JSL}, x^{JSL}), or both are Nash equilibria).*

Proof: a) here is the same as part a) in the proof of proposition 9. b) Now consider a situation where all firms choose (q^{JSL}, x^{JSL}), earning the profit $\Pi^{JSL}(q^{JSL}, x^{JSL}) = \left[P(nq^{JSL}) - c(x^{JSL})\right] q^{JSL} - L^{JSL}(q^{JSL}, x^{JSL})$, with $L^{JSL}(q^{JSL}, x^{JSL}) \equiv \alpha\,[\theta.s_i + (1-\theta)p]$ $.h(nx^{JSL}))\left(nq^{JSL}\right)^2$. Assume that one firm unilaterally deviates to (q^{JSL}, x^{sw}) (shifts to the due care level for the same output q^{JSL}, while its $n-1$ opponents still choose (q^{JSL}, x^{JSL})). The profit of deviation is $\Pi^d(q^{JSL}, x^{sw}) = \left[P(nq^{JSL}) - c(x^{sw})\right] q^{JSL}$, and deviating is profitable now if $\Pi^d(q^{JSL}, x^{sw}) > \Pi^{JSL}(q^{JSL}, x^{JSL})$, or:

$$\left[c(x^{sw}) - c(x^{JSL})\right] q^{JSL} < L^{JSL}(q^{JSL}, x^{JSL}) \tag{3.5.9}$$

It is immediate that: either A) $x^{JSL} > x^{sw} \Rightarrow c(x^{JSL}) > c(x^{sw})$ and thus (3.5.9) is always satisfied; but (q^{JSL}, x^{sw}) is not a Nash equilibrium (if a Nash equilibrium exists, it is given by $(\tilde{q}^{nl}, x^{sw})$). Or B) $x^{JSL} < x^{sw} \Rightarrow c(x^{JSL}) < c(x^{sw})$ and thus (3.5.9) may hold, but it may also not hold.

To sum up: if $\tilde{q}^{nl} > q^{sw}$ then a unilateral deviation from the standard x^{sw} (holding $\tilde{q}^{nl}$) is never profitable (stage a)), and if $x^{JSL} > x^{sw}$ then a unilateral deviation from x^{JSL} (holding q^{JSL}) is always profitable (stage b)). Thus:

- if $\tilde{q}^{nl} > q^{sw}$ and if $x^{JSL} > x^{sw}$, the Nash equilibrium is $(\tilde{q}^{nl}, x^{sw})$. This proves Part i).

- if a deviation from $\tilde{q}^{nl}(< q^{sw})$ is profitable and if a deviation from $x^{JSL}(< x^{sw})$ is not profitable, the Nash equilibrium is (q^{JSL}, x^{JSL}).

- if $\tilde{q}^{nl} > q^{sw}$ and if a deviation from $x^{JSL}(< x^{sw})$ is not profitable, there exist two Nash equilibria – both $(\tilde{q}^{nl}, x^{sw})$ and (q^{JSL}, x^{JSL}) are a Nash equilibrium.

- if a deviation from $\tilde{q}^{nl}(< q^{sw})$ is profitable and if a deviation from $x^{JSL}(< x^{sw})$ is profitable, there is no Nash equilibrium – neither $(\tilde{q}^{nl}, x^{sw})$ nor (q^{JSL}, x^{JSL}) is a Nash equilibrium.

This proves Part ii). ■

We can remark that introducing a right of contribution does not give more deterrence effects. To see this, note that with a right of contribution if firm i deviates while its $n-1$ competitors still abide with $(\tilde{q}^{nl}, x^{sw})$ (thus $\gamma = 1$ and $\mu = 0$), then its expected liability cost is simply $L_i^{JSL}(q_i, x_i) = \alpha ph(x + (n-1)x^{sw}) \left(n\tilde{q}^{nl}\right)^2$ which, by definition, would be its liability cost without a right of contribution. Hence, the introduction of a right of contribution does not change the incentives to deviate from the due care level at individual level.

Comments 4: Compared with Tietenberg (1989), our analysis of negligence gives a more complex picture, nevertheless far less favorable to the negligence rule. Tietenberg concluded that, with indivisible harm, simple negligence in a Joint Liability context is a weak revenue raiser compared with strict liability, because negligence will induce from any of the firms to abide with the due level of care when set at the first best level. Put differently, negligence for indivisible harm dominates strict liability (whatever the damages sharing rule considered) under Joint Liability, since it arrives at an efficient result regarding care activity, while strict liability fails to induce efficient care. This also holds when Courts err in the determination of the due level of care they require, implying that firms still abide with an inefficient level of care as long as it is not too different from x^{sw} – hence, in any case, the amount of expected damages collected for victims is essentially zero under negligence. Our result shows in contrast that as a result of the interaction between care and output decisions (despite firms symmetry), generally speaking there exist incentives to deviate from the legal standard of care: the deviation from the standard allows a large cut in care decision but a large increase in output. In all, the deviation from the standard of care (and the associated liability burden, despite it is not shared with other competitors) may provide the firm with an increase in its profits which represents an improvement compared with the situation where the firm abides with the care level and bears the associated cost. Furthermore, in contrast to Tietenberg's analysis, it appears here that the expected liability cost of the deviant firms (both its level, and its behavior with p and θ) is important for the comparison between the effects of introducing or not a right of contribution under Joint and Several Liability, since it shapes firms incentives to deviate.

3.6 Concluding remarks

We have shown here that negligence is not an efficient rule for the purpose of providing firms with efficient incentives in preservation measures in a multidimensional decision context. Introducing firms productive decisions (interactions existing at firm level, between care and output decisions) and/or competition externalities (market interactions between firms),they may have strong incentives to deviate from the (efficient) due care level. This conclusion holds for the different ways of implementing the doctrine of Joint and Several Liability (with or without a right of contribution). Indeed, we obtain a result quite similar to the one by Daughety and Reinganum (2014) for product liability, that is negligence is not a stable liability rule: more specifically, we find here that the outcome of negligence is very uncertain in the sense that the prediction regarding the possible equilibrium encompasses various situations in between no equilibrium, and multiple equilibria – in contrast with the uniqueness of the prediction associated with strict liability. On the other hand, we show that there is no general reason to explain why (in a symmetric oligopoly) firms should invest more under Joint and Several Liability (with or without a right of contribution) than under Joint Liability. In contrast strict liability in combination with the per capita rule may lead to identical equilibria under Joint and Several Liability with contribution and Joint Liability, for more constellations of parameters than the market share rule.

Finally, we have also discussed a specific property of optimal damages multipliers under Joint and Several Liability. When the per capita rule is used for apportioning damages between responsible firms, indeed optimal (ad hoc) damages multipliers produce a neutralization of differences between liability regimes.

The discussion is focused here on primary environmental preservation measures, i.e. dedicated to avoid environmental harms ex ante. In order to complete the picture, this analysis should be extended to include secondary preservation measures, as those necessary ex post to clean up a site, after the occurrence of accidental harm. This will be the topic of future research, and requires a more specific dynamic framework to capture both clean-up decisions (see Friehe and Langlais (2017) for the case of a monopoly) and interactions under imperfect competition.

General Conclusion

In this dissertation, we conduct an analysis of the economic efficiency of different liability regimes when firms collectively produce an indivisible harm.

In the last decades various activities have led to the creation of an indivisible harm, in the sense that it is impossible to disentangle the contribution of each firm pertaining to these industry in the creation of the harm. We might illustrate such health or environmental issues with the litigations caused by diesel, lead paint, pharmaceutical drugs such as DES, gasoline additives such as the MTBE or spatial debris. Theses new industrial risks collectively generated by firms pertaining to the same industry - automobile manufacturers, petrochemical industries, or pharmaceutical laboratories - force public actors to revisit liability rules.

Indeed, when harm is indivisible within the same branch of industry, the liability design is not just limited to the liability rule used (strict liability, negligence, no liability) but includes others essentials elements such as the sharing rule used (*per capita* rule, Market share rule) or the legal doctrine applied to settle cases (Joint liability, Joint and Several Liability). Thus, the different designs of the liability regime may raise different incentives for firms - involving that the efficiency of the liability regime is closely linked to these elements. Moreover, firms are not strangers the one for each others in such framework, but compete on the same market. Thus, there is a close interdependence between the market performance (i.e. the amount of goods produced and traded in the market) and the liability performance (i.e the precautionary measures taken by firms in order to reduce the expected harm). It is therefore essential to adjust competition authorities' policies to the design of the liability rule.

In this perspective, the economic analysis of the different liability regimes is declined in several questions. From a positive viewpoint, what are the incentives raised by the different liability regimes ? How do they impact precautionary choices realised by firms and the market performance ? From a normative viewpoint, is there a liability design which allowing to reach the social optimum ? At least, is there a liability regime which dominates the others in term of social well-being ?

The three chapters which composed this dissertation attempt to answer those questions.

Summary

In the first chapter, we demonstrate that none of the liability regime (strict liability v. negligence) allows to decentralise the socially optimal level of care, regardless of the sharing rule used. Yet, an environmental liability based on strict liability coupled with an equal sharing and an optimal damages' multiplier induce firms to adopt the socially optimal level of care given the output's level produced. A main consequence is that a "conventional competition policy" aiming to reduce the firms' market power not only induce the aggregate output level to converge to its socially optimal level, but also the aggregate care level, thus, improving social welfare. Such result can't be reached with another environmental liability regime.Under a strict liability regime augmented with an apportionment proportional to the market share of the firm, or with a regime of negligence, decreasing firms' market power might result in a social well-being deterioration. Such situations may then justify the application of quite unconventional competition policies limiting the number of firms in the market. Thus, a strict liability regime augmented with an equal sharing rule and an optimal damages multiplier seems to be the best design for an environmental liability.

In the second chapter, we demonstrate that sharing rules' impact on collusion sustainability depends on the expected harm structure. In a perfect linear framework, apportioning damages among firms equally (i.e. the *per capita* rule) or in proportion of their market share has no influence on the likelihood of collusion. On the contrary, if we step aside from a linear framwork and assume that firms collectively generate a cumulative harm (i.e expected harm level increases more than proportionally in the aggregate output level) then the sharing rule used has an influence on the collusion's sustainability. More precisely, collusions are less likely to occur if the harm is shared in proportion of the firms' market share. Furthermore, we also find that collusion are more likely to occur with a cumulative harm. Thus, we conclude that competition authorities should concentrate their investigations on non linear harm, and moreover take into account that the design of the liability regime - and particularly the sharing rule used.

In the third chapter, we highlight that none of the doctrine between the joint liability and the joint and several liability - with or without a right of contribution - allow to decentralize the social optimum, irrespective of the liability rule used (strict liability v. negligence). Furthermore, none of the doctrine is preferable to the other. Depending on the parameters of the model, firms' levels of care and output may be lower as well as higher under one doctrine or another. Yet, negligence appears in our framework as unpredictable. Under such rule, we may end up with two Nash equilibrium, one or none. Such result contrast with the previous literature, in which the activity level is exogenous, and which consider negligence as an efficient tool to decentralize the socially optimal level of care.

Limits and prospects

This dissertation has of course several limitations.

A part of these limitations is due to the choices made to analyse several issues. Two of them seems particularly important.

Such choices first include the way we represent the market interaction among firms. Most of this dissertation is built on a symmetric Cournot oligopoly. This model is extremely convenient for us given its simplicity (for instance, there is no discontinuity in the output's best response function of the firms). Yet, as the section 7 of chapter 2 shows, other forms of competition, such as Bertrand competition, might lead to different results. Thus, extending the analysis to Bertrand competition would be a pertinent development of our research. The way we choose to represent indivisibility of the harm might also bring some limitations. Indeed, our analysis is essentially focused on cumulative harm (i.e. harm increasing more-than-proportionally in the aggregate output level). Yet the notion of indivisibility might also include harms increasing less-than-proportionally in the aggregate/individual output level, the extreme case being an harm independent of the firms' joint production. Thus, it is likely that some of our results depends on this cumulative aspect, and would not be verified for other forms of indivisible harm.

Another part of these limitations is due to the the omissions that we necessarily had to make.

First of all, we assume that victims are third-parties. Yet, our analysis could be easily extend to cases in which indivisible harms also includes consumers. In this perspective, Daughety and Reinganum (2013a) and Friehe et al. (2019) provide the analysis of harms to both consumers and third-parties victims for a monopolistic market, and find significant departures related to the comparison of strict liability and negligence for example. Moreover, our conclusions call for courts to use punitive damages, increasing the effective damages firms have to pay. Such high levels for effective damages raise, and at the same time may help in solving, the judgment-proofness problem or the disappearing defendants issues. These two important problems are beyond the scope of the present dissertation. This will be the topic of future researches.

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Appendix

Chapter 1

Should environment be a concern for competition policy when firms face environmental liability

This chapter is published. See Charreire, M. and Langlais, E. (2021). Should environment be a concern for competition policy when firms face environmental liability. *International Review of Law and Economics*, 67:105990.

Direct Link to the Appendix : https://www.sciencedirect.com/science/article/abs/pii/S0144818821000144

Chapter 2

Market collusion with joint harm and liability sharing

This chapter is published. See Baumann, F., Charreire, M., and Cosnita-Langlais, A. (2020). Market collusion with joint harm and liability sharing. *International Review of Law and Economics*, 62:105885

Direct Link to the Appendix : https://www.sciencedirect.com/science/article/pii/S0144818819300481?casa_token=HVjaAcS6Eq0AAAAA:dwqB2S_jIAHgCTnk7Ro9pWrtYQqHewQoRk4cmmhfA91OaCOM6kbezq9SfhjSU09hr-lvQDp01Kii

Chapter 3

Apportioning indivisible environmental harm, and the Joint and Several Liability Doctrine

Social welfare maximization. The first-order conditions (3.3.2)-(3.3.3) for an interior solution (q^{sw}, x^{sw}) may be written respectively as: $SW_q = 0 = P(nq) - c(x) - 2h(nx)nq$ and $SW_x = 0 = -h'(nx).n^2q - c'(x)$. Second order conditions for social welfare maximization (where usual notations are used for second order derivatives) require that at (q^{sw}, x^{sw}): $\Delta^{SW} \equiv SW_{qq}.SW_{xx} - (SW_{qx})^2 > 0$ holds, where: $SW_{qq} = -n(P'(nq) + 2h(nx)) < 0$, $SW_{qx} = SW_{xq} = -h'(nx)n^2q > 0$ and $SW_{xx} = -(h''(nx)n\,(nq)^2 + c''(x)) < 0$. Substituting, we obtain:

$$\begin{aligned}\Delta^{SW} =&(-P'(nq)n + 2nh(nx))(h''(nx)n^3q + c''(x)) - 4n^4q\,(h'(nx))^2\\ >&2n^4q\left[h(nx)h''(nx) - 2\,(h'(nx))^2\right]\end{aligned}$$

Thus under (3.C1), $\Delta^{SW} > 0$ holds.

Let us now denote as $q^{sw}(x)$ the output level that solves (3.3.2) for any given x, and $x^{sw}(q)$ the care level that solves (3.3.3) for any given q, which is the level of care which is social welfare maximizing, for any given value of output. Straightforward calculations show that these functions are positively sloped in the space (q, x) since:

$$\frac{d\tilde{x}^{sw}}{dq} = -\frac{SW_{qq}}{SW_{qx}} > 0\ ,\ \frac{dx^{sw}}{dq} = -\frac{SW_{xq}}{SW_{xx}} > 0$$

where we denote $\tilde{x}^{sw}(q)$ for the inverse of $q^{sw}(x)$; thus, care and activity levels are strategic complements at the social optimum. The stability of the Nash equilibrium described by (3.3.2)-(3.3.3) requires that $\frac{dq^{sw}}{dx} \times \frac{dx^{sw}}{dq} < 1 \Leftrightarrow \frac{d\tilde{x}^{sw}}{dq} > \frac{dx^{sw}}{dq}$. Observe that according to the second order conditions $\Delta^{SW} > 0 \Leftrightarrow -\frac{SW_{qq}}{SW_{qx}} > -\frac{SW_{xq}}{SW_{xx}} \Rightarrow \frac{d\tilde{x}^{sw}}{dq} > \frac{dx^{sw}}{dq}$ – thus any Nash equilibrium (q^{sw}, x^{sw}) satisfying (3.3.2)-(3.3.3) is stable. This also implies the uniqueness of (q^{sw}, x^{sw}). To see why, consider that the condition $\frac{d\tilde{x}^{sw}}{dq}(q) > \frac{dx^{sw}}{dq}(q)$ means that the slope of $q^{sw}(x)$ is larger than the slope of $x^{sw}(q)$ in the space (q, x), and they cross at least once for (q^{sw}, x^{sw}) that satisfy (3.3.2)-(3.3.3). Should they cross twice, this would require that there exists another local maximum $(\tilde{q}^{sw}, \tilde{x}^{sw})$ satisfying (3.3.2)- (3.3.3) and for which the condition $\frac{d\tilde{x}^{sw}}{dq}(q) < \frac{dx^{sw}}{dq}(q)$ now holds – implying that $\Delta^{SW} > 0$ does not hold, which is a contradiction.

Strict liability and the per capita rule. Denoting by $q_{-i} = \sum_{s \neq i} q_s$ and $x_{-i} = \sum_{s \neq i} x_s$, the first-order conditions for firm i are:

$$
\begin{aligned}
\Pi_q^{JSL} =& 0 = P(q_i + q_{-i}) + P'(q_i + q_{-i})q_i - c(x_i) - 2\left[\theta.\frac{1}{n} + (1-\theta).p\right]\alpha h(x_i + x_{-i})(q_i + q_{-i}) \\
\Pi_x^{JSL} =& 0 = -h'(x_i + x_{-i}).\left[\theta.\frac{1}{n} + (1-\theta).p\right]\alpha(q_i + q_{-i})^2 - c'(x_i)q_i
\end{aligned}
$$

Second order conditions at firm level require that at (q^{JSL}, x^{JSL}) (we use usual notations for second order derivatives): $\Delta^{JSL} \equiv \Pi_{qq}^{JSL}.\Pi_{xx}^{JSL} - \left(\Pi_{qx}^{JSL}\right)^2 > 0$ at (q^{JSL}, x^{JSL}), with $\Pi_{qq}^{JSL} = -(2P'(nq) + P''(nq)q + 2\left[\theta.\frac{1}{n} + (1-\theta).p\right]\alpha h(nx)) < 0$, $\Pi_{qx}^{JSL} = \Pi_{xq}^{JSL} = -\left[\theta.\frac{1}{n} + (1-\theta).p\right]\alpha h'(nx)nq > 0$, and $\Pi_{xx}^{JSL} = -(h''(nx)\left[\theta.\frac{1}{n} + (1-\theta).p\right]\alpha n^2 q + c''(x))q < 0$. Substituting, we obtain:

$$
\begin{aligned}
\Delta^{JSL} =& \left(2P'(nq) + P''(nq)q + 2\left[\theta.\frac{1}{n} + (1-\theta).p\right]\alpha h(nx)\right) \\
& \times \left(\left[\theta.\frac{1}{n} + (1-\theta).p\right]\alpha h''(nx)\,(nq)^2 + c''(x)q\right) - \left[\theta.\frac{1}{n} + (1-\theta).p\right]^2 (h'(nx)\alpha nq)^2 \\
& > \left[\theta.\frac{1}{n} + (1-\theta).p\right]^2 (\alpha nq)^2 \left[2h(nx)h''(nx) - (h'(nx))^2\right]
\end{aligned}
$$

Thus under (3.C1), $\Delta^{JSL} > 0$ holds.

Let us now denote as $q^{JSL}(x)$ the output level that solves (3.4.2) for any given x; similarly $x^{JSL}(q)$ is the care level that solves (3.4.3) for any given q. Straightforward calculations show that these functions are positively sloped in the space (q, x); denoting $\tilde{x}^{JSL}(q)$ the inverse of $q^{JSL}(x)$. Let us denote the first order conditions for profit maximization at equilibrium respectively as: $\hat{\Pi}_q^{JSL} = 0 = P(nq) + P'(nq)q - c(x) - 2\left[\theta.\frac{1}{n} + (1-\theta).p\right]\alpha h(nx)nq$ and $\hat{\Pi}_x^{JSL} = 0 = -h'(nx).\left[\theta.\frac{1}{n} + (1-\theta).p\right]\alpha (nq)^2 - c'(x)q$; we obtain: $\frac{d\tilde{x}^{JSL}}{dq} = -\frac{\hat{\Pi}_{qq}^{JSL}}{\hat{\Pi}_{qx}^{JSL}} > 0$, $\frac{dx^{JSL}}{dq} = -\frac{\hat{\Pi}_{qx}^{JSL}}{\hat{\Pi}_{xx}^{JSL}} > 0$, since we can verify that at (q^{JSL}, x^{JSL}): $\hat{\Pi}_{qq}^{JSL} = -((1+n)P'(nq) + P''(nq) + 2\left[\theta.\frac{1}{n} + (1-\theta).p\right]\alpha nh(nx)) < 0$, $\hat{\Pi}_{qx}^{JSL} = \hat{\Pi}_{xq}^{JSL} = -h'(nx)\left[\theta.\frac{1}{n} + (1-\theta).p\right]\alpha n^2 q > 0$, and $\hat{\Pi}_{xx}^{JSL} = -(h''(nx)\left[\theta.\frac{1}{n} + (1-\theta).p\right]\alpha (nq)^2 - c''(x))q < 0$. Hence output and care are strategic complements under the per capita rule. Moreover note that $-\frac{\hat{\Pi}_{qq}^{JSL}}{\hat{\Pi}_{qx}^{JSL}} > -\frac{\hat{\Pi}_{qx}^{JSL}}{\hat{\Pi}_{xx}^{JSL}}$ is equivalent to the condition:

$$
\begin{aligned}
&\left((1+n)P'(nq) + P''(nq) + 2\left[\theta.\frac{1}{n} + (1-\theta).p\right]\alpha h(nx)n\right) \\
\times &\left(h''(nx)\left[\theta.\frac{1}{n} + (1-\theta).p\right]\alpha (nq)^2 + c''(x)q\right) \\
> &\left[\theta.\frac{1}{n} + (1-\theta).p\right]^2 (h'(nx)\alpha nq)^2
\end{aligned}
$$

which obviously holds under (3.C1). Hence this implies $\frac{d\tilde{x}^{JSL}}{dq} > \frac{dx^{JSL}}{dq}$ – any Nash equilibrium (q^{JSL}, x^{JSL}) satisfying (3.4.2)-(3.4.3) is thus stable. This also implies the unicity of (q^{JSL}, x^{JSL}). To see why, consider that the condition $\frac{d\tilde{x}^{JSL}}{dq}(q) > \frac{dx^{JSL}}{dq}(q)$ means that the slope of $q^{JSL}(x)$ is larger than the slope of $x^{JSL}(q)$ in the space (q, x), and they cross at least once for (q^{JSL}, x^{JSL}) that satisfy (3.4.2)-(3.4.3). Should they cross twice, this would require that there exists another local maximum $(\tilde{q}^{JSL}, \tilde{x}^{JSL})$ satisfying (3.4.2)-(3.4.3) and for which the condition $\frac{d\tilde{x}^{JSL}}{dq}(q) < \frac{dx^{JSL}}{dq}(q)$ now holds – implying that $\Delta^{JSL} > 0$ does not hold, which is a contradiction.

Strict liability with the market share rule. Let us assume now that at the second trial, Courts assess individual contributions according to individual market shares, i.e. $s_i = \frac{q_i}{Q}$, $\forall i = 1, ..., n$. We assume that the individual liability cost function $L_i^{MS}(q_i, x_i) = \left[\theta.\left(\frac{q_i}{Q}\right) + (1-\theta).p\right].\alpha H(Q, X)$ is convex in (q_i, x_i), which implies that the following condition holds:

For any $(Q,X)>0$:

$$[\theta+(1-\theta).p]\left[\theta.\left(\frac{q_i}{Q}\right)+(1-\theta).p\right].h(X).h''(X)-\left[\theta.\left(\frac{q_i+Q}{2Q}\right)+(1-\theta).p\right]^2 2(h'(X))^2>0 \tag{3.C2}$$

This requirement is stronger than (3.C1), but allows that second order conditions for profit maximization under the market share rule are satisfied. Firm i chooses now a level of output and level of care that maximize the profit:

$$\Pi^{MS}(q_i,x_i)=\left[P(Q)-c(x_i)\right]q_i-\left[\theta.\left(\frac{q_i}{Q}\right)+(1-\theta).p\right].\alpha h(X)Q^2$$

The first-order conditions for firm i are:

$$\begin{aligned}\Pi_q^{MS} =&0=P(q_i+q_{-i})+P'(q_i+q_{-i})q_i-c(x_i)-\left[\theta.\left(2q_i+q_{-i}\right)+(1-\theta).p2\left(q_i+q_{-i}\right)\right]\alpha h(x_i+x_{-i})\\ \Pi_x^{MS} =&0=-h'(x_i+x_{-i}).\left[\theta.\left(\frac{q_i}{Q}\right)+(1-\theta).p\right]\alpha(q_i+q_{-i})^2-c'(x_i)q_i\end{aligned}$$

Second order conditions at firm level require that: $\Delta^{MS}\equiv\Pi_{qq}^{MS}.\Pi_{xx}^{MS}-\left(\Pi_{qx}^{MS}\right)^2>0$ at (q^{MS},x^{MS}), where:

$\Pi_{qq}^{MS}=-(2P'(nq)+P''(nq)+2\left[\theta+(1-\theta).p\right]\alpha h(nx))<0$, and (using $\Pi_x^{MS}=0$ at (q^{MS},x^{MS})):

$\Pi_{qx}^{MS}=-c'(x)-\left[\theta.\frac{1}{n}+(1-\theta).p\right]2nq.\alpha h'(nx)=-h'(nx).\alpha nq\left[\theta.\frac{1}{n}+(1-\theta).\left(2-n\right)p\right]=\Pi_{xq}^{MS}$

and finally: $\Pi_{xx}^{MS}=-(h''(nq)\left[\theta.\frac{1}{n}+(1-\theta).p\right]\alpha\left(nq\right)^2+c''(x)q)<0.$

Substituting, we obtain:

$$\begin{aligned}\Delta^{MS} =&(2P'(nq)+P''(nq)+2\left[\theta+(1-\theta).p\right]\alpha h(nx))(h''(nx)\left[\theta.\frac{1}{n}+(1-\theta).p\right]\alpha\left(nq\right)^2+c''(x)q)\\ &-\left[\theta.\frac{1}{n}+(1-\theta).\left(2-n\right)p\right]^2\left(h'(nx).\alpha nq\right)^2\\ &>\left(\alpha nq\right)^2\left(2h(nx)h''(nx)\left[\theta+(1-\theta).p\right]\left[\theta.\frac{1}{n}+(1-\theta).p\right]-\left[\theta.\frac{1}{n}+(1-\theta).\left(2-n\right)p\right]^2\left(h'(nx)\right)^2\right)\end{aligned}$$

This last term is positive (given that $\theta.\frac{1}{n}+(1-\theta).(2-n)\,p<\theta.\frac{1+n}{n}+(1-\theta).2p)$ since (3.C2) implies that $2\left[\theta+(1-\theta).p\right]\left[\theta.\frac{1}{n}+(1-\theta).p\right]h(nx)h''(nq)>\left[\theta.\frac{1+n}{n}+(1-\theta).2p\right]^2(h'(nx))^2$; thus $\Delta^{MS}>0$ holds.

It is straightforward to verify using the first order conditions, that the symmetric Cournot-Nash equilibrium where $q_1=...=q_n=q^{MS}$ and $x_1=...=x_n=x^{MS}$ solves now:

$$P(nq)+P'(nq)q = c(x)+2\alpha\left[\theta.\frac{1+n}{2n}+(1-\theta).p\right].h(nx).nq \quad \text{(A)}$$

$$-h'(nx).\alpha\left[\theta.\frac{1}{n}+(1-\theta).p\right].n^2q = c'(x) \quad \text{(B)}$$

with a meaning equivalent to (3.4.2)-(3.4.3). The LHS in (A) also exhibits the standard distortion due to imperfect competition according to which the marginal markets proceeds are smaller than the market demand price. It is easy to verify once more that under (3.C1), output and care levels defined by (A)-(B) are strategic complements.

Let us now denote as $q^{MS}(x)$ the output level that, for any given value of care, solves (A); similarly $x^{MS}(q)$ will denote the care level that, for any given value of the output, solves (B). Straightforward calculations show now that these functions are positively sloped in the space (q,x). Let us denote the first order conditions for profit maximization at equilibrium as $\hat{\Pi}_q^{MS}=0=P(nq)+P'(nq)q-c(x)-2\left[\theta.\frac{1+n}{2n}+(1-\theta).p\right]\alpha h(nx)nq$ and $\hat{\Pi}_x^{MS}=0=-h'(nx).\left[\theta.\frac{1}{n}+(1-\theta).p\right]\alpha\,(nq)^2-c'(x)q$, we have:

$$\frac{d\tilde{x}^{MS}}{dq}=-\frac{\hat{\Pi}_{qq}^{MS}}{\hat{\Pi}_{qx}^{MS}}>0\ ,\quad \frac{dx^{MS}}{dq}=-\frac{\hat{\Pi}_{xq}^{MS}}{\hat{\Pi}_{xx}^{MS}}>0$$

since: $\hat{\Pi}_{qq}^{MS}=-\left((1+n)P'(nq)+P''(nq)q+\left[\theta.\frac{1+n}{2n}+(1-\theta).p\right]2n\alpha h(nx)\right)<0$, $\hat{\Pi}_{qx}^{MS}=-h'(nx)\left[\theta+(1-\theta).p\right]\alpha n^2q>0$, $\hat{\Pi}_{xq}^{MS}=-h'(nx)\left[\theta+(1-\theta).np\right]\alpha nq>0$ (using $\hat{\Pi}_x^{MS}=0$), and $\hat{\Pi}_{xx}^{MS}=-\left(h''(nx)\left[\theta.\frac{1}{n}+(1-\theta).p\right]\alpha n\,(nq)^2+c''(x)q\right)<0$. Hence output and care are strategic complements under the market share rule. Moreover $-\frac{\hat{\Pi}_{qq}^{MS}}{\hat{\Pi}_{qx}^{MS}}>-\frac{\hat{\Pi}_{xq}^{MS}}{\hat{\Pi}_{xx}^{MS}}$ is equivalent to the next condition:

$$
\begin{aligned}
&\left((1+n)P'(nq)+P''(nq)q+\left[\theta.\frac{1+n}{2n}+(1-\theta).p\right]2n\alpha h(nx)\right)\\
&\times\left(h''(nx)\left[\theta.\frac{1}{n}+(1-\theta).p\right]n\alpha\left(nq\right)^2+c''(x)q\right)\\
&>\left[\theta+(1-\theta).p\right]\left[\theta\frac{1}{n}+(1-\theta).p\right]n^2\left(h'(nx)\alpha nq\right)^2
\end{aligned}
$$

which holds under (3.C1) since:

$$
\begin{aligned}
&\left((1+n)P'(nq)+P''(nq)q+\left[\theta.\frac{1+n}{2n}+(1-\theta).p\right]2n\alpha h(nx)\right)\\
&\times\left(h''(nx)\left[\theta.\frac{1}{n}+(1-\theta).p\right]n\alpha\left(nq\right)^2+c''(x)q\right)\\
&>\left(\alpha nq\right)^2.h(nx)h''(nx).2n^2.\left[\theta.\frac{1+n}{2n}+(1-\theta).p\right]\left[\theta.\frac{1}{n}+(1-\theta).p\right]
\end{aligned}
$$

hence $\frac{d\tilde{x}^{MS}}{dq}>\frac{dx^{MS}}{dq}$ – any Nash equilibrium (q^{MS},x^{MS}) satisfying (A)-(B) is thus stable. This also implies the uniqueness of (q^{MS},x^{MS}). To see why, consider that the condition $\frac{d\tilde{x}^{MS}}{dq}(q)>\frac{dx^{MS}}{dq}(q)$ means that the slope of $q^{MS}(x)$ is larger than the slope of $x^{MS}(q)$ in the space (q,x), and they cross at least once for (q^{MS},x^{MS}) that satisfy (A)-(B). Should they cross twice, this would require that there exists another local maximum $(\tilde{q}^{MS},\tilde{x}^{MS})$ satisfying (A)-(B) and for which the condition $\frac{d\tilde{x}^{MS}}{dq}(q)<\frac{dx^{MS}}{dq}(q)$ now holds – implying that $\Delta^{MS}>0$ does not hold, which is a contradiction.

We have the following result: i) The per capita rule yields a level of output and a level of care larger than the market share rule $\left[q^{JSL}>q^{MS}\ \textit{and}\ x^{JSL}>x^{MS}\right]$. ii) Whatever the damages rule, the equilibrium is inefficient, with output and care levels that may be larger as well as smaller than their socially optimal levels.

Proof: In order to simplify the exposition of the results, we assume here that $\alpha=1$ without lost of generality, the rationale being that we forward the more important discussion about optimal damages multipliers below (alternatively, α must be low enough in a sense to be specified – although set in an inefficient manner, which is sufficient for our purpose here).

Remark first that: $\theta.\frac{1}{n}+(1-\theta).p<\theta.\frac{1+n}{2n}+(1-\theta).p<1$ for any $\theta,p\in]0,1[$. Let us denote as $q^{sw}(x)$ the output level that solves (3.3.2), for any given value of care;

while $x^{sw}(q)$ is the care level that solves (3.3.3), for any given value of the output. Similarly, let us denote as $q^{JSL}(x)$ the output level that solves (3.4.2), for any given value of care; while $x^{JSL}(q)$ is the care level that solves (3.4.3), for any given value of the output; and let $q^{MS}(x)$ be the output level that solves (A), for any given value of care; while $x^{MS}(q)$ is the care level that solves (B), for any given value of the output.

i) According to conditions (3.4.3) and (B): $\forall q > 0$, $x^{JSL}(q) = x^{MS}(q)$. In contrast, according to the RHS in (3.4.2) and (A): $2\left[\theta.\frac{1}{n} + (1-\theta).p\right] h(nx)nq < 2\left[\theta.\frac{1+n}{2n} + (1-\theta).p\right] h(nx)nq$ implying that: $\forall x > 0$, $q^{JSL}(x) > q^{MS}(x)$. Hence: $x^{JSL} > x^{MS}$ and $q^{JSL} > q^{MS}$ since care and output are strategic complements under both rules. ii) and iii) From (3.3.3)-(3.4.3)-(B), it comes that: $-h'(nx).\left[\theta.\frac{1}{n} + (1-\theta).p\right] n^2q < -h'(nx).n^2q$; hence: $\forall q > 0$, $x^{sw}(q) > x^{JSL}(q) = x^{MS}(q)$. In turn, comparing (3.3.2)-(3.4.2)-(A) shows there are two opposite effects on output. On the one hand (comparing the LHS): $P(nq) + P'(nq)q < P(nq)$; this reduces the incentives to produce under strict liability at any level of care, compared with the social optimum. On the other hand (comparing the RHS): $2\left[\theta.\frac{1}{n} + (1-\theta).p\right].h(nx)nq < 2\left[\theta.\frac{1+n}{2n} + (1-\theta).p\right].h(nx)nq < 2h(nx).nq$; this increases now the incentives to produce at any level of care, compared with the social optimum. Thus, $q^{sw}(x)$ is not generally comparable with $q^{JSL}(x)$ or $q^{MS}(x)$. Hence the result. ■

Proof of propositions 13ii).

Let us denote (3.4.2)-(3.4.3) the first conditions for profit maximization under Joint and Several Liability with a right of contribution, and the per capita rule, as:

$$\hat{\Pi}_q = R(q) - c(x) - 2\alpha h(nx)nq.\Delta = 0 \tag{C}$$
$$\hat{\Pi}_x = -\, h'(nx).\alpha n^2 q.\Delta - c'(x) = 0 \tag{D}$$

where $R(q) = P(nq) + P'(nq)q$, and $\Delta = \theta\frac{1}{n} + (1-\theta)p$ for any $\theta, p \in]0,1[$. Differentiating (C)-(D) in θ, given that $\hat{\Pi}_{qq}.\hat{\Pi}_{xx} - \hat{\Pi}_{qx}.\hat{\Pi}_{xq} > 0$, we obtain:

$$sign\frac{dq}{d\theta} = sign\left(-\hat{\Pi}_{q\theta}.\hat{\Pi}_{xx} + \hat{\Pi}_{x\theta}.\hat{\Pi}_{qx}\right)$$
$$sign\frac{dx}{d\theta} = sign\left(-\hat{\Pi}_{x\theta}.\hat{\Pi}_{qq} + \hat{\Pi}_{q\theta}.\hat{\Pi}_{xq}\right)$$

with:

$$\begin{aligned}
\hat{\Pi}_{qq} =& R'(q) - 2\alpha h(nx)n\Delta < 0 \\
\hat{\Pi}_{qx} =& -2\alpha nqh'(nx)n\Delta - c'(x) = -\alpha nqh'(nx)n\Delta \lesseqgtr 0 \text{ using } \hat{\Pi}_x = 0 \\
\hat{\Pi}_{xq} =& -\alpha nh'(nx)n\Delta > 0 \\
\hat{\Pi}_{xx} =& -\left(\alpha h''(nx)n^2 qn\Delta + c''(x)\right) < 0 \\
\hat{\Pi}_{q\theta} =& -2\alpha qh(nx)n\frac{d\Delta}{d\theta} \\
\hat{\Pi}_{x\theta} =& -\alpha nqh'(nx)n\frac{d\Delta}{d\theta}
\end{aligned}$$

and $R'(q) = (1+n)P'(nq) + P''(nq)q < 0$. Developing it comes:

$$\begin{aligned}
-\hat{\Pi}_{q\theta}.\hat{\Pi}_{xx} + \hat{\Pi}_{x\theta}.\hat{\Pi}_{qx} =& -\frac{d\Delta}{d\theta}\left(2\alpha nqh\left(nx\right)c''(x) + \left(\alpha nq\right)^2 n^2\Delta\left[2h(nx).h''(nx) - \left(h'(nx)\right)^2\right]\right) \\
-\hat{\Pi}_{x\theta}.\hat{\Pi}_{qq} + \hat{\Pi}_{q\theta}.\hat{\Pi}_{xq} =& \frac{d\Delta}{d\theta}.\alpha n^2 qh'(nx).R'(q)
\end{aligned}$$

A/ Comparison of Joint and Several Liability with and without a right of contribution. In the case $\theta = 0$ (for any $p \in]0,1[$), then (C)-(D) correspond to the first order conditions obtained under Joint and Several Liability without a right of contribution, (3.4.5)-(3.4.6). Hence for $\theta = 0$: $\Delta = p$ and $\frac{d\Delta}{d\theta} = \frac{1}{n} - p$; thus, given that $\left[2h(nx).h''(nx) - \left(h'(nx)\right)^2\right] > 0$ under condition (3.C1), we obtain:

$$\begin{aligned}
sign\left(\frac{dq}{d\theta}\right)_{\theta=0} =& sign\left(-\hat{\Pi}_{q\theta}.\hat{\Pi}_{xx} + \hat{\Pi}_{x\theta}.\hat{\Pi}_{qx}\right)_{\theta=0} = sign\left(p - \frac{1}{n}\right) \\
sign\left(\frac{dx}{d\theta}\right)_{\theta=0} =& sign\left(-\hat{\Pi}_{x\theta}.\hat{\Pi}_{qq} + \hat{\Pi}_{q\theta}.\hat{\Pi}_{xq}\right)_{\theta=0} = sign\left(\frac{1}{n} - p\right)
\end{aligned}$$

Given that a move from JSL without a right of contribution towards JSL with a right of contribution (from $\theta = 0$ towards $\theta > 0$) means an increase in θ, we obtain for the per capita rule:

$$\left[p < \tfrac{1}{n} \Rightarrow \left(\tfrac{dq}{d\theta}\right)_{\theta=0} < 0 \text{ and } \left(\tfrac{dx}{d\theta}\right)_{\theta=0} > 0\right] \Leftrightarrow$$
$$\left[p < \tfrac{1}{n} \Rightarrow q^{NRC} > q^{JSL} \text{ and } x^{NRC} < x^{JSL}\right]$$

$$\left[p > \tfrac{1}{n} \Rightarrow \left(\tfrac{dq}{d\theta}\right)_{\theta=0} > 0 \text{ and } \left(\tfrac{dx}{d\theta}\right)_{\theta=0} < 0\right] \Leftrightarrow$$
$$\left[p > \tfrac{1}{n} \Rightarrow q^{NRC} < q^{JSL} \text{and } x^{NRC} > x^{JSL}\right]$$

B/ Comparison of Joint Liability and Joint and Several Liability with a right of contribution. When $\theta = 1$ (for any $p \in]0, 1[\frac{1}{n}$), then (C)-(D) correspond to the first order conditions obtained under Joint Liability with the per capita rule, (3.4.8)-(3.4.9). Thus $\Delta = \frac{1}{n}$, and $\frac{d\Delta}{d\theta} = \frac{1}{n} - p$; thus we obtain under condition (3.C1):

$$\begin{aligned}
sign\left(\frac{dq}{d\theta}\right)_{\theta=1} &= sign\left\{\left(p - \frac{1}{n}\right)\left(2\alpha nh\left(nx\right)c''(x) + (\alpha nq)^2 n\left[2h(nx).h''(nx) - \left(h'(nx)\right)^2\right]\right)\right\} \\
&= sign\left(p - \frac{1}{n}\right) \\
sign\left(\frac{dx}{d\theta}\right)_{\theta=1} &= sign\left(\left(\frac{1}{n} - p\right).\alpha n^2 pR'(q).h'(nx)\right) = sign\left(\frac{1}{n} - p\right)
\end{aligned}$$

Given that a move from JL to JSL means a decrease in θ (from $\theta = 1$ towards $\theta < 1$), we obtain for the per capita rule:

$$\left[p < \tfrac{1}{n} \Rightarrow \left(\tfrac{dq}{d\theta}\right)_{\theta=1} < 0 \text{ and } \left(\tfrac{dx}{d\theta}\right)_{\theta=1} > 0\right] \Leftrightarrow \left[p < \tfrac{1}{n} \Rightarrow q^{JL} < q^{JSL} \text{ and } x^{JL} > x^{JSL}\right]$$

$$\left[p > \tfrac{1}{n} \Rightarrow \left(\tfrac{dq}{d\theta}\right)_{\theta=1} > 0 \text{ and } \left(\tfrac{dx}{d\theta}\right)_{\theta=1} < 0\right] \Leftrightarrow \left[p > \tfrac{1}{n} \Rightarrow q^{JL} > q^{JSL} \text{and } x^{JL} < x^{JSL}\right]$$

C/ Comparison of Joint Liability and Joint and Several Liability without a right of contribution. On the one hand when $\theta = 0$ (for any $p \in]0, 1[$), then (C)-(D) correspond to the first order conditions obtained under Joint and Several Liability without a right of contribution, (3.4.5)-(3.4.6); on the other hand, when $\theta = 0$ and $p = \frac{1}{n}$, then (C)-(D) correspond to the first order conditions obtained under Joint Liability with the per capita rule, (3.4.8)-(3.4.9). Differentiating (C)-(D) in p, given that $\hat{\Pi}_{qq}.\hat{\Pi}_{xx} - \hat{\Pi}_{qx}.\hat{\Pi}_{xq} > 0$, we obtain now:

$$\begin{aligned}
sign\frac{dq}{dp} &= sign\left(-\hat{\Pi}_{qp}.\hat{\Pi}_{xx} + \hat{\Pi}_{xp}.\hat{\Pi}_{qx}\right) \\
sign\frac{dx}{dp} &= sign\left(-\hat{\Pi}_{xp}.\hat{\Pi}_{qq} + \hat{\Pi}_{qp}.\hat{\Pi}_{xq}\right)
\end{aligned}$$

with:

$$\hat{\Pi}_{qp} = -\,2\alpha q h(nx) n \frac{d\Delta}{dp}$$
$$\hat{\Pi}_{xp} = -\,\alpha n q h'(nx) n \frac{d\Delta}{dp}$$

Developing it comes:

$$-\hat{\Pi}_{q\theta}.\hat{\Pi}_{xx} + \hat{\Pi}_{x\theta}.\hat{\Pi}_{qx} = -\frac{d\Delta}{dp}\left(2\alpha n q h\left(nx\right) c''(x) + \left(\alpha n q\right)^2 n^2 \Delta\left[2h(nx).h''(nx) - \left(h'(nx)\right)^2\right]\right)$$
$$-\hat{\Pi}_{x\theta}.\hat{\Pi}_{qq} + \hat{\Pi}_{q\theta}.\hat{\Pi}_{xq} = \frac{d\Delta}{dp}.\alpha n^2 q h'(nx).R'(q)$$

with $\frac{d\Delta}{dp} = 1-\theta$. For $\theta = 0$: $\Delta = p$ and $\frac{d\Delta}{dp} = 1$; thus, given that $\left[2h(nx).h''(nx) - \left(h'(nx)\right)^2\right] > 0$ under condition (3.C1)

$$sign\left(\frac{dq}{dp}\right)_{\theta=0,p=\frac{1}{n}} = sign\left(-\hat{\Pi}_{qp}.\hat{\Pi}_{xx} + \hat{\Pi}_{xp}.\hat{\Pi}_{qx}\right)_{\theta=0,p=\frac{1}{n}} \Rightarrow sign\left(\frac{dq}{dp}\right)_{\theta=0,p=\frac{1}{n}} < 0$$
$$sign\left(\frac{dx}{dp}\right)_{\theta=0,p=\frac{1}{n}} = sign\left(-\hat{\Pi}_{xp}.\hat{\Pi}_{qq} + \hat{\Pi}_{qp}.\hat{\Pi}_{xq}\right)_{\theta=0,p=\frac{1}{n}} \Rightarrow sign\left(\frac{dx}{dp}\right)_{\theta=0,p=\frac{1}{n}} > 0$$

Hence given that at $p = \frac{1}{n}$, we have $q^{JL} = q^{NRC}$ and $x^{JL} = x^{NRC}$, then:

$$\left[p < \tfrac{1}{n} \Rightarrow \left(\tfrac{dq}{dp}\right)_{p=\frac{1}{n}} > 0 \text{ and } \left(\tfrac{dx}{dp}\right)_{p=\frac{1}{n}} < 0\right] \Leftrightarrow$$
$$\left[p < \tfrac{1}{n} \Rightarrow q^{JL} < q^{NRC} \text{and } x^{JL} > x^{NRC}\right]$$

$$\left[p > \tfrac{1}{n} \Rightarrow \left(\tfrac{dq}{dp}\right)_{p=\frac{1}{n}} < 0 \text{ and } \left(\tfrac{dx}{dp}\right)_{p=\frac{1}{n}} > 0\right] \Leftrightarrow$$
$$\left[p > \tfrac{1}{n} \Rightarrow q^{JL} > q^{NRC} \text{ and } x^{JL} < x^{NRC}\right]$$

Hence, collecting the different results leads to proposition 13ii.