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Localisation des productions agricoles et durabilité des systèmes d'approvisionnement alimentaire en milieu urbain.

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Introduction

Au cours des soixante dernières années, la population mondiale a connu un sursaut spectaculaire, passant de 2,5 milliards d'habitants à la fin de la Seconde Guerre mondiale à 7 milliards en 2011. Cette croissance démographique se distingue des précédents épisodes tant par son importance que par l'apparition conjointe d'une tendance nouvelle et soutenue à la concentration des populations au sein des villes. Processus fortement porté par deux siècles de mutations économiques et sociales, l'urbanisation se présente comme l'un des faits majeurs du 21ème siècle. Ainsi, sur les 9 milliards de personnes que comptera le monde d'ici 2050, plus des deux tiers seront urbains [United Nations, 2014].

Appelée à se renforcer partout dans le monde, cette tendance au grossissement des villes lance un véritable défi à la communauté internationale en matière de durabilité de notre système économique : "comment parvenir à concilier croissance économique, développement et préservation de l'environnement, tout en faisant face à des contraintes de raréfaction de ressources ?"

Parmi les grands enjeux qui se profilent, celui de la sécurité alimentaire revêt une importance capitale, à la fois par son statut de besoin primaire, mais également par la complexité du défi qu'elle impose. Cette problématique n'est pas nouvelle ; bien qu'aujourd'hui essentiellement cantonnée aux seuls pays du Sud, elle a longtemps été une priorité pour l'ensemble des sociétés de l'ère préindustrielle. Sous l'effet des bouleversements induits par l'accroissement démographique, elle pourrait redevenir centrale, y compris dans les pays industrialisés à économie de marché. Comme souligné par Morgan [2014], les grandes villes des pays du Nord seront inéluctablement impactées par cette transition, certaines d'entre elles se retrouvant même en première ligne de cette "nouvelle équation alimentaire".

En concentrant désormais plus de la moitié de la population mondiale, les villes doivent aujourd'hui trouver réponse à la question : "comment nourrir durablement une population urbaine en constante progression ?" Cette problématique est au cœur de cette thèse. De manière générale, l'ensemble des travaux regroupés au sein de ce manuscrit interroge la durabilité environnementale et sociale de la localisation des productions agricoles par rapport aux grands centres de consommations. Cette thèse a pour ambition de proposer un traitement théorique de la question de *l'approvisionnement alimentaire des villes dans un contexte de réflexion générale sur le changement climatique et le développement durable.* A la frontière entre économie géographique et économie de l'environnement, elle poursuit comme objectif principal de permettre la conduite d'une analyse formalisée des arbitrages environnementaux et sociaux dans un cadre spatial explicite. En outre, l'idée selon laquelle aucune réponse ne saurait être satisfaisante sans qu'une attention spécifique soit portée aux interactions spatiales, économiques et écologiques entre espaces urbains et agriculture constitue l'un des positionnements clés défendus dans ce travail.

Le premier chapitre de cette thèse est dédié à une présentation factuelle du contexte. Celle-ci nous amène à avancer l'idée que la géographie urbaine telle qu'observée aujourd'hui est pour l'essentiel le résultat d'une construction jointe et mutuellement entretenue de l'agriculture et des villes. La localisation des grands pôles urbains dans l'espace a en effet été significativement guidée par la nature des terres disponibles, l'hétérogénéité des sols combinée aux contraintes de temps et de coût ayant naturellement conduit les populations à organiser l'ensemble des activités de production autour des terres les plus fertiles.

Ce rapide aperçu de l'évolution des relations entre ville et agriculture nous permet à la fois de mieux cerner les contours de la nouvelle problématique alimentaire et de faire ressortir les principaux facteurs à prendre en compte dans notre modélisation.

Suite à cette introduction, nous proposons trois travaux théoriques abordant la question de l'approvisionnement alimentaire des villes sous différents aspects. Le chapitre 2 questionne dans un premier temps la pertinence en termes de bénéfices économiques et environnementaux d'un système d'approvisionnement exclusivement local, reposant sur l'autosuffisance alimentaire de l'ensemble des villes appartenant à une même entité géographique donnée. L'objectif de ce chapitre n'étant pas d'étayer les théories de localisation de l'activité agricole, mais de rendre compte de l'impact de la structuration d'un territoire sur la qualité écologique du système pris dans son ensemble, les hypothèses retenues pour le modèle se veulent volontairement "simplificatrices" car nécessaires pour répondre à cette *problématique d'allocation des biens dans un cadre spatial multirégional*.

Les chapitres 3 et 4 proposent un traitement davantage "micro spatial" de la problématique, s'intéressant tout deux aux conditions économiques nécessaires à l'émergence d'une filière agricole alternative en périphérie des grandes villes. De manière plus précise, le chapitre 3 s'interroge sur la capacité d'une agriculture de proximité à s'implanter durablement en l'absence d'intervention publique. Dans ce modèle, agriculture conventionnelle et alternative proposent des biens imparfaitement substituables et se distinguent également de par leurs pratiques de production. Le chapitre 4 entre quant à lui un peu plus dans le détail en considérant de manière plus fine les préférences des consommateurs (introduction de différenciation verticale et horizontale des produits agricoles), et en tenant compte de l'interaction entre activités urbaine et agricole avoisinantes (introduction d'une externalité environnementale).

Le cinquième et dernier chapitre de ce manuscrit dresse finalement le bilan des enseignements pouvant être tirés des travaux proposés et ouvre la discussion sur les perspectives et les extensions envisageables.

1.1 L'approvisionnement alimentaire des villes : un rapide historique

1.1.1 Sédentarisation de l'activité agricole et naissance des villes

Le système agro-alimentaire dans sa forme actuelle est le résultat d'une construction de très long terme. Pour bâtir leur croissance, les villes ont historiquement eu à assurer leur sécurité alimentaire, menant progressivement agriculture et élevage à se substituer aux activités de cueillette et de chasse. L'offre alimentaire se fixant au sol, les premières cultures ont logiquement pris place sur les terres les plus fertiles. Ces dernières avaient alors pour fonction de nourrir les agriculteurs, population encore dominante dans les pays développés au 18^{eme} siècle, mais également de fournir un excédant alimentaire suffisant pour approvisionner les actifs nouvellement installés dans les cités.

De par le jeu conjoint des gains en productivité dans le secteur agricole et de la dynamique insufflée par le développement industriel, les villes mutèrent progressivement en pôles majeurs d'activité. Leur localisation géographique trouve, quant à elle, sa principale explication dans le coût particulièrement élevé du transport, celui-ci amenant naturellement une grande majorité des villes à se développer à proximité des zones agricoles afin de limiter les pertes liées à l'acheminement des denrées.

1.1.2 D'une agriculture de subsistance à une agro-industrie mondialisée

Pour les pays développés, le 19^{me} siècle, et en particulier la période comprise entre 1820-1830 et 1914, constitue le tournant entre une société encore essentiellement rurale, et une société urbanisée dans laquelle près de 90% de la population ne se retrouve plus directement impliquée dans l'agriculture.

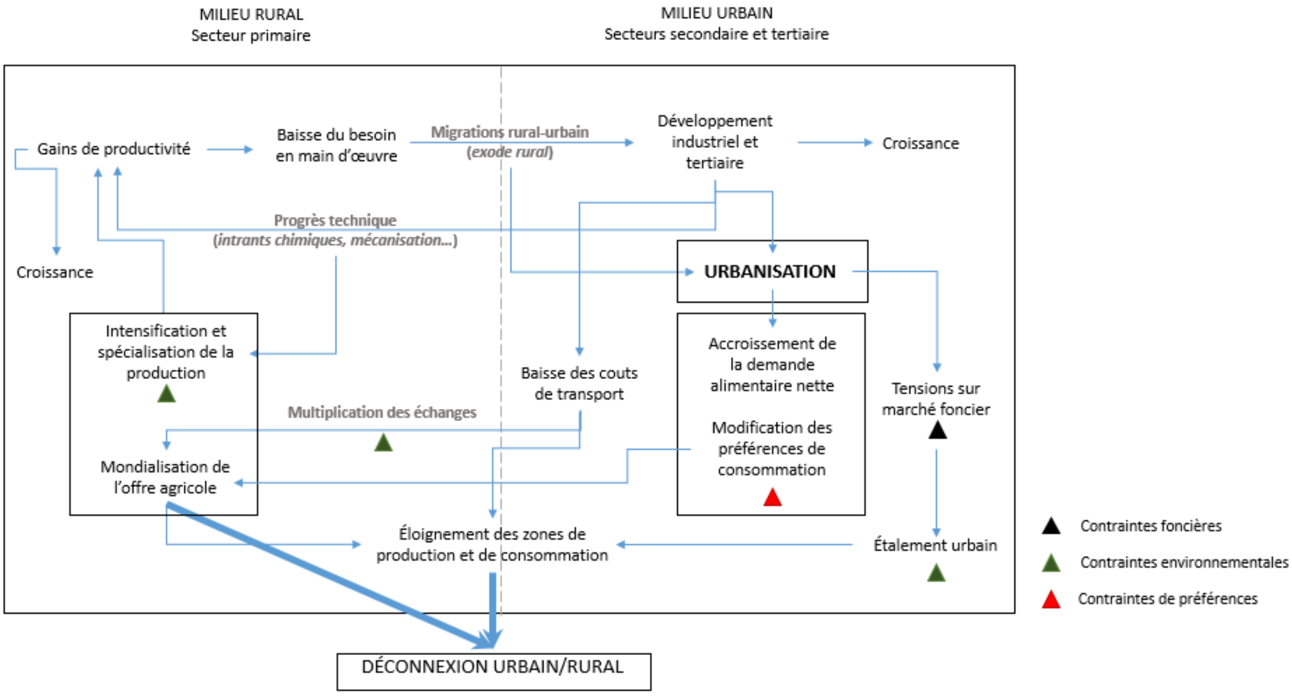

Figure 1.1 – *Dynamiques et interrelations économiques entre secteurs*

Parmi les facteurs ayant contribué à l'urbanisation, l'accroissement de la productivité agricole joue un rôle indéniable. En se basant sur des données relatives à vingt pays sur la période 1830-1920, Bairoch and Goertz [1986] mettent en évidence une corrélation positive et fortement significative entre niveau d'urbanisation et productivité agricole, expliquant cette relation par un phénomène de migration sectorielle ; l'amélioration de l'efficacité productive a permis de libérer une part de plus en plus importante de la main d'œuvre agricole, cette dernière étant alors disponible pour travailler dans l'industrie localisée en milieu urbain.

Parallèlement aux gains de productivité enregistrés dans le secteur agricole, les progrès techniques réalisés dans le domaine des transports ont progressivement contribué à gommer la contrainte de distance qui pesait sur l'organisation de la filière d'approvisionnement alimentaire. L'espace et plus encore la localisation relative des différents acteurs de la chaine perdent en importance. S'opèrent alors de profondes modifications dans la logistique d'acheminement des produits alimentaires, aboutissant un siècle et demi plus tard à la mondialisation des flux d'échange que nous connaissons aujourd'hui.

Bien que de plus en plus diffus, les liens entre ville et campagne demeureront tout de même fortement présents jusqu'au début du 20^{eme} siècle ; au-delà de l'approvisionnement alimentaire qui se pérennise en tant que relation marchande, d'autres formes d'activités nécessitant d'étroits liens d'échange entre zones urbaines et rurales se développent. Ces dernières, réunies sous la dénomination de "proto-industrie" par Mendels [1972], permettent entre autre de fournir des ressources complémentaires aux populations rurales, corrigeant le déséquilibre entre raréfaction de l'emploi agricole et surcharge démographique. La filière textile des pays du Nord Ouest de l'Europe notamment apparaît comme l'un des exemples les plus aboutis de proto-industrie, les ateliers ruraux se chargeant des opérations simples ne nécessitant pas ou peu de capitaux, et celles requérant plus de technicité étant transférées vers les manufactures urbaines.

1.1.3 Caractériser le système agro-alimentaire actuel

Amorcé dès la fin du 18^{eme} siècle pour les pays du Nord, le renversement du rapport de force entre villes et campagnes s'est poursuivi tout au long du 19^{eme} siècle, se concrétisant définitivement au début du siècle dernier ; auparavant "leader" au sens où elle conditionnait localisation, nature, et rythme du développement urbain, l'agriculture doit désormais s'adapter aux exigences d'une nouvelle société urbaine. Toutefois, bien qu'elle ne soit plus perçue principale initiatrice de croissance et de développement, l'agriculture conserve un rôle essentiel, fournissant notamment l'alimentation nécessaire à la main d'œuvre non nourricière localisée dans les pôles urbains.

Le panorama actuel des relations villes-campagnes est le résultat des trois derniers siècles de mutations conjointes. D'une économie où activités agricoles et non agricoles étaient géographiquement regroupées et relativement équilibrées, les pays développés sont désormais passés à une économie caractérisée par une *offre alimentaire dispersée devant satisfaire une demande nette croissante et fortement concentrée.*

Les avancées technologiques réalisées dans le domaine du transport expliquent en grande partie l'émergence de cette nouvelle forme d'organisation des systèmes d'approvisionnement alimentaire. Le poids des coûts de transport devenu négligeable, les flux d'échange ont progressivement échappé à la logique de rationalisation du volume et la multiplication des trajets s'est alors imposée, répondant davantage aux exigences des consommateurs (goût prononcé pour la diversification de la nature et de la provenance des biens). Ce passage d'économie de stocks à économie de flux conceptualisé sous la dénomination “stock roulant” est commun à l'ensemble des pays industrialisés [Oudin, 2001]. Dans les faits, cette nouvelle forme de gestion des flux s'illustre par un recours de plus en plus fréquent aux parcours de type “navette” et au principe du “juste-à-temps” [Leglise, 2007]. Ainsi, s'il reste principalement inter-régional, le trafic de denrées alimentaire a toutefois considérablement cru sous l'effet de la multiplication des fréquences d'envoi et d'un allongement des distances lié à la polarisation de l'économie.

Cette tendance à la globalisation de l'approvisionnement alimentaire a par ailleurs contribué au rapide déclin de nombreuses productions vivrières peu rentables, accompagné d'une spécialisation géographique de la production. Dans la périphérie des grandes villes notamment, l'agriculture a poursuivi son adaptation à l'environnement urbain, se transformant progressivement en exploitations de petites tailles, spécialisée dans des cultures à hauts revenus par hectare, et ayant recours à des techniques de production plus intensives [Heimlich, 1989].

1.2 Villes et alimentation : définir la nouvelle problématique

De manière simple, la question de la réorganisation de la chaine d'approvisionnement alimentaire peut être appréhendée comme une réflexion sur les moyens à mettre en œuvre pour permettre à terme, la réalisation d'économies de flux sous contraintes environnementales, sociales, et à localisation de la demande fixe. Par opposition aux précédents enjeux qui s'inscrivaient presqu'exclusivement dans une logique de réponse quantitative à une demande nette croissante, il s'agit désormais d'une problématique plus fine d'allocation d'une production entre plusieurs points géographiquement fixés, de sorte que l'espace – ou plus précisément la localisation relative de l'ensemble des acteurs de la chaîne – redevient central.

Nourrir les villes nécessite donc de trouver et de maintenir un schéma cohérent et organisé entre espaces urbains et ruraux. Il s'agit aujourd'hui de répondre à une demande alimentaire caractérisée par une forte concentration géographique et de nouvelles exigences sociales, environnementales et sanitaires de la part des consommateurs. Bien que le principe demeure similaire - produire suffisamment pour garantir l'équilibre entre offre et demande -, il est désormais de nouvelles contraintes à intégrer, ces dernières pouvant être regroupées en trois grands items.

1.2.1 Contraintes environnementales

Le modèle agricole actuellement prépondérant – intensif, spécialisé et mondialisé - génère des externalités négatives qui, à terme, menacent l'équilibre écologique de la planète. Au sens large, les implications environnementales des systèmes d'approvisionnement alimentaire portent sur deux champs majeurs que sont la production et le transport.

Contrôler les impacts liés à la production Reposant sur l'optimisation de la production par rapport à la surface cultivée, le système agricole moderne se caractérise principalement par une utilisation accrue d'engrais chimiques et de pesticides. Les conséquences environnementales de cette intensification productive sont aujourd'hui largement montrées du doigt. Les émissions directement liées à la production agricole représentent environ un cinquième des émissions françaises de GES. Les changements d'usage des sols de ou vers l'agriculture ont également des conséquences importantes sur les stocks de carbone, et donc sur le bilan net en émissions de GES.

Par ailleurs, les énergies fossiles étant utilisées comme source d'énergie pour le carburant des machines ou le chauffage des bâtiments, et comme matière première pour la fabrication des intrants chimiques, l'agriculture est et sera directement impactée par la crise énergétique latente, renforçant par la même les arguments plaidants en faveur d'un changement dans les pratiques de production.

Maitriser les flux de transports Premiers émetteurs de gaz à effet de serre en France, les transports produisent près d'un tiers des émissions de dioxyde de carbone (CO_2) [CITEPA, 2010]. À l'échelle mondiale, la combustion des carburants fossiles provoque des émissions de CO_2 de l'ordre de 7 milliards de tonnes, soit 27% de l'ensemble des émissions du système énergétique planétaire (Enerdata). Les transports constituent par ailleurs l'unique activité à avoir vu sa contribution au bilan des rejets nationaux croître aussi rapidement au cours des 30 dernières années (+13,5% sur la période 1990-2008). Sous l'hypothèse de constance dans nos habitudes de consommation, ces émissions pourraient atteindre 9 milliards de tonnes à horizon 2030 [Dessus and Girard [2009]].

Puisqu'il est largement admis que l'amélioration de l'efficacité énergétique sera insuffisante pour réduire les émissions à un niveau compatible avec les engagements internationaux, d'autres politiques en lien notamment avec l'aménagement du territoire seront nécessaires [EEA, 2009] ; en tenant compte des ajustements dans la localisation des productions agricoles, les modes d'approvisionnement des bassins de consommation, et de leurs conséquences sur les distances parcourues par les marchandises, la planification urbaine pourrait compter parmi les leviers d'action efficaces.

1.2.2 Contraintes en ressources humaine et foncière

Avec l'émergence des villes, une transition dans le rapport de l'Homme à l'espace s'est amorcée ; du point de vue de la logique urbaine, les terres disponibles trouvent désormais de la valeur à travers la surface physique qu'elles offrent et non plus de par la qualité biologique intrinsèque de leur sol. Activités urbaines et agricoles sont donc en concurrence pour l'usage des sols : d'un côté, terre et qualités des sols demeurent un facteur essentiel et difficilement compressible à la production de biens agricoles. De l'autre, l'urbanisation et le développement d'infrastructures, synonymes de consommation d'espace, sont appelés à renforcer leur emprise foncière.

Cette compétition qui plus est défavorable aux activités agricoles du fait de leur faible rentabilité relative, est à l'origine de tensions croissantes sur le marché foncier, qui, en l'absence d'intervention publique, se soldent majoritairement par une extension de la ville aux dépens de l'agriculture. Cet étalement urbain compromet fortement la cohabitation ville-campagne et rend d'autant moins probable la relocalisation d'une activité agricole à proximité des grandes métropoles. Par conséquent, dans l'optique de l'instauration d'une forme plus durable d'approvisionnement alimentaire, les mesures garantissant la préservation d'espace dédiée à la production doivent faire l'objet d'un examen approfondi.

De manière analogue, la population vue à travers sa fonction de facteur de production offre une problématique sensiblement proche. Au sein d'une entité spatiale combinant espaces urbains et espaces ruraux, la question de l'emploi revêt un intérêt tout particulier. La concurrence que se livrent villes et campagnes est là encore particulièrement déséquilibrée, le milieu rural souffrant d'une désaffection relative par rapport au milieu urbain fortement attractif. Par conséquent, même si l'opportunité de création d'emplois en milieu rural est réelle, les conditions économiques sont peu favorables à leur concrétisation sans intervention publique. Ainsi, au même titre que la ressource foncière, mobiliser la main d'œuvre de manière efficace –c'est-à-dire de sorte à pouvoir répondre aux besoins anticipés des populations tout en garantissant une qualité de vie proche sinon égale entre urbains et ruraux—est un enjeu à prendre en considération dans la réflexion sur la durabilité des futurs systèmes d'approvisionnement alimentaire.

1.2.3 Contraintes de préférences

Le passage d'une société rurale à une société essentiellement urbaine s'est accompagné d'une transformation des préférences de consommation. La demande alimentaire urbaine présente en effet des caractéristiques spécifiques et différentes de celles traditionnellement observées. Ces caractéristiques comprennent entre autre un renforcement des exigences en matière de qualité nutritive des biens et de traçabilité des produits ; les crises sanitaires publiquement révélées depuis la fin des années 90 combinées à la diffusion des connaissances médicales ont sensiblement contribué à renforcer la méfiance des consommateurs à l'égard de l'industrie agro-alimentaire au sens large, les amenant progressivement à penser leurs achats alimentaires davantage en terme "d'investissement santé".

Les consommateurs urbains se distinguent également par l'importance croissante qu'ils tendent à accorder aux impacts indirects sociaux et environnementaux induits par leur consommation. Désormais soucieux de contribuer à la pérennisation de l'activité économique en milieu rural, ils peuvent pour certains prendre en considération le caractère équitable de la redistribution de la valeur ajoutée parmi les acteurs de la chaîne.

La demande de plus en plus fréquente d'accès à une information moins opaque sur l'origine des produits, l'empreinte carbone associée à leur commercialisation ou encore un indice de redistribution de la valeur ajoutée, constitue l'un des signes d'un changement de préférences de consommation. Ces dernières combinent par ailleurs des éléments parfois difficilement conciliables voire incompatibles, ajoutant un degré supplémentaire de complexité. Le cas des biens exotiques compte parmi les exemples les plus évidents de souhaits a priori contradictoires ; en raison des contraintes météorologiques et climatiques qui éliminent de fait la possibilité d'une production locale et durable, l'accès à ce type de biens suppose donc le maintien d'échanges marchands potentiellement coûteux en terme d'émissions de GES.

Définis par la combinaison de ces trois types de contraintes, les nouveaux contours de la problématique alimentaire apparaissent comme extrêmement complexes, et le deviennent encore davantage si l'on prend en compte l'existence d'externalités environnementales entre milieux urbain et agricole.

1.3 Les systèmes d'approvisionnement alimentaire alternatifs

L'émergence de systèmes d'approvisionnement alimentaire dits "alternatifs" (Alternative Food Network ou AFN dans la littérature anglo-saxone) est un mouvement commun à l'ensemble des pays industrialisés. Multiples de par leur nature, ils forment toutefois une entité cohérente au sens où l'ensemble de ces initiatives, symbole d'efforts consentis à la re-spacialisation et la re-socialisation conjointes des chaines d'approvisionnement alimentaire, partagent des moyens d'actions proches. Dans son article consacré à l'approvisionnement alimentaire des grandes métropoles, Jarosz [2008] retient entre autres quatre caractéristiques permettant de conceptualiser plus finement les AFNs :

Réduire la distance entre producteurs et consommateurs. Les agriculteurs produisent leurs biens à proximité des centres où ils seront consommés, l'objectif premier étant de diminuer la distance parcourue et la consommation énergétique associée au transport des aliments. La réduction du nombre d'intermédiaires impliqués dans la chaîne afin d'instaurer un lien plus direct entre agriculteurs et consommateurs y est également centrale (La Trobe and Acott [2000], O'Hara and Stagl [2001]) and Renting et al. [2003]). En passant par ce canal de distribution, les producteurs captent et conservent une part plus importante de leur revenu.

Minimiser l'impact environnemental de l'activité de production. Les filières alternatives reposent en grande partie sur une offre agricole provenant d'exploitations de petite taille ayant recours à des techniques de production respectueuses de l'environnement. Par opposition à l'industrie agro-alimentaire conventionnelle, ces exploitants s'orientent vers des pratiques où engrais synthétiques, pesticides, et semences génétiquement modifiées sont totalement absents de la production [Kloppenburg et al., 2000].

Ancrer la relation d'échange entre producteurs et consommateurs durablement dans le temps en privilégiant des circuits de vente exclusivement consacrés à la filière alternative (coopératives alimentaires, vente directe, AMAP ...) et en misant sur le développement de partenariats avec les administrations publiques (groupes scolaires, cantines centrales) [1] [Hendrickson and Heffernan, 2002].

Inscrire les pratiques de l'ensemble des acteurs de la chaîne dans le respect de normes sociales, économiques et environnementales communes. Une attention particulière est notamment portée sur les aspects justes et équitables des relations d'échanges entre producteurs, consommateurs, et intermédiaires dans l'acheminement et la distribution des denrées.

Un système alternatif se définit alors selon son positionnement le long d'un axe gradué de faible à important, pour chacun des items susmentionnés [Watts et al., 2005].

1.3.1 Des avantages invoqués...

Nombre d'arguments sont invoqués pour promouvoir le développement de ces filières d'un genre nouveau. Sur le plan écologique d'abord, les AFNs sont souvent perçus comme promouvant des pratiques et une organisation plus favorables à l'environnement. L'absence de pesticides et d'engrais de synthèse dans les pratiques culturales, et le rapprochement géographique des lieux de production et de consommation semblent en effet jouer dans le sens d'une diminution de l'impact environnemental de la chaîne d'approvisionnement dans son ensemble.

D'un point de vue social ensuite, les AFNs permettent de restaurer un lien d'échange direct et durable entre consommateurs et producteurs.

Economiquement enfin, les AFNs créeraient plus d'emplois et la réalisation d'économies tout au long de la chaîne de distribution via la suppression d'intermédiaires pourraient avoir des retombées régionales conséquentes [2].

1. Voir notamment le rapport de MacLeod and Scott [2007] qui examine les avantages environnementaux, économiques et sociaux de l'approvisionnement alimentaire local et offre une revue préliminaire de la littérature sur les initiatives liées à la production alimentaire locale.

2. A titre d'illustration, les fermes mettant en pratique un système alternatif en France ont une

1.3.2 ... à la validée contestée

La viabilité des AFNs comme réponse à la nouvelle problématique alimentaire est encore sujette à trop d'incertitudes. Si l'ensemble des objectifs affichés par ces systèmes alternatifs semblent s'inscrire dans une démarche cohérente de développement durable, nous disposons toutefois de peu de recul sur ces initiatives et d'un manque de retours et d'analyses sur leurs bienfaits effectifs [Edwards-Jones et al., 2008].

L'empreinte écologique des AFNs et leur capacité à réduire les émissions de GES est l'un des points les plus controversés, notamment du fait de l'association souvent abusive entre diminution du nombre de kilomètres-aliments et réduction des émissions. Born and Purcell [2006] relèvent à ce propos que le caractère "local" des AFNs n'est pas un gage intrinsèque de bénéfice environnemental, le mode de transport ainsi que la logique d'acheminement des produits pouvant dans certains cas jouer de manière très défavorable dans le bilan énergétique total.

Par ailleurs, le transport ne constitue qu'une seule des étapes dans le cycle de vie d'un aliment et n'est pas forcément responsable d'une part prépondérante des émissions. Ceci amènent Pirog et al. [2001] et Garnett [2003] à souligner l'importance de continuellement garder une vision d'ensemble de la chaîne d'approvisionnement alimentaire afin de réduire globalement les émissions de CO_2, plutôt que de cibler un seul aspect au détriment des autres.

Parmi les critiques les plus virulentes, Desrochers and Shimizu [2012] vont jusqu'à affirmer qu'une politique de souveraineté alimentaire passant par un retour à l'agriculture de proximité, ne ferait qu'exacerber les problèmes. D'un point de vue de la sécurité alimentaire tout d'abord, ils soulignent qu'historiquement, les échanges internationaux ont permis de répartir les risques inhérents aux productions agricoles et relatifs aux aléas climatiques, en permettant un rééquilibrage permanant entre régions. Les auteurs

moyenne de 1,8 employés à plein temps contre 1,5 dans le circuit conventionnel [Chambres d agriculture, 2012] critiquent également la pérennisation artificielle de productions locales potentiellement non concurrentielles, allant à l'encontre de la logique économique de spécialisation régionale des productions agricoles, et se traduisant par un gain économique de l'agriculteur protégé aux dépens des consommateurs. D'un point de vue environnemental, Desrochers and Shimizu [2012] invalident l'argument selon lequel produire localement réduirait les émissions de GES, les segments liés à la production ayant un impact souvent plus important que le transport sur longues distances, et recommandent au contraire de produire autant que possible dans les régions les plus appropriées. En conclusion, ces auteurs soutiennent qu'en décourageant l'utilisation efficace et optimale des ressources agricoles mondiales, la promotion du local ne peut être garante d'une souveraineté alimentaire durable.

Marsden [2009] et Franklin et al. [2011] enfin, apportent un avis plus nuancé sur la question. Rejetant l'idée selon laquelle les AFNs seraient la version moderne d'une posture protectionniste, Marsden [2009] avance que la viabilité à long terme de ces systèmes reposent essentiellement sur leur capacité à intéragir intelligemment avec le marché mondial conventionnel. En se basant sur une étude de cas en Grande-Bretagne, Franklin et al. [2011] soulignent quant à eux que, bien qu'encore imparfaits et fragiles, les AFNs seront amenés à se modifier dans le temps de manière à mieux cadrer avec les enjeux alimentaires globaux et offriront alors des leviers d'action non négligeables.

1.4 La dimension spatiale dans la théorie économique

Pour apporter un éclairage théorique sur la problématique de l'approvisionnement alimentaire en milieu urbain, deux éléments sont nécessaires :

- les processus de localisation doivent être endogènes afin de permettre à l'économie considérée de prendre une forme spatiale propre à ses caractéristiques
- la nature de la concurrence pour représenter l'agriculture alternative doit être imparfaite afin de capter l'effet des différents rapports de force du côté de l'offre

et de la demande

Cette quatrième et dernière sous-partie offre un rapide aperçu des travaux faisant explicitement le lien entre économie géographique, économie agricole, et économie de l'environnement.

1.4.1 La dimension spatiale dans la théorie économique

La prise en compte de l'espace dans la théorie économique reste relativement récente. A l'exception de quelques travaux parmi lesquels ceux de Von Thünen [1827], Christaller [1933] ou Lösch [1940], il faudra véritablement attendre la seconde moitié du 20^{eme} siècle pour voir se développer un courant exclusivement consacré à l'étude des dynamiques spatiales. Les travaux théoriques se rapportant à ce courant peuvent être classés en deux sous-champs :

- les modèles d'allocation des sols
- les modèles de nouvelle économie géographique (NEG)

Economie urbaine et allocation des sols : une dimension micro-spatiale

Largement inspirés par la ville-marché de Von Thünen [1827], les modèles développés dans ce sous-champ de l'économie spatiale ont pour structure commune une ville monocentrique formée d'un axe unidimensionnel et d'un "Central Business District" (CBD) [Alonso, 1964]. Le CBD, point de l'espace fixé de manière exogène, regroupe l'ensemble des unités de production. Les agents résidant dans cette ville s'installent le long de l'axe, chaque point constituant une localisation caractérisée par sa distance au centre (accessibilité au marché centre). Ces derniers se rendent quotidiennement dans le CBD pour y travailler, engendrant des coûts de transport supposés proportionnels à leur distance au centre. Cet élément les amène à déterminer une fonction d'enchère foncière, décrivant leur disponibilité individuelle à payer pour chaque emplacement de l'espace. L'allocation des sols est alors définie par la confrontation de l'ensemble de ces courbes d'enchère sur le marché foncier ; à l'équilibre, chaque emplacement de l'espace est occupé par l'agent ayant proposé l'enchère la plus élevée.

Ces modèles proposent ainsi une vision "intra-" ou "micro-spatiale" de l'économie au sens où ils rendent simplement compte de la répartition des agents au sein d'une ville, sans chercher à justifier la taille ni même l'existence de cette ville. Ils offrent par ailleurs une base de modélisation intéressante dans le cadre de notre problématique où la répartition des sols entre usages urbains et agricoles est un aspect essentiel.

Nouvelle économie géographique et équilibre inter-régional

L'article de Krugman [1991] est couramment cité comme le papier fondateur de la NEG, faisant apparaître pour la première fois, un cadre de formalisation capable de rendre compte des mutations spatiales. Le modèle proposé dans cet article associe une structure de concurrence monopolistique de type Dixit and Stiglitz [1977] à une fonction d'utilité à élasticité de substitution constante (CES). Le choix de localisation des firmes repose ensuite sur une logique d'utilité comparée, les agents choisissant l'emplacement qui leur permet d'atteindre une satisfaction maximale. De manière générale, la localisation des agents dans les modèles d'inspiration NEG est vue comme le jeu d'arbitrages plus ou moins complexes entre avantages (rendements croissants) et inconvénients (coûts de transport) relatifs à chaque point de l'espace. Krugman montre en particulier que par un processus de causalité cumulative et circulaire, une structure spatiale de type "core-periphery" tend à émerger :

"Manufactures production will tend to concentrate where there is a large market, but the market will be large where manufactures production is concentrated " p. 486

Ce résultat tient à l'introduction de concurrence imparfaite qui redonne de l'importance à la taille de marché ; dans le cadre d'une industrie en concurrence monopolistique, un pays qui dispose d'une demande locale plus élevée attirera une part plus que proportionnelle à sa taille de firmes (Home Market Effect).

A la suite de Krugman [1991], de nombreux travaux s'appuieront sur ce même schéma qui, aujourd'hui encore, constitue le cadre de référence des travaux cherchant à expliquer la formation d'agglomérations plus ou moins importantes.

Vers une formalisation spatiale multiscalaire

Bien que proposant chacun une vision différente de la dimension spatiale en tant qu'objet d'étude, ces deux sous-champs n'en demeurent pas moins complémentaires, et ouvrent la voie à des perspectives intéressantes d'unification de la théorie spatiale.

Les développements proposés par Fujita [1989], Fujita and Krugman [1995], ou encore Ottaviano et al. [2002] s'inscrivent dans cette logique. Les cadres analytiques obtenus à partir de ces travaux offrent un traitement plus complet de la dimension spatiale, permettant à décrire simultanément les dynamiques de migration à l'échelle inter-régionale et le processus d'allocation des sols à l'échelle intra-régionale.

Ottaviano et al. [2002] apportent par ailleurs une modification intéressante caractérisée par l'abandon de préférence CES en faveur d'une fonction d'utilité quasi-linéaire et présentant l'avantage d'être plus aisément manipulable.

Indépendamment des formes fonctionnelles utilisées, ces modèles de localisation de l'activité économique reposent tous sur un même principe de confrontation entre forces centripètes et forces centrifuges : à l'issue d'un processus impliquant des mouvements de natures et d'intensités variées, l'espace économique se structure et donne naissance à une organisation spécifique de l'activité. L'avancée majeure de ce courant théorique tient ainsi en la reconnaissance du caractère organisé des choix de localisation : le territoire ne se façonne pas de manière aléatoire mais répond à une véritable logique d'arbitrage entre coûts et bénéfices que procure un emplacement donné.

PRINCIPALES FORCES D'AGGLOMÉRATION ET DE DISPERSION

Forces centrifuges	**Forces centripètes**
- Immobilité d'un facteur de production - Coûts de transport faibles ou élevés - Différence de salaire - Rentes foncières	- Existence d'un grand marché du travail - Coûts de transport intermédiaires - Relations verticales

1.4.2 Economie géographique et agriculture

Dans les modèles d'inspiration NEG, le secteur agricole fait traditionnellement l'objet d'un traitement peu satisfaisant car relativement minimaliste ; la nature de la concurrence y est généralement parfaite, la production présente des rendements constants, et les produits sont le plus souvent supposés homogènes et pouvant être échangés sans coût de transport.

Si ces hypothèses simplificatrices se justifient pour les travaux se focalisant sur des aspects vraiment précis du secteur manufacturier, elles ne peuvent en revanche plus tenir lorsque l'agriculture devient un élément clé de l'objet d'étude.

Parmi les travaux théoriques ayant cherché à redonner du poids au secteur agricole, Fujita et al. [1999] fournit une synthèse assez complète des conséquences de l'introduction d'un coût de transport agricole non nul, montrant en substance que ce dernier a pour effet de ralentir l'effet d'agglomération ; de la même manière que les coûts de transport dans le secteur manufacturier, les coûts agricoles donnent aux agents une incitation à se disperser dans l'espace.

En supposant que le transport agricole est coûteux, Davis [1997] aboutit, lui, au résultat surprenant que le HME tend à disparaitre, donnant à l'hypothèse de cout de transport agricole nul un caractère décisif pour la formation d'agglomération.

Il faudra attendre les travaux de Zeng and Kikuchi [2005] pour comprendre que la conclusion de Davis [1997] tient en réalité au caractère homogène du bien agricole ; repartant de son travail mais en introduisant de la différenciation dans les biens agricoles, Zeng and Kikuchi [2005] démontrent que le résultat de Krugman [1991] perdure même en présence de coût de transport.

1.4.3 Economie spatiale et environnement

L'économie spatiale dans son ensemble offre un cadre particulièrement bien adapté à la prise en compte de problématiques environnementales. En témoigne l'important corpus de littérature liant espace et environnement. Ces travaux abordent des thématiques variées telles que commerce et dumping environnemental, choix de localisation en présence de pollution ou d'aménités, ou encore planification urbaine durable.

L'introduction des préoccupations écologiques dans les modèles d'économie spatiale peut prendre formes extrêmement diverses. Selon (i) le cadre analytique retenu et (ii) la motivation première du papier, il est toutefois possible de procéder à la classification suivante :

	Modèle d'inspiration NEG		Modèle d'allocation des sols
	l'environnement agit sur les décisions de localisation (facteur d'hétérogénéité spatiale)	les décisions de localisation agissent sur l'environnement (résultant de la dynamique spatiale)	
Pollution et changement climatique	Rauscher [2009], Lange and Quaas [2007], Van Marrewijk [2005] Brock and Xepapadeas [2010]	Gaigné et al. [2012], Borck and Pflüger [2013]	Hardie et al. [2004], Lichtenberg et al. [2007] Glaeser and Kahn [2010]
Biodiversité et conflits fonciers	Barbier and Rauscher [2007]	Barbier and Rauscher [2007], Eppink and Withagen [2009], Rus [2012]	Mitchell Polinsky and Shavell [1976] Lee and Fujita [1997], Anas et al. [1998], Irwin and Bockstael [2004], Wu et al. [2004], Lewis and Plantinga [2007]

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Chapitre 2

Urbanization, Agricultural Location, and Greenhouse Gas Emissions

In this chapter, we argue that 'buying local' does not necessarily reduce greenhouse gas emissions, even if transport modes, production technologies, and natural endowment are homogeneous in space. We develop a model of rural-urban systems where the spatial distribution of food production within and between regions is endogenously determined. We exhibit cases where locating a significant share of the food production in the least-urbanized regions results in lower transport-related emissions than in configurations where all regions are self-sufficient. In addition, the optimal spatial allocation of food production does not exclude the possibility that some regions should rely solely on local production, provided their urban population sizes are neither too large nor too small.

Keywords : Urban pollution, Peri-urban Farming, Land allocation

JEL Classification : F12 ; Q10 ; Q54 ; Q56 ; R12

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2.1 Introduction

More than half of the world population lives in cities. With this share expected to keep growing [United Nations, 2010], urbanization may have major consequences for the sustainability of food chains [Wu et al., 2011], notably because of larger quantities of food to be brought into cities and spatial extension of residential areas at the expense of agricultural land. [1] In addition, only firms with high value-added per unit of land can operate profitably in the most urbanized regions because of agglomeration economies and fierce competition over land [Fujita and Thisse, 2002]. As a result, lower value-added activities–such as those in the food and agricultural sectors–may be displaced further away from urban centers [Bagoulla et al., 2010]. Agricultural products are thus expected to be transported in larger quantities and over longer distances. Evidence of such a trend can be found in recent US transportation data, which indicate that, for instance, the average mileage per shipment for grains has almost doubled between 2007 and 2012 [BTS and U.S. Census Bureau, 2010, 2013].

In this context, the environmental impact of food transportation, in particular with regard to energy use and greenhouse gas (GHG) emissions, has emerged as a growing concern for public authorities. Promoting 'local-food' and reducing 'food-miles' [Paxton, 1994] have become recurring themes in Climate Change Action Plans [Kampman et al., 2010]. Support for shorter and 'alternative' food networks has gained momentum [Sonnino and Marsden, 2006]. The rationale is that the mitigation of GHG emissions requires that food production be located closer to consumption centers so as to reduce reliance on food imports from distant regions.

This view is often justified by the comparison of transport-related emissions of locally-grown vs. imported food products. One such example (among many) can be

1. As an illustration, residential land use in the US grew 47.5% between 1976 and 1992, while population only rose by 17.8% over the same period [Overman et al., 2008]. Europe faces a similar trend ; between 1990 and 2000, built-up areas increased by 12% whereas population grew just 2% [EEA, 2004].

found in a study by BioIS [2007], which concludes that GHG emissions from the transportation of one ton of apples consumed in France are 14 times larger when imported from Chile than when locally grown. However, the conventional wisdom that shorter food chains are necessarily environmentally-friendlier has been challenged by several empirical studies based on lifecycle analysis. These studies argue that, in presence in differences in production technologies in importing and exporting regions and depending on the transport modes used, the overall impact on GHG emissions might be larger for domestic products than for imported ones. For example, lambs produced and consumed in Europe may be responsible for more emissions than imported lambs from New Zealand, which are shipped to Europe by boat and are less dependant on energy inputs and industrial feed [Saunders et al., 2006]. This debate highlights that the sign of the overall environmental impact is very much dependent on the type of product, the transport modes, and the production technologies prevailing in importing and exporting regions.

The contribution of the present chapter is to provide a novel and more general argument supporting that shorter food chains are not necessarily good for the environment. We argue that, even though transport modes, production technologies, and natural endowment do not vary in space, buying local may increase emissions due to food transportation. When assessing the impact of food systems on GHG emissions, the existing literature overlooks two major issues.

First, GHG emissions from *intra-regional* transport are usually not considered explicitly. Yet, an important share of the value and tonnage in the transportation of agricultural and food products is characterized by short-distance shipments. In the US, for instance, cereal grains–the largest consumer of transportation services–are shipped 139 miles on average (see Table 2.1). US data also show that, with few exceptions, freight flows occur predominantly within the same state or with immediate neighboring states : for nine states out of ten, within-state haulages account for at least 50% of total flows [78% when including flows with surrounding states, FHWA, 2011]. As intra-regional transport is often handled by trucks, this may have a significant impact on GHG emissions.

	Ton-mileage	Average distance [miles]			
	[10^9 t.miles]	All	Truck	Rail	Water
Live animals and live fish	3.9	739	236	1463	n/a
Cereal grain	203.4	139	84	800	1008
Other agricultural products	88.2	354	207	998	1024
Animal feed	76.1	499	136	884	2241
Meat, fish, seafood	48.5	247	128	980	952
Milled grain and bakery products	50.7	403	103	1065	n/a
Other prepared foodstuffs	171.4	268	95	1092	n/a

Tableau 2.1 – *Total ton-mileage and average shipment distance of agricultural commodities and food products by transport mode in the U.S. (2007). Source : Adapted from from BTS and U.S. Census Bureau [2010]*

Second, the environmental assessment of food systems should be conducted at the entire urban system level rather than at the city level. This is particularly important to account for *the relocation* of agricultural activities in response to urbanization in the long run. The relocation of food production in the most populated regions may reduce inter-regional trade, but at the same time increase the need for intra-regional transport in other regions. Whether the net environmental impact is positive or negative remains an open question. Addressing this question requires a full-fledged analysis that endogenously accounts for the location of agricultural production within and between regions.

In the spatial model developed in this chapter, the spatial allocation of food production across regions depends on land rents, transport costs, and the distribution of the urban population. The model takes into account the damage caused by emissions from the food-transportation sector (both within and between regions), as well as the welfare implications for urban and rural households. This framework extends the model proposed by Gaigné et al. [2012] by including an agricultural sector and considering a more general m-region spatial configuration. Although the multi-region case adds some complexity, the model remains analytically tractable when considering that trade flows are organized according to a 'hub and spoke' method, a widespread system in the logistics of food supply chains [Konishi, 2000].

Our framework differs from the models proposed by Fujita et al. [1999], Picard and Zeng [2005] and Daniel and Kilkenny [2009] since the location of agricultural production is not exogenously treated but determined by a social planner or market mechanisms through bid rent. Our approach also differs from Daniel and Kilkenny [2009] in several dimensions. First, we consider that land is also used by the urban population, so that the spatial allocation of land between urban activities and agricultural production is endogenously determined. Second, we derive a complete analytical characterization of the location equilibrium and provide some comparative statics results. Because the results are not based on numerical simulations, the chapter offers a fair level of generality. Third, a welfare analysis is developed.

Our results confirm that the assessment of environmental and welfare implications of the spatial allocation of food production cannot rely solely on the distance between food production areas and the location of end consumers. The main intuition lies in the trade-off between intra- and inter-regional transportation flows. The distance traveled by food products within a region depends on the size of the urban and rural areas. As food production is determined by agricultural area, an increase of agricultural output in any given region induces a more than proportional increase in the average distance within the region of production. As a consequence, intra-regional flows are minimized when food production is distributed mainly among the least-urbanized regions. By contrast, inter-regional flows are minimized when the regions with the largest urban population also host the largest agricultural areas. Therefore, the relocation of food production closer to large cities increases intra-regional trade in proportions that may offset the decrease in inter-regional flows.

A direct consequence is that configurations in which all regions are self-sufficient –referred to as 'pure local-food'– do not necessarily minimize emissions due to food transportation even if there is no difference in technology and productivity across regions. In other words, the existence of (some) interregional trade does not necessarily conflict with environmental objectives. We characterize cases in which locating a significant share of food production in the least (rather than the most) urbanized regions results in lower emissions than in the pure local-food configuration. Of course, this is more likely when the mode of transport for inter-regional shipments is less emissions-intensive than that used for intra-regional shipments (e.g. rail vs. truck). Our analysis also unveils the role played by agricultural yields and the distribution and size of urban populations in the relationship between the location of food production and GHG emissions.

In addition, we find that the optimal allocation of food production does not exclude the possibility that some regions should rely solely on local food. However, this possibility is restricted to regions with urban populations that are neither too large nor too small. The m-region model proposed here makes it possible to characterize urban population size threshold values for which a region should be self-sufficient. We also show that market forces alone do not lead to a pure local-food configuration unless the urban population is evenly distributed across regions and/or except for very particular values of the parameters.

In order to disentangle the various effects on welfare, we proceed in three main steps. After presenting the model (Section 2.2), we analyze the emissions-minimizing spatial distribution of food production and highlight the trade-off between intra- and inter-regional trade related emissions (Section 2.3). In Section 2.4, we examine the effects on welfare by combining the impacts on urban and rural households' surpluses, and on the environment. In Section 2.5, we focus on the market forces driving the location of agricultural production and analyze the resulting spatial equilibrium. Section 2.6 discusses the robustness of the results to some alternative assumptions. Section 3.7 concludes.

2.2 A model

Consider an economy with two sectors (agriculture and services) and three primary goods (labor, land, and a composite good as the numéraire). The agricultural sector produces a homogeneous good using land and (rural) labor, while the service sector produces a differentiated good using only (urban) labor. The agricultural market is integrated across regions so that the price of the agricultural product is unique under perfect competition. The service sector operates under monopolistic competition. The total population is normalized to 1, and split into λ_u and λ_r urban and rural inhabitants, respectively. This economy comprises m regions, indexed by $j = \{1, .., m\}$. Each region hosts an urban and rural population of λ_{uj} and λ_{rj}, respectively ($\sum_j \lambda_{uj} + \sum_j \lambda_{rj} = \lambda_u + \lambda_r = 1$). The spatial distribution of the urban population across regions is characterized by the m-vector $\boldsymbol{\lambda}_u = (\lambda_{u1}, \ldots, \lambda_{um})$. Similarly, $\boldsymbol{\lambda}_r = (\lambda_{r1}, \ldots, \lambda_{rm})$ denotes the profile of the rural population across regions.

2.2.1 Spatial structure

The largest city is assumed to be located in the 'core' region, indexed by $j = 1$. The $m - 1$ remaining regions are hereafter referred to as 'peripheral'. Without loss of generality, peripheral regions are ordered by decreasing urban population, so that $\lambda_{u1} \geq \lambda_{u2} \geq \cdots \geq \lambda_{um}$. For simplicity, they are assumed to be all located at the same distance ν from region 1. Each region is formally described by a one-dimensional space encompassing both urban and rural areas. Natural amenities are homogeneously supplied within and between regions. Within each region, locations are denoted x, and are measured from the center of the region. Without loss of generality, we focus on the right-hand side of the region, the left-hand side being perfectly symmetrical.

Each city has a central business district (CBD) [2], located at $x = 0$, where firms in the service sector are located. All urban inhabitants work for these firms. The space used by the service sector is considered negligible, so that urban area is used entirely for residential purposes. Each urban inhabitant consumes a residential plot of a fixed size, normalized to unity for simplicity.

Farmers live and produce in rural areas. With some additional assumptions regarding commuting and transport costs (see section 2.2.5), farmers are located in the periphery of the urban area. Each farmer is assumed to use $1/\mu$ units of land to produce one unit of the agricultural good, so that μ can be interpreted as the agricultural yield. Each region is assumed to be endowed with enough land to host all agricultural activities in equilibrium. The right endpoint of region j is thus :

$$\bar{x}_j = \frac{\lambda_{uj}}{2} + \frac{\lambda_{rj}}{2\mu}. \tag{2.1}$$

2.2.2 Transportation/distribution network

Agricultural goods are first shipped from the farm gate to a collecting point (e.g. an elevator), and then from the collecting point to the CBD (see left side of Figure 2.1, left). For simplicity, assume that there is one elevator at each side of the region, located at the center of the respective rural area. (In Section 2.6, we consider the case where the number of elevators depends on the mass of farmers). The right-hand side elevator in region j is located at :

$$x_j^c = \frac{\lambda_{uj}}{2} + \frac{\lambda_{rj}}{4\mu}. \tag{2.2}$$

The agricultural good may then be exported to another region. Inter-regional trade is assumed to follow a 'hub and spoke' transportation/distribution method, whereby each peripheral region is connected to the 'hub' (located in the core region) by a 'spoke'

2. See the survey in Duranton and Puga [2004] for the reasons for the existence of a CBD

of length ν (see right side of Figure 2.1). This system is frequent in the logistics and freight of commodities. Economic justification for the existence of these systems can be found in Konishi [2000] and Furusawa and Konishi [2007]. As a modeling strategy, this assumption keeps the analysis of the m-region case tractable by reducing the number of trade flows to be considered.

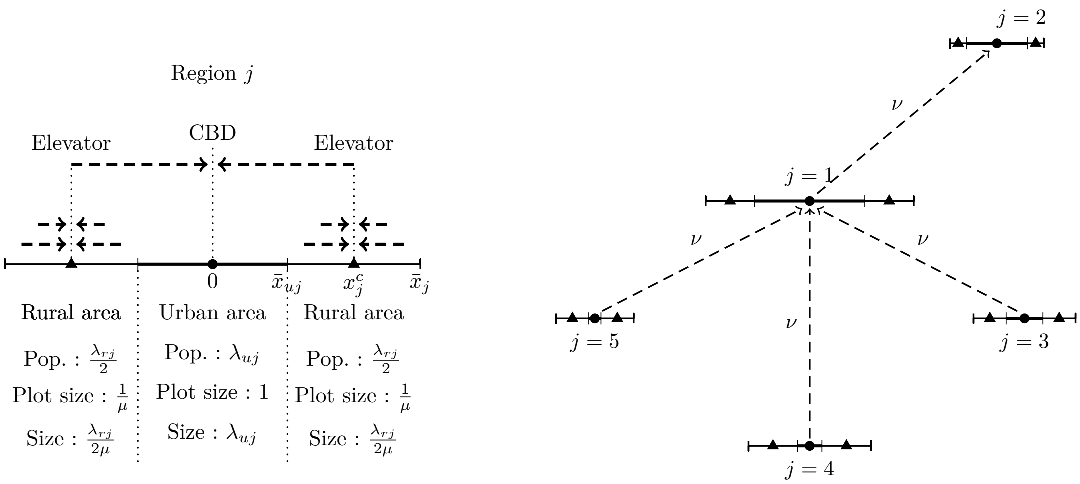

Figure 2.1 – *Spatial structure and transportation flows (dashed lines) of the agricultural good within (left side) and between (right side) regions. In this example, regions 1 and 2 are importers ; regions 3, 4, and 5 are exporters.*

To save on notation, we make the simplifying assumption that unit transport costs for the farm-to-elevator and elevator-to-CBD segments are both equal to t_a. (This assumption is relaxed in Section 2.6). Following Behrens et al. [2009], we assume also that the inter-regional transport market is not segmented. Inter-regional transportation and distribution involves a fixed fee (f) which does not depend on distance. This assumption is justified by the fact that, in practice, an important share of inter-regional transportation cost is related to distance-independent cost items (logistics, loading/unloading infrastructure, etc.). Thus, transport costs are given by :

$$C_{aj}(x) = t_a \left| x - x_j^c \right| + t_a x_j^c + f \tag{2.3}$$

2.2.3 Producers

Each farmer is assumed to supply inelastically one unit of labor, and to produce at constant returns to scale. For clarity of exposition, we assume also that producing one unit of an agricultural good requires one unit of labor. A farmer located at x in region j bears the costs of transportation of his/her production to the end consumer and the (rural) land rent $R_j(x)$. Thus, the profit for this farmer is given by

$$\pi_{aj}(x) = p_a - \frac{R_j(x)}{\mu} - C_{aj}(x) \tag{2.4}$$

2.2.4 Consumers

Preferences over the three consumption goods are the same across urban and rural households. The first good is homogeneous, can be traded costlessly, and is chosen as the numéraire. The second good is the agricultural product, which is homogeneous and can be shipped from one region to another. The third good (services), which is non-tradable across regions, is a differentiated good made available under the form of a continuum of varieties. Variety support may vary between regions (v ranging from 0 to $\bar{v}_j$). We assume also that the utility function is additive with respect to the quantity of the agricultural good (q_a) and services ($q_s(v)$ for variety $v \in [0, \bar{v}_j]$) :

$$\begin{aligned} U(q_0, q_a, q_s(v)) =& q_0 + \left(a - b\frac{q_a}{2}\right) q_a \\ &+ \alpha \int_0^{\bar{v}_j} q_s(v)dv - \frac{\beta - \gamma}{2} \int_0^{\bar{v}_j} [q_s(v)]^2 dv - \frac{\gamma}{2\bar{v}_j} \left(\int_0^{\bar{v}_j} q_s(v)dv \right)^2 \end{aligned} \tag{2.5}$$

To abstract from income effects, the marginal utility with respect to the numéraire is constant and each consumer's initial endowment ($\bar{q}_0$) is sufficient to ensure strictly positive consumption (q_0) in equilibrium. As a consequence, as in e.g. Ottaviano et al. [2002] , our modeling strategy is akin to a partial equilibrium approach. Nevertheless, note that, due to equilibrium conditions on labor and regional land markets, this assumption does not remove the interactions between the agricultural and service sectors. The simple linear-quadratic specification (parameterized by $a > 0$ and $b > 0$) of the second term in Eq. (2.5) eases tractability by leading to linear demand functions for the agricultural good. As for services, we follow Tabuchi and Thisse [2006] and use the specification proposed by Vives [1990]. Parameters α, β, and γ are all positive. We assume that $\beta > \gamma$ to ensure the quasi-concavity of the utility function. γ measures the substitutability between varieties, while $\beta - \gamma$ expresses the intensity of taste for variety. This specification ensures that the parameters defining the demand function are independent of the number of varieties supplied in the region. Note that utility is increasing with respect to $\bar{v}_j$. This will play a major role as an agglomeration force, as agents are better off when given access to a wider range of services.

To abstract from redistribution effects, we assume that land is owned by absentee landlords. Agricultural sector profits (2.4) are assumed to be completely absorbed by farmers. The budget constraint faced by a rural household located at x in region j is thus :

$$q_0 + q_a p_a + \int_0^{\bar{v}_j} q_s(v) p_{sj}(v) dv = \bar{q}_0 + \pi_{aj}(x) = \bar{q}_0 + p_a - \frac{R_j(x)}{\mu} - C_{aj}(x) \tag{2.6}$$

Urban costs, defined as the sum of the commuting costs and land rents, are borne by urban households. The budget constraint faced by an urban household resident at x in region j is :

$$q_0 + q_a p_a + \int_0^{\bar{v}_j} q_s(v) p_{sj}(v) dv = \bar{q}_0 + w_j - R_j(x) - t_u x \tag{2.7}$$

where $p_{sj}(v)$ is the price of service v in region j, p_a is the price of the agricultural product, w_j is the service sector wage in region j, and t_u is the per-mile commuting cost.

Maximizing utility (2.5) subject to budget constraints (2.6) and (2.7) leads to the inverse demand function for the agricultural good :

$$p_a(q_a) = \max\{a - b q_a, 0\} \tag{2.8}$$

and the inverse demand for service of variety v :

$$p_{sj}(v) = \max\left\{\alpha \frac{\beta - \gamma}{\beta} - (\beta - \gamma) q_{sj}(v) + \frac{\gamma}{\beta} \frac{P_{sj}}{\bar{v}_j}, 0\right\} \tag{2.9}$$

where $P_{sj} = \int_0^{\bar{v}_j} p_{sj}(v)dv$ is the price index of services for the range supplied in region j.

2.2.5 Equilibrium

Given our assumptions related to the supply-side of the farming sector, agricultural output in region j is equal to λ_{rj}. Combined with Eq. (2.8), the market clearing price for the agricultural good then is :

$$p_a^* = a - b\sum_j \lambda_{rj} = a - b\lambda_r \tag{2.10}$$

Our assumptions related to the agricultural market (integrated inter-regional market, perfect competition, homogeneity of the agricultural commodity) imply that the price received by all farmers is the same (p_a^*) regardless of the region of production. Therefore, total agricultural output does not depend on the spatial allocation of food production and the agricultural price does not play a role in farmers' location choices. [3] Food imports in region j are given by $(\lambda_{uj} + \lambda_{rj})q_a - \lambda_{rj}$. Replacing q_a with its equilibrium value and using simple algebraic manipulations, imports in region j become $\lambda_{uj}\lambda_r - \lambda_{rj}\lambda_u$.

In the service sector, each variety is supplied by a single firm producing under increasing returns as in Tabuchi and Thisse [2006]. Hence, $\bar{v}_j$ is also the number of firms active in region j. Producing q_s units of service requires $1/\phi > 0$ units of labor so that ϕ is equivalent to the labor productivity in services. The profits of a services firm operating in region j are given by

$$\pi_{sj}(v) = q_{sj}(v)p_{sj}(v) - w_j/\phi \tag{2.11}$$

Each firm sets its price so as to maximize its profits taking into account the response of demand to the price of the service it supplies (given by Eq. (2.9)) and taking the

3. Note that these assumptions rule that product differentiation based on the region of origin framework.

price index P_{sj} as given. Hence, P_{sj} and w_j are treated as parameters Ottaviano et al. [2002]. Since all firms are identical, profit maximization leads to an equilibrium price that is common to all varieties and all regions :

$$p_s^* = \frac{\alpha(\beta - \gamma)}{\beta + (\beta - \gamma)} > 0. \tag{2.12}$$

The labor market clearing conditions imply that there are $\bar{v}_j = \phi\lambda_{uj}$ firms in region j (up to the integer problem). We assume local urban labor markets. The equilibrium wage is determined by a bidding process in which firms compete for workers by offering them higher wages until no firm can profitably enter the market. Therefore, operating profits are completely absorbed by the wage bill and the equilibrium wage paid by service firms established in city j is equal to :

$$w_j^* = \frac{\phi}{\beta - \gamma} p_s^{*2}(\lambda_{uj} + \lambda_{rj}). \tag{2.13}$$

Eq. (2.13) indicates that wages in the service sector differ across regions only according to regional population size, which determines the size of the market since services are sold exclusively in the region of their production.

We next turn to the equilibrium land rent for both urban and rural households. Let $V_{uj}(x)$ and $V_{rj}(x)$ denote the indirect utility of urban and rural households, respectively, obtained by plugging the respective budget constraints (2.6) and (2.7) and equilibrium quantities and prices into (2.5) :

$$V_{uj}(x) = p_a^* q_a(p_a^*) + \int_0^{\overline{v}_s} p_{sj}^*(v) q_{sj}(p_{sj}^*) \mathrm{d}v + \overline{q}_0 + w_j^* - R_j(x) - t_u x. \tag{2.14}$$

Similarly, for rural households :

$$V_{rj}(x) = p_a^* q_a(p_a^*) + \int_0^{\overline{v}_s} p_{sj}^*(v) q_{sj}(p_{sj}^*) \mathrm{d}v + \overline{q}_0 + p_a^* - \frac{R_j(x)}{\mu} - C_{aj}(x). \tag{2.15}$$

Because of the fixed lot size assumption, the value of consumption of non-spatial goods at the residential equilibrium (sum of the first three terms in (2.14) and (2.15)) is the same regardless of the household's location.

For urban workers, the equilibrium land rent must solve $\partial V_{uj}(x)/\partial x = 0$ or, equivalently, $\frac{\partial R_j(x)}{\partial x} + t_u = 0$, which solution is $R_j(x) = \bar{r}_{uj} - t_u x$, where $\bar{r}_{uj}$ is a constant. Similarly, the equilibrium land rent for rural households must satisfy $\partial V_{rj}(x)/\partial x = 0$. As a consequence, the bid rents of rural workers are such that $R_j(x) = \bar{r}_{rj} - \mu t_a \left| x - x_j^c \right|$. Assuming that $t_u > \mu t_a$, the (right-hand side) urban workers reside around the CBD in the land strip $(0, \overline{x}_{uj}]$ where $\overline{x}_{uj} = \lambda_{uj}/2$ is the (right-hand side) city limit. Rural households live in $(\overline{x}_{uj}, \overline{x}_j]$. Because the opportunity cost of land is equal to zero, the land rent at the region limit is zero, i.e. $R_j^*(\overline{x}_j) = 0$. This implies that $\bar{r}_{rj} = t_a \lambda_{rj}/4$. In addition, urban and rural land rents at the city limit $\bar{x}_{uj}$ must be equal, so that $\bar{r}_{uj} = t_u \overline{x}_{uj} + R_j(\overline{x}_{uj})$. As a result, the equilibrium land rent is equal to :

$$R_j^*(x) = \begin{cases} t_u \left(\frac{\lambda_{uj}}{2} - x \right) & \text{if } x \leq \overline{x}_{uj} \text{ (urban households)} \\ \mu t_a \left(\frac{\lambda_{rj}}{4\mu} - \left| x - x_j^c \right| \right) & \text{if } \overline{x}_{uj} < x \leq \overline{x}_j \text{ (rural households)} \end{cases} \tag{2.16}$$

2.2.6 Emissions

Emissions from the food-transportation sector stem from both intra- and inter-regional trade. Within each region, the total distance traveled by agricultural goods depends on the distance (i) from each farm gate to the elevator, and (ii) from the elevator to the CBD (see left side of Figure 2.1). The total ton-mileage traveled by agricultural commodities within regions (T_w) can be expressed as a function of the profiles of the urban and rural populations :

$$T_w(\boldsymbol{\lambda}_r, \boldsymbol{\lambda}_u) = \sum_{j=1}^{m} 2 \left[\int_{\bar{x}_{uj}}^{\bar{x}_j} \mu |x - x_j^c| \mathrm{d}x + \frac{\lambda_{rj}}{2} x_j^c \right] = \sum_{j=1}^{m} \left(\frac{3}{8\mu} \lambda_{rj}^2 + \frac{1}{2} \lambda_{uj} \lambda_{rj} \right) \tag{2.17}$$

$T_w(\boldsymbol{\lambda}_r, \boldsymbol{\lambda}_u)$ is an increasing and convex function of λ_{rj}. As a consequence, any marginal change in food production in region j leads to a more than proportional change in the intra-regional distance traveled by food items.

Because of the 'hub-and-spoke' assumption, total between-region ton-mileage (T_b) can be deduced from the sum of incoming and outgoing trade flows to and from peripheral regions (see right side of Figure 2.1) :

$$T_b(\boldsymbol{\lambda}_r, \boldsymbol{\lambda}_u) = \sum_{j=2}^{m} \nu \left| \lambda_{rj}\lambda_u - \lambda_{uj}\lambda_r \right| \tag{2.18}$$

Comparing Eqs (2.17) and (2.18) highlights the trade-off between intra- and inter-regional flows. For a given rural population λ_r, total intra-regional ton-mileage is minimized when $\lambda_{rj} = \frac{\lambda_r}{m} + \frac{2\mu}{3}\left(\frac{\lambda_u}{m} - \lambda_{uj}\right)$, while inter-regional flows are minimized–and equal to 0–when $\lambda_{rj}\lambda_u = \lambda_{uj}\lambda_r$ for all j.

The emission intensity, i.e. the quantity of GHG emissions per ton-mile, generally differs for intra- and inter-regional trade transport modes [Weber and Matthews, 2008]. Without loss of generality, the units used to measure are scaled such that the emission factor associated with intra-regional trade is normalized to 1. Let e_b denote the (relative) emission factor associated with inter-regional transportation of the agricultural product. Values of e_b lower than unity indicate that the transport mode used for inter-regional trade is less emissions-intensive (per ton-mile) than that exploited for intra-regional trade, such as if agricultural commodities are transported predominantly by rail or water between regions, but transported by truck within regions. [4] Total emissions (E) are thus :

$$E(\boldsymbol{\lambda}_r, \boldsymbol{\lambda}_u) = T_w(\boldsymbol{\lambda}_r, \boldsymbol{\lambda}_u) + e_b T_b(\boldsymbol{\lambda}_r, \lambda_u) \tag{2.19}$$

2.3 Emissions-minimizing spatial distribution of food production

What is the spatial distribution of food production best suited to curb transport-related emissions ? In the context of the above described framework, three food systems can be envisaged : (i) a 'pure local-food' system where all regions are self-sufficient in food ($\lambda_u\lambda_{rj} = \lambda_r\lambda_{uj}$ for all j), (ii) a global food system where all regions export or import agricultural products ($\lambda_u\lambda_{rj} \neq \lambda_r\lambda_{uj}$ for all j), and (iii) a mixed system where some regions are self-sufficient while other regions export or import food.

4. As an illustration, Weber and Matthews [2008, p. 3509] report U.S. emission factors for rail or water transportation that are 8 to 16 times smaller than those for trucks.

For a given distribution of the urban population across regions, the emissions-minimizing spatial allocation of food production is defined as :

$$\hat{\boldsymbol{\lambda}}_r \equiv \arg\min_{\boldsymbol{\lambda}_r} E(\boldsymbol{\lambda}_r; \boldsymbol{\lambda}_u) \text{ subject to } \sum_j \lambda_{rj} = 1 - \lambda_u \text{ and } \lambda_{rj} \geq 0 \text{ for all } j \tag{2.20}$$

Because of the absolute values in Eq. (2.18), solving (2.20) requires a distinction between sets of importing (M), exporting (X), and self-sufficient (S) regions. Let m_M, m_X, and m_S denote the sizes of M, X, and S, respectively ($m_M + m_X + m_S = m$). For interior solutions such that $\hat{\lambda}_{rj} > 0$ for all j, the emissions-minimizing rural population located in any peripheral region $j = 2, \ldots, m$ is characterized by (see 2.8 for details) :

$$\hat{\lambda}_{rj} = \begin{cases} \frac{\lambda_r}{\lambda_u}\overline{\lambda} + \frac{2\mu}{3}\left(\overline{\lambda} - \lambda_{uj}\right) & \text{if region } j \text{ imports, i.e. if } \lambda_{uj} > \overline{\lambda} \\ \frac{\lambda_r}{\lambda_u}\underline{\lambda} + \frac{2\mu}{3}\left(\underline{\lambda} - \lambda_{uj}\right) & \text{if region } j \text{ exports, i.e. if } \lambda_{uj} < \underline{\lambda} \\ \frac{\lambda_r}{\lambda_u}\lambda_{uj} & \text{if region } j \text{ is self-sufficient, i.e. if } \underline{\lambda} \leq \lambda_{uj} \leq \overline{\lambda} \end{cases} \tag{2.21}$$

where $\underline{\lambda}$ and $\overline{\lambda}$ are defined as (for $m_M + m_X \neq 0$) :

$$\underline{\lambda} \equiv \frac{1}{m_M + m_X}\left(\sum_{k\in M}\lambda_{uk} + \sum_{k\in X}\lambda_{uk} - \frac{4\lambda_u^2\mu\nu e_b}{3\lambda_r + 2\lambda_u\mu}(2m_M - 1)\right) \tag{2.22}$$

$$\overline{\lambda} \equiv \frac{1}{m_M + m_X}\left(\sum_{k\in M}\lambda_{uk} + \sum_{k\in X}\lambda_{uk} + \frac{4\lambda_u^2\mu\nu e_b}{3\lambda_r + 2\lambda_u\mu}(2m_X + 1)\right) \tag{2.23}$$

As an inter-regional trade hub, region 1 plays a special role in the system. It is easily shown that region 1 either imports or is self-sufficient. The emissions-minimizing rural population in region 1 (for interior solutions, see 2.8) is given by :

$$\hat{\lambda}_{r1} = \begin{cases} \frac{\lambda_r}{\lambda_u}\left(\frac{\underline{\lambda}+\overline{\lambda}}{2}\right) + \frac{2\mu}{3}\left(\frac{\underline{\lambda}+\overline{\lambda}}{2} - \lambda_{u1}\right) & \text{if region 1 imports, i.e. if } \lambda_{u1} > \frac{\underline{\lambda}+\overline{\lambda}}{2} \\ \frac{\lambda_r}{\lambda_u}\lambda_{u1} & \text{if region 1 is self-sufficient, i.e. if } \lambda_{u1} \leq \frac{\underline{\lambda}+\overline{\lambda}}{2} \end{cases} \tag{2.24}$$

Note that, in Eqs. (2.21)-(2.24), $\hat{\lambda}_{rj}$ depends on $\underline{\lambda}$ and $\overline{\lambda}$, which depend on the sets of importing and exporting regions at the optimum which, in turn, are determined–through the inequalities in (2.21)–by the values taken by the cumulative distribution function of the urban population at $\underline{\lambda}$ and $\overline{\lambda}$. Therefore, in the absence of further specification of the distribution of urban population across regions, Eqs. (2.21)-(2.24) do not provide a closed-form characterization of the emissions-minimizing rural population profile. This characterization nevertheless offers some interesting insights. In particular, notice that $\overline{\lambda} - \underline{\lambda}$ does not depend on the distribution of the urban population across regions :

$$\overline{\lambda} - \underline{\lambda} = \frac{8\lambda_u^2 \mu \nu e_b}{3\lambda_r + 2\lambda_u \mu} \tag{2.25}$$

Since $\overline{\lambda} - \underline{\lambda}$ is positive, the inequalities defining the existence of self-sufficient regions in Eq. (2.21) are not trivial. More importantly, $\overline{\lambda} - \underline{\lambda}$ embeds the terms of the trade-off between intra- and inter-regional trade related emissions. The (relative) emission factor associated with inter-regional transportation (e_b) plays an obvious role in this trade-off, as does the distance between the CBDs of the core region and any peripheral region (ν). $1/\mu$ is the field-plot size required to produce one unit of the agricultural good. Hence, the greater μ (agricultural yield), the smaller the spatial extension of rural areas for a given level of agricultural output, and the shorter the distance that the agricultural good has to be transported within the region of production. The overall urban population rate in the economy (λ_u) has two opposite effects. A larger value of λ_u increases the average spatial extension of cities, which involves longer distances from the elevator to the CBD within the region of production. But, as $\lambda_r = 1 - \lambda_u$, this also reduces the average spatial extension of rural areas, implying shorter distances from farms to the elevator, and from the elevator to the CBD in the region of production. Given our assumptions about the location and number of elevators, the latter effect dominates. Based on Eq. (2.25), it can be readily shown that $\overline{\lambda} - \underline{\lambda}$ is increasing with respect to e_b, ν, μ, and λ_u. Hence, the larger $\overline{\lambda} - \underline{\lambda}$, the greater the weight of inter-regional transportation relative to intra-regional transportation in total emissions. [5]

5. Note that when inter-regional emissions are negligible ($e_b \nu \rightarrow 0$), the difference between the threshold values tends to 0, and $\overline{\lambda}$ and $\underline{\lambda}$ both tend to $\frac{\lambda_u}{m}$, which implies that $\hat{\lambda}_{rj} = \frac{\lambda_r}{m} + \frac{2\mu}{3}(\frac{\lambda_u}{m} - \lambda_{uj})$

Proposition 1 *A 'pure local-food' configuration (where all regions are self-sufficient in food) minimizes emissions due to food transportation if and only if the range of urban population across regions is such that :* $\lambda_{u1} - \lambda_{um} \leq \frac{\bar{\lambda}-\underline{\lambda}}{2} = \frac{4\lambda_u^2 \mu\nu e_b}{3\lambda_r + 2\lambda_u \mu}$. *Whenever this condition does not hold, the emissions-minimizing distribution of agricultural production across regions requires at least some inter-regional trade between the most urbanized (importers) and the least urbanized (exporters) regions.*

Proof : See 2.10.

The intuition behind Proposition (1) is as follows. Consider a pure local food configuration such that $\lambda_r \lambda_{uj} = \lambda_u \lambda_{rj}$ for all j. In this configuration, emissions are only due to intra-regional food transportation. If the difference in urban population between the most ($j = 1$) and the least ($j = m$) urbanized regions is large enough relatively to the ratio of the corresponding marginal effects on emissions due to inter- relative to intra-regional flows, it is possible to reduce total emissions by shifting some food production from region 1 to region m. This increases interregional trade flows (region m becomes an exporter) but decreases within-region ton-mileage (because distances are shorter in region m, see 2.8). Since, in this case, the decrease in within-region ton-mileage more than offsets the increase in interregional trade flows, a pure local food system cannot minimize emissions.

Proposition (1) conveys two important messages. First, contrary to the usual recommendation based on the 'food-miles' argument [Garnett, 2003], a pure local-food system does not necessarily minimize the emissions due to food transportation. The proposition highlights the importance of taking into account the relative intensity and magnitude of intra- vs. inter-regional transportation related emissions. Second, the proposition underscores the role played by the distribution of the urban population across regions. The wider the range of the urban population ($\lambda_{u1} - \lambda_{um}$), the less likely that a pure local-food system minimizes emissions. Unless the urban population is uniformly distributed across regions (i.e. unless $\lambda_{uj} = \lambda_u/m$ for all j), locating a significant share of food production in the least urbanized regions, and allowing these regions to export to the most urbanized ones, may lead to lower emissions than in the situation where all regions are self-sufficient.

The above configuration is depicted in Figure 2.2. Consider an example with $m = 50$ regions and assume that the distribution of the urban population follows a (generalized) Zipf law ($\lambda_{uj} = \lambda_{u1}/j^{\zeta}$ for all j). The parameter values chosen for this example are such that the condition given in Proposition 1 is not met. In the example, the emissions-minimizing distribution of agricultural production implies that 68% of the regions are such that $\lambda_{uj} < \underline{\lambda}$ (see Figure 2.2, right axis). These regions export food to the five most urbanized regions (such that $\lambda_{uj} > \overline{\lambda}$). Self-sufficiency is limited to the remaining eleven regions characterized by urban populations that are neither too small nor too large ($\underline{\lambda} \leq \lambda_{uj} \leq \bar{\lambda}$). Note that although the parameter values were chosen mostly for illustrative purposes, they capture some essential stylized features of current global land use. The urban and rural population for the year 2012 are approximately 3.7 bn and 3.3 bn, respectively [World Bank, 2013]. We thus set $\lambda_u = 3.7/7 \approx 0.53$ and $\lambda_r \approx 0.47$. The World Bank dataset also indicates that 15.1% of urban inhabitants live in the largest city in their respective countries. The exponent of the Zipf distribution is calibrated to $\zeta \approx 0.79$ so that $\lambda_{u1} = 0.151 \times 0.53$. μ is set assuming a world agricultural area of about 4.9 Gha [World Bank, 2013], and a world urban area of 0.066 Gha [Schneider et al., 2009]. Thus, average urban plot size is approximately 0.018 ha per capita (0.066/3.7), while the average area needed to feed one person is about 0.7 ha (4.9/7). This means that average field size is roughly 39 (0.7/0.018) times larger than the average urban residential plot. We thus set $\mu = 1/39 \approx 0.026$. The value of e_b is based on the emission factors of international water and truck transportation reported by Weber and Matthews [2008] : $e_b = 14/180 \approx 0.08$. Lastly, ν is chosen to be large enough ($\nu = 4$) for regions not to overlap, i.e. $\nu > \bar{x}_1 + \bar{x}_j$ for all $j \neq 1$ [6].

6. In solving the problem numerically, importing/exporting regions are determined iteratively by incrementing m_M and m_X and updating the values of $\overline{\lambda}$ and $\underline{\lambda}$ accordingly until the conditions given

In this example, imposing that all regions be self-sufficient would significantly increase emissions (by 67%, see Table 2.2 in 2.11) compared to the emissions-minimizing configuration.

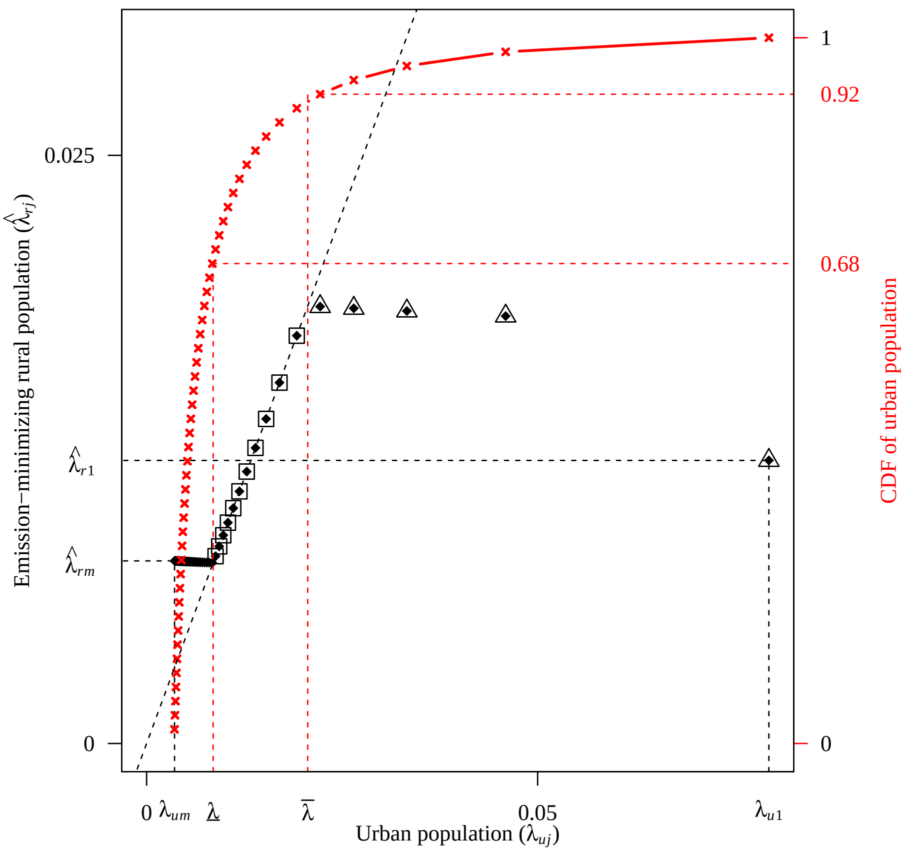

Figure 2.2 – *Emissions-minimizing distribution of the rural population (diamonds, left axis) and cumulative distribution function of the urban population across regions (red crosses, right axis). Self-sufficient regions are signaled by squares and importing regions by triangles. Parameter values :* $m = 50$, $\lambda_u \approx 0.53$, $\lambda_r \approx 0.47$, $\lambda_{u1} \approx 0.0796$, $\lambda_{uj} = \lambda_{u1}/(j^{0.79})$ *for all* j, $\mu \approx 0.026$, $e_b \approx 0.08$, $\nu = 4$.

2.4 Welfare-maximizing spatial distribution of food production

The spatial distribution of food production influences not only emissions, but also the utility of urban and rural households though its effect on transport costs and land rents. We therefore turn to the spatial distribution of food production that maximizes

in Eq. (2.21) are met.

the welfare of the whole region's population. Let $W(\lambda_r, \boldsymbol{\lambda}_u)$ be a measure of the social welfare in the economy :

$$W(\boldsymbol{\lambda}_r, \boldsymbol{\lambda}_u) \equiv \sum_j \lambda_{rj} V_{rj}(\lambda_{rj}, \lambda_{uj}) + \sum_j \lambda_{uj} V_{uj}(\lambda_{rj}, \lambda_{uj}) - dE(\boldsymbol{\lambda}_r, \boldsymbol{\lambda}_u) \tag{2.26}$$

where $d > 0$ measures the marginal environmental damage, which is expressed in units of numéraire and is assumed constant for simplicity.

Using the number of varieties ($\bar{v}_j = \phi\lambda_{uj}$) and equilibrium wage (given by Eq. (2.13)) at the equilibrium of the urban labor market into Eq. (2.14), we obtain :

$$V_{uj}(\lambda_{rj}, \lambda_{uj}) = \bar{q}_0 + \frac{b}{2}\lambda_r^2 + \phi\delta\lambda_{uj} + \frac{2\phi\delta(\beta - \gamma)}{\beta}(\lambda_{uj} + \lambda_{rj}) - t_u \frac{\lambda_{uj}}{2} \tag{2.27}$$

The fourth term in Eq. (2.27) reflects the effect of market size on service sector wages. This effect reinforces inter-sectoral agglomeration because it increases the interest in locating food production in the most urbanized regions.

Similarly, the indirect utility of a rural household established in region j (Eq. (2.15)) becomes :

$$V_{rj}(\lambda_{rj}, \lambda_{uj}) = \bar{q}_0 + \frac{b}{2}\lambda_r^2 + \frac{\alpha^2\beta}{2(2\beta - \gamma)^2}\phi\lambda_{uj} + (a - b\lambda_r) - f - t_a\left(\frac{\lambda_{uj}}{2} + \frac{\lambda_{rj}}{2\mu}\right) \tag{2.28}$$

The second and third terms in Eq. (2.28) represent the surplus associated with the consumption of the agricultural good, and services, respectively. The last term captures the effect of land rent (through transportation costs) on the utility of a rural household.

We can now characterize the welfare-maximizing distribution of agricultural production across regions for a given distribution of the urban population :

$$\boldsymbol{\lambda}_r^o \equiv \arg\max_{\boldsymbol{\lambda}_r} W(\lambda_r; \boldsymbol{\lambda}_u) \text{ subject to } \sum_j \lambda_{rj} = 1 - \lambda_u \text{ and } \lambda_{rj} \geq 0 \text{ for all } j \tag{2.29}$$

Since $W(\boldsymbol{\lambda}_r; \boldsymbol{\lambda}_u)$ integrates the environmental damage due to emissions, the resolution of (2.29) closely follows that of (2.20). It requires the sets of importing, exporting, and self-sufficient regions to be distinguished. The structure of the solution is similar to that given by Eqs. (2.21)–(2.24), and detailed in 2.9. The interior solutions ($\lambda_{rj}^o > 0$) for peripheral regions ($j \neq 1$) are given by :

$$\lambda_{rj}^o = \begin{cases} \frac{\lambda_r}{\lambda_u}\overline{\lambda}^o + \frac{2\mu}{3d+4t_a}\left[d + t_a - 2\phi\delta\frac{3\beta-2\gamma}{\beta}\right](\overline{\lambda}^o - \lambda_{uj}) & \text{if region } j \text{ imports} \\ \frac{\lambda_r}{\lambda_u}\underline{\lambda}^o + \frac{2\mu}{3d+4t_a}\left[d + t_a - 2\phi\delta\frac{3\beta-2\gamma}{\beta}\right](\underline{\lambda}^o - \lambda_{uj}) & \text{if region } j \text{ exports} \\ \frac{\lambda_r}{\lambda_u}\lambda_{uj} & \text{if region } j \text{ is self-sufficient} \end{cases} \quad (2.30)$$

As in Eq. (2.21), the importer/exporter status of any region $j \neq 1$ is determined by the position of λ_{uj} relative to the threshold values $\overline{\lambda}^o$ or $\underline{\lambda}^o$ (provided in 2.9). Since $\overline{\lambda}^o$ and $\underline{\lambda}^o$ depend on the set of importing and exporting regions, the resolution does not provide a general closed-form solution. However, similar to what was described in Section 2.3, it is possible to further characterize the welfare-maximizing distribution of food production by examining the difference :

$$\overline{\lambda}^o - \underline{\lambda}^o = \frac{8\lambda_u^2\mu\nu e_b d}{(3d+4t_a)\lambda_r + 2\lambda_u\mu\left(d + t_a - 2\delta\phi\frac{3\beta-2\gamma}{\beta}\right)} \quad (2.31)$$

This difference summarizes the net social-welfare effect of all the aforementioned trade-offs (intra- vs. inter-regional trade related emissions, within-region transport costs vs. access to services, and market-size effect on urban wages). The difference is unambiguously increasing with respect to the emission factor (e_b) and distance (ν) associated with inter-regional trade. Note that if marginal damage is low (if $d \to 0$), then $\overline{\lambda}^o - \underline{\lambda}^o$ also tends to zero. Standard calculations show that, in this case, $\overline{\lambda}^o$ and $\underline{\lambda}^o$ both tend to λ_u/m implying that only the regions with an urban population sufficiently close to the overall average urban population should be self-sufficient. In contrast to our findings in Section 2.3, $\overline{\lambda}^o - \underline{\lambda}^o$ is not necessarily positive. In particular, if the inter-sectoral agglomeration forces related to the service sector are sufficiently large (e.g. if δ is sufficiently large), cases where $\overline{\lambda}^o < \underline{\lambda}^o$ are possible. In such cases, the welfare-maximizing solution implies that rural areas in the most urbanized regions should be large enough for these regions to export to the least urbanized ones. Last, note that for a specific value of the transport costs ($t_a = \frac{\lambda_u \mu}{2\lambda_r + \lambda_u \mu} \frac{2\phi\delta(3\beta - 2\gamma)}{\beta}$) the agglomeration and dispersion forces at play in the indirect utility functions cancel out. In that case, the welfare-maximizing and the emissions-minimizing allocations of food production coincide.

Proposition 2 *A pure local-food configuration maximizes social welfare if and only if the range of urban population across regions is such that $\lambda_{u1} - \lambda_{um} \leq \frac{|\overline{\lambda}^o - \underline{\lambda}^o|}{2}$. Whenever this condition does not hold, the welfare-maximizing distribution of agricultural production across regions requires at least some inter-regional trade.* Proof *: See* *2.9.*

The proposition underscores that the welfare-maximizing spatial allocation of food production depends on the relative magnitude of various agglomeration and dispersion forces that extend beyond the sole effect of the distance traveled by food items. Thus, the pure local-food configuration may not necessarily coincide with the welfare-maximizing spatial food allocation. The condition given in the proposition emphasizes the role of heterogeneity in the urban population distribution across regions. In particular, the wider the range of the urban population ($\lambda_{u1} - \lambda_{um}$), the less likely that a pure local-food configuration maximizes welfare. As in the emissions-minimizing case, the optimal allocation of food production may require that some regions engage in trade while others remain self-sufficient. The size of the urban populations in the latter regions should be neither too large nor too small (such that $\underline{\lambda}^o \leq \lambda_{uj} \leq \overline{\lambda}^o$ or $\overline{\lambda}^o \leq \lambda_{uj} \leq \underline{\lambda}^o$, depending on the sign of $\overline{\lambda}^o - \underline{\lambda}^o$).

2.5 Spatial-equilibrium distribution of food production

We now examine the economic drivers of the location of agricultural production among regions, and analyze the spatial-equilibrium allocation of food production for a given distribution of the urban population. In our model, the location of agricultural production is driven by the location of farmers. We recognize that, at the individual level, farmers are tied to their land. However, empirical evidence shows that the inter-regional distribution of farms varies in the long run. The question addressed in this chapter is that of the spatial allocation of food production in the long run. As a result, we adopt the modelling strategy applied in the agglomeration and trade literature which studies the location of manufactured good production by analyzing the spatial allocation of workers [Fujita and Thisse, 2002, see for instance]. In our case, a spatial equilibrium occurs if no farmer is better off by moving to another region. It is also worth stressing that we disregard the adjustment in the location of urban households to a change in the location of agricultural production because its effect is not significant.

Based on a well-established tradition in migration modeling if more than two regions are involved [Tabuchi et al., 2005, see], an interior spatial equilibrium arises at $0 < \lambda_{rj}^* < 1$ when :

$$\Delta V_{rj}(\boldsymbol{\lambda}_r^*, \boldsymbol{\lambda}_u) \equiv V_{rj}(\lambda_{rj}^*, \lambda_{uj}) - \frac{1}{m}\sum_{k=1}^{m} V_{rk}(\lambda_{rk}^*, \lambda_{uk}) = 0 \text{ for all } j \tag{2.32}$$

For simplicity, we consider no cost of mobility. An interior equilibrium [7] is stable if and only if the slope of the indirect utility differential is strictly negative in the neighborhood of the equilibrium (i.e. $\partial \Delta V_{rj}/\partial \lambda_{rj} < 0$ at λ_{rj}^*). Combining Eqs. (2.28) and (2.32), the indirect utility differential becomes :

$$\Delta V_{rj}(\boldsymbol{\lambda}_r, \boldsymbol{\lambda}_u) = \left(\lambda_{uj} - \frac{\lambda_u}{m}\right)\phi\delta - \frac{t_a}{2}\left(\lambda_{uj} - \frac{\lambda_u}{m} + \frac{\lambda_{rj}}{\mu} - \frac{\lambda_r}{\mu m}\right) \tag{2.33}$$

where $\delta \equiv \frac{\alpha^2\beta}{2(2\beta-\gamma)^2}$. Since ΔV_{rj} is decreasing with respect to λ_{rj}, the interior equilibrium is stable. Solving $\Delta V_{rj}(\boldsymbol{\lambda}_r^*, \boldsymbol{\lambda}_u) = 0$ leads to :

$$\lambda_{rj}^*(\lambda_{uj}) = \frac{\lambda_r}{m} + \mu\left(\lambda_{uj} - \frac{\lambda_u}{m}\right)\left[\frac{2\phi\delta}{t_a} - 1\right] \text{ for all } j \tag{2.34}$$

The spatial equilibrium defined by Eq. (2.34) results from the interactions between various agglomeration and dispersion forces. The term in square brackets in Eq. (2.34) captures the net effect of inter-sectoral agglomeration and separation forces. On the one

7. An agglomerated equilibrium (such that all the rural population is concentrated in the same region j, i.e. such that $\lambda_{rj}^* = \lambda_r$) may also exist if $\Delta V_{rj}(\boldsymbol{\lambda}_r^*, \boldsymbol{\lambda}_u) > 0$. Whenever it exists, an agglomerated equilibrium is stable.

hand, farmers have an incentive to locate near larger cities so as to enjoy a wider range of services (inter-sectoral agglomeration). This centripetal force is equivalent to the Home Market Effect. On the other hand, a larger urban population induces fiercer competition between urban and agricultural land uses, which tends to increase agricultural land rents. The latter effect favors the location of food production in the least urbanized regions (inter-sectoral separation). The spatial equilibrium results from the comparison between the marginal increase in the utility of rural households ($\phi\delta$) and the marginal increase in the land rent ($t_a/2$) due to the presence of one additional urban worker. When these two effects are balanced, the rural population is evenly distributed across regions ($\lambda_{rj}^* = \lambda_r/m$ for all j). In addition, for a given level of agricultural output, the lower the agricultural yield (μ), the larger the spatial extension of the rural area in any given region, and therefore the more costly is within-region food transportation. As a result, low agricultural yields ($\mu \to 0$) favor, *ceteris paribus*, the spatial dispersion of food production across regions ($\lambda_{rj}^* \to \lambda_r/m$ for all j). Last, the role of the heterogeneity in the distribution of the urban population is apparent in Eq. (2.34). The deviation between the urban population of any given region and the average urban population acts as a scaling factor on the rural migration flows.

Proposition 3 *A pure local-food configuration emerges as a spatial equilibrium if and only if at least one of the following two conditions is met : (i)* $\lambda_{uj} = \frac{\lambda_u}{m}$ *for all* j *or (ii)* $t_a = \frac{2\phi\delta\lambda_u\mu}{\lambda_r+\lambda_u\mu}$. *If neither condition holds, then the spatial-equilibrium rural population in any region* j *is increasing (decreasing) with respect to the urban population in region* j *if the transportation cost* t_a *is small (large), i.e. if* $t_a \leq 2\phi\delta$ *(*$t_a > 2\phi\delta$*).*

Proof : See 2.10.

The proposition indicates that, in general, the spatial-equilibrium allocation of food production leads to a global food system. It coincides with a pure local-food configuration only under very specific conditions. Moreover, whether food production tends to locate in the most or in the least urbanized regions depends on the comparison between inter-sectoral agglomeration and separation forces. This comparison also determines the direction and magnitude of trade flows at the spatial equilibrium.

For very low values of intra-regional transport cost (i.e. $0 < t_a < \frac{2\phi\delta\lambda_u\mu}{\lambda_r+\lambda_u\mu}$), the food production locates predominantly in the most-urbanized regions. In this case, the most-urbanized regions export food to the least-urbanized ones, leading to large intra-regional transportation flows. As t_a rises, food production relocates to less urbanized regions, thus simultaneously reducing intra- and inter-regional flows, and therefore emissions until $t_a = \frac{2\phi\delta\lambda_u\mu}{\lambda_r+\lambda_u\mu}$, the value at which a pure local-food configuration emerges. For $\frac{2\phi\delta\lambda_u\mu}{\lambda_r+\lambda_u\mu} < t_a < 2\phi\delta$, inter-regional trade resumes but now, from the least- to the most-urbanized regions. Finally, for any transportation cost higher than $2\phi\delta$, food production locates mainly in the least-urbanized regions, inducing a substantial increase in inter-regional trade flows. The role of t_a on the spatial-equilibrium distribution of food production is depicted in Figure 2.3 for two values of t_a (left side :0< $t_a < \frac{2\phi\delta\lambda_u\mu}{\lambda_r+\lambda_u\mu}$ and right side : $\frac{2\phi\delta\lambda_u\mu}{\lambda_r+\lambda_u\mu} < t_a < 2\phi\delta$).

The spatial equilibrium differs from the welfare-maximizing allocation of food production because of the presence of two types of externalities. Farmers' location choices do not take account of their impacts on (i) emissions, and (ii) the welfare of urban households. The discrepancy between the two situations is depicted in Figure 2.3 for the same distribution of the urban population and the same values for μ, e_b, and ν as in Figure 2.2, and two values of the within-region transportation cost t_a. If t_a is high (right side of Figure 2.3), the spatial-equilibrium tends to allocate relatively more (less) food production in the least (most) urbanized regions than in the welfare-maximizing configuration. In this case, only five regions should be self-sufficient (i.e. such that $\underline{\lambda}^o < \lambda_{uj} < \overline{\lambda}^o$). The number of self-sufficient regions in the welfare-maximizing configuration rises to eleven for the smaller value of t_a (left side of Figure 2.3). In both examples, the emission level in the welfare-maximizing configuration is close to that in the emissions-minimizing configuration. If t_a is large, emissions in the spatial-equilibrium configuration are slightly

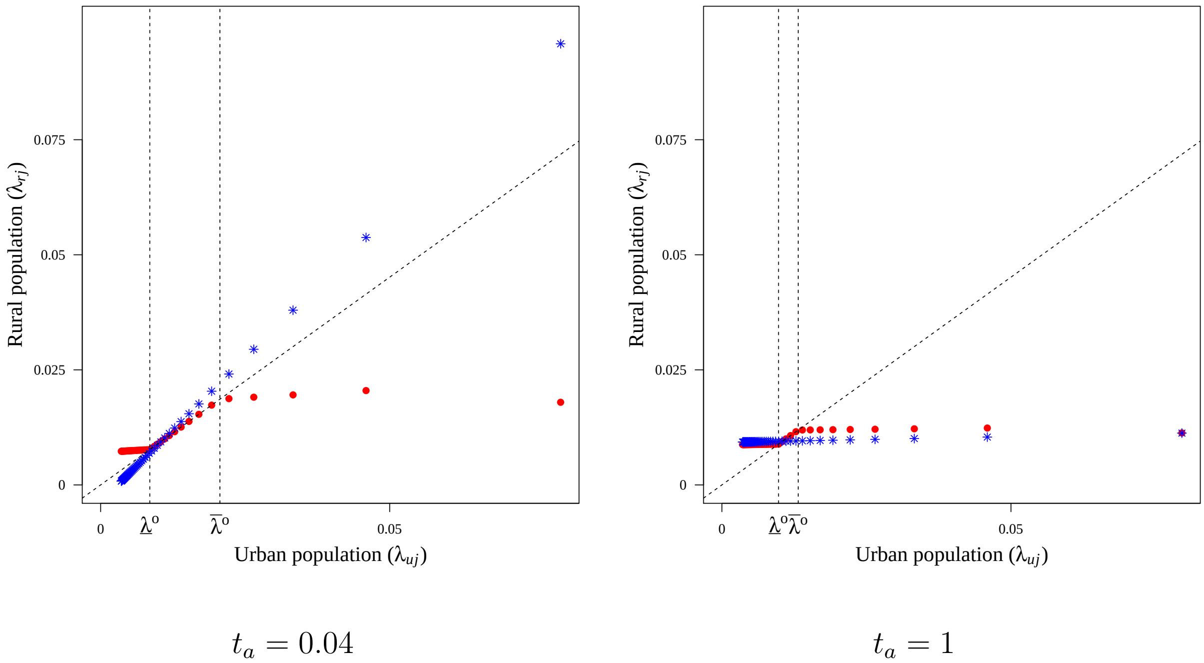

Figure 2.3 – *Welfare-maximizing (dots) and spatial equilibrium (asterisks) for two values of within-region transport costs (t_a). Parameter values : $m = 50$, $\lambda_u \approx 0.53$, $\lambda_r \approx 0.47$, $\lambda_{u1} \approx 0.0796$, $\lambda_{uj} = \lambda_{u1}/(j^{0.79})$ for all j, $\mu \approx 0.026$, $e_b \approx 0.08$, $\nu = 4$, $\phi = 1$, $\delta = 1$, and $d = 0.5$.*

larger than in the welfare-maximizing case but still significantly lower than in the pure local-food configuration (See Table 2.2 in 2.11).

2.6 Discussion and possible extensions

In this section, we discuss some of our assumptions and assess how relaxing them might impact on our findings. First, considering that each region is endowed with enough land to host all agricultural and urban activities is arguably a strong hypothesis. Relaxing this assumption would increase the likelihood that more urbanized regions import as soon as their land constraints become binding. Consequently, introducing a land resource constraint would restrict the possibility for pure local food configurations to emerge as emissions-minimizing and/or welfare-maximizing configurations.

Second, some of our assumptions tend to increase within-region transportation costs, and therefore, make the emergence of pure local-food configurations less likely. This is the case especially for two assumptions regarding the organization of food transportation within each region, namely that (i) there are only two elevators per region, and (ii) unit transportation costs from farm-gate to elevator and from elevator to CBD are both equal to t_a. Increasing the number of elevators would reduce the distance traveled by food products within regions. Moreover, because storage capacities at collecting points may allow for bulk shipment of several farms' output to the CBD, it could be argued that unit transport costs associated with the elevator-to-CBD segment might be lower than farm-to-CBD costs. Assume now that there are $K_j = \kappa\lambda_{rj}/2$ elevators (instead of 1) in each rural area and that, once gathered in the elevators, agricultural production is bundled and sent in bulk shipments to the CBD. The ability to group commodities is measured by parameter τ with $0 < \tau \leq 1$. This generalization is explored in 2.12. Allowing for several elevators per rural area reduces the distance that each farmer has to cover, and therefore reduces transport costs and increases farmers' profits. These changes are likely to favor inter-sectoral agglomeration in the spatial equilibrium. The effect of τ on farmers' profits is more ambiguous (see Eq. (2.58) in 2.12). Emissions due to intra-regional transportation are clearly decreasing with respect to the number of elevators (K_j) and the bundling capacity (i.e. increasing with respect to τ). However, intra-regional transport flows are still an increasing convex function of the rural population share λ_{rj} and rise with the urban population share λ_{uj}. As a result, our findings hold qualitatively with an endogenous number of regional elevators, and economies of scale in transportation within production areas.

Last, all regions are assumed to enjoy the same quality of land (represented by the agricultural yield μ). Considering that land quality could vary from one region to another would affect both transport related emissions and the distribution of profit in the farming sector and, hence, the spatial equilibrium. The spatial extension of regions with the highest yields would be smaller (for a given regional population), thus entailing lower food-mileage and lower emissions from intra-regional transportation in these regions. There would be environmental interest in gathering food production in these regions. Allowing for yield heterogeneity would modify profits, and in turn, spatial distribution of food production in equilibrium. Since farmers operating in regions with the best-quality land will enjoy a higher income, the incentives to produce in these regions will increase.

2.7 Concluding remarks

Should local food be promoted on the basis that it contributes to the reduction of the distance traveled by food items, and therefore, transport-related emissions ? Even from a strictly environmental perspective, the answer to this question is not as straightforward as conventional wisdom suggests. It depends, among other things, on the extent to which emissions savings permitted by less inter-regional trade are offset by potentially larger intra-regional transportation flows. Thus, food trade does not necessarily conflict with the objective of mitigating emissions from the food transportation sector. Beyond these purely environmental considerations, social welfare analyses that examine this question should integrate interactions with other agglomeration and dispersion economic forces through transport costs, land rents, and other spatial externalities including those affecting non-agricultural markets. In this chapter, we derive the conditions for a pure local-food system to be socially optimal when combining these elements. If these conditions are not met, the relocation of some food production closer to consumption centers may deteriorate both the environment and welfare.

The nature (intra- or inter-regional) and volume of food transportation flows depend strongly on the spatial distribution of the urban population. In the limit case of an urban population evenly distributed across regions, pure local-food configurations emerge as the spatial equilibrium, and, simultaneously minimizing emissions and maximizing welfare. However, as soon as there is some heterogeneity in the distribution of the urban population, market outcome and the optimal configuration may diverge. Our findings indicate that the greater the difference in the populations of the largest and the smallest cities, the less likely that pure-local food configurations will maximize welfare and minimize emissions. These findings offer a fair level of generality since they do not require additional specifications for the number of regions or the distribution of the urban population.

These findings suggest that proximity on its own is not an appropriate basis for policies aimed at improving the sustainability of food-supply chains. By focusing solely on food-miles, fundamental effects that affect social welfare are ignored, and ultimately, may distort the economic and environmental assessment of the consequences of the spatial allocation of food production. However, this is not to say that local-food systems should be systematically ruled out. Indeed, our results indicate that the welfare-maximizing allocation of food production might correspond to a configuration that combines trade between some regions and self-sufficiency for other regions. In this case, the size of the urban population in the self-sufficient region should be neither too large nor too small.

The presence of environmental and other spatial externalities may justify the use of policy instruments targeting for example emissions, transport costs, and/or land-use. Our findings suggest that such instruments should focus on the multi-regional level rather than the level of individual regions. The analysis proposed in this text lays the groundwork for further investigation of the design and properties of these policy instruments.

2.8 Emissions-minimizing distribution of food production

To deal with the absolute values in (2.20), we use the change of variables $\lambda_{rj} = (X_j - M_j + \lambda_{uj}\lambda_r)/\lambda_u$, where $X_j - M_j$ denotes net exports with $X_j \geq 0$ and $M_j \geq 0$, and rewrite (2.20) as :

$$\min_{(X_j,M_j)} E = \sum_{j=1}^{m} \left[\frac{3}{8\mu\lambda_u^2} \left(X_j - M_j + \lambda_{uj}\lambda_r\right)^2 + \frac{\lambda_{uj}}{2\lambda_u} \left(X_j - M_j + \lambda_{uj}\lambda_r\right) \right] + \nu e_b \sum_{j=2}^{m} (X_j + M_j)$$
$$\text{s.t. } \sum_{j=1}^{m} X_j - M_j + \lambda_{uj}\lambda_r = \lambda_r\lambda_u, \text{ and } X_j \geq 0, M_j \geq 0, M_j - X_j \leq \lambda_{uj}\lambda_r \text{ for all } j \tag{2.35}$$

For interior solutions such that $\lambda_{rj} > 0$ for all j, the corresponding Lagrangian is :

$$\mathcal{L}_E = E - \sum_{j=1}^{m} \left[\rho_1 \left(X_j - M_j + \lambda_r(\lambda_{uj} - \lambda_u)\right) + \rho_{2j} X_j + \rho_{3j} M_j\right] \tag{2.36}$$

The first-order conditions lead to :

$$\frac{3}{4\mu\lambda_u^2}(X_1 - M_1 + \lambda_{u1}\lambda_r) + \frac{\lambda_{u1}}{2\lambda_u} - \rho_1 = \rho_{21} = -\rho_{31} \tag{2.37}$$
$$\frac{3}{4\mu\lambda_u^2}(X_j - M_j + \lambda_{uj}\lambda_r) + \frac{\lambda_{uj}}{2\lambda_u} - \rho_1 = \rho_{2j} - \nu e_b = \nu e_b - \rho_{3j} \text{ for } j \neq 1 \tag{2.38}$$

We thus have $\rho_{21} + \rho_{31} = 0$, which implies that $\rho_{21} = \rho_{31} = 0$ (as both multipliers are non-negative) and $\rho_{2j} + \rho_{3j} = 2\nu e_b$ for $j \neq 1$. The complementarity slackness conditions impose that $\rho_{2j} = 0$ if $X_j > 0$ ($j \in X$) and $\rho_{2j} = 2\nu e_b$ if $M_j > 0$ ($j \in M\backslash\{1\}$). Substituting into (2.37) and (2.38), eliminating ρ_{3j} and ρ_1, and reverting back the change of variables, the F.O.C. become :

$$\hat{\lambda}_{r1} = \frac{\lambda_r}{m} + \frac{2\mu}{3}\left(\frac{\lambda_u}{m} - \lambda_{u1}\right) + \frac{4\mu\lambda_u}{3m}\left[(m + 1 - 2m_M)\nu e_b - \sum_{k\in S}\rho_{2k}\right] \tag{2.39}$$
$$\hat{\lambda}_{rj} = \frac{\lambda_r}{m} + \frac{2\mu}{3}\left(\frac{\lambda_u}{m} - \lambda_{uj}\right) + \frac{4\mu\lambda_u}{3m}\left[m\rho_{2j} + (1 - 2m_M)\nu e_b - \sum_{k\in S}\rho_{2k}\right] \text{ for } j \neq 1 \tag{2.40}$$

Summing the last equation over $j \in S$ (for $m - m_S = m_M + m_X \neq 0$), it comes :

$$\sum_{k\in S}\rho_{2k} = \frac{m}{m - m_S}\frac{3\lambda_r + 2\mu\lambda_u}{4\mu\lambda_u^2}\left(\sum_{k\in S}\lambda_{uk} - \frac{m_S}{m}\lambda_u\right) + \frac{m_S}{m - m_S}(2m_M - 1)\nu e_b \tag{2.41}$$

Re-injecting in Eqs. (2.39) and (2.40) and using the values of ρ_{2j} for $j \in X$ and $j \in M$, we obtain :

$$\hat{\lambda}_{r1} = \frac{3\lambda_r + 2\lambda_u\mu}{3\lambda_u(m_M + m_X)}\left(\lambda_u - \sum_{k\in S}\lambda_{uk} + \frac{4\lambda_u^2\mu\nu e_b(m_X - m_M + 1)}{3\lambda_r + 2\lambda_u\mu}\right) - \frac{2\mu}{3}\lambda_{u1} \quad (2.42)$$

$$\hat{\lambda}_{rj} = \frac{3\lambda_r + 2\lambda_u\mu}{3\lambda_u(m_M + m_X)}\left(\lambda_u - \sum_{k\in S}\lambda_{uk} + \frac{4\lambda_u^2\mu\nu e_b(2m_X + 1)}{3\lambda_r + 2\lambda_u\mu}\right) - \frac{2\mu}{3}\lambda_{uj} \text{ if } j \in M\backslash\{1\} \quad (2.43)$$

$$\hat{\lambda}_{rj} = \frac{3\lambda_r + 2\lambda_u\mu}{3\lambda_u(m_M + m_X)}\left(\lambda_u - \sum_{k\in S}\lambda_{uk} - \frac{4\lambda_u^2\mu\nu e_b(2m_M - 1)}{3\lambda_r + 2\lambda_u\mu}\right) - \frac{2\mu}{3}\lambda_{uj} \text{ if } j \in X \quad (2.44)$$

The conditions $\hat{\lambda}_{rj} < \frac{\lambda_r}{\lambda_u}\lambda_{uj}$ and $\hat{\lambda}_{rj} > \frac{\lambda_r}{\lambda_u}\lambda_{uj}$ for $j \in M$ and $j \in X$, respectively, lead to the thresholds values given in (2.21) and (2.24).

Proof of Proposition 1 Notice that if region 1 does not import, no other region $k \neq 1$ does since $\lambda_{uk} \leq \lambda_{u1} \leq (\overline{\lambda} + \underline{\lambda})/2 \leq \overline{\lambda}$. Since the market must be in equilibrium, this implies that all regions are self-sufficient. Thus, there is an equivalence between region 1 being self-sufficient and a pure local-food system. Following a similar reasoning, if region m does not export ($\lambda_{um} \geq \underline{\lambda}$), no other region does, leading to a pure local-food system. Combining these two conditions, we easily obtain that $\lambda_{u1} - \lambda_{um} \leq (\overline{\lambda} - \underline{\lambda})/2$ provides a necessary and sufficient condition for a pure local-food system to minimize emissions.

Consider a pure local food configuration such that $\lambda_r\lambda_{uj} = \lambda_u\lambda_{rj}$ for all j. In this configuration, emissions are only due to intra-regional food transportation. Consider now a marginal shift in rural population $d\ell$ from region 1 to region m such the total rural population λ_r is kept constant. In the new configuration, region m exports food to region 1 in quantity $\lambda_u d\ell$, causing emissions in quantity $\lambda_u e_b \nu d\ell$. At the same time, emissions due to within-region food transportation (i) decrease in region 1, and (ii) increase in region m. Using Eq. (2.17), simple calculations indicate that the net change in intra-regional emissions is $[(3\lambda_r + 2\lambda_u\mu)(\lambda_{u1} - \lambda_{um}) - 3\lambda_u d\ell](d\ell/4\lambda_u\mu)$. Since $d\ell$ is positive and arbitrarily small, if the gap in urban population between the largest and the smallest region is greater than the ratio of the marginal changes in emissions due to inter- and intra-regional flows, then a pure local food system cannot minimize emissions. QED.

2.9 Welfare-maximizing distribution of food production

The resolution of program (2.29) closely follows that of (2.35) (see 2.8). Using the same change of variables and omitting the terms that are independent of λ_{rj}, the objective function becomes :

$$W = \sum_{j=1}^{m} \frac{X_j - M_j + \lambda_{uj}\lambda_r}{\lambda_u} \left[\frac{\phi\delta(3\beta - 2\gamma)}{\beta}\lambda_{uj} - \left(\lambda_{uj} + \frac{X_j - M_j + \lambda_{uj}\lambda_r}{\mu\lambda_u}\right)\frac{t_a}{2}\right] - dE \tag{2.45}$$

For interior solutions, the first-order conditions for the core region lead to :

$$\left(\frac{\phi\delta(3\beta - 2\gamma)}{\beta} - \frac{t_a}{2\mu\lambda_u}\right)\lambda_{u1} - \frac{3d + 4t_a}{4\mu\lambda_u^2}(X_1 - M_1 + \lambda_{u1}\lambda_r) + \rho_1 = -\rho_{21} = \rho_{31} \tag{2.46}$$

Eq. (2.46) implies that $\rho_{21} = \rho_{31} = 0$. As for peripheral regions ($j \neq 1$), the F.O.C. lead to :

$$\left(\frac{\phi\delta(3\beta - 2\gamma)}{\beta} - \frac{t_a}{2\mu\lambda_u}\right)\lambda_{uj} - \frac{3d + 4t_a}{4\mu\lambda_u^2}(X_j - M_j + \lambda_{uj}\lambda_r) + \rho_1 = d\nu e_b - \rho_{2j} = \rho_{3j} - d\nu e_b \tag{2.47}$$

Eq. (2.47) implies that $\rho_{2j} + \rho_{3j} = 2d\nu e_b$. The complementarity slackness conditions impose that $\rho_{2j} = 0$ if $X_j > 0$ and $\rho_{2j} = 2d\nu e_b$ if $M_j > 0$. Substituting into (2.46) and (2.47), eliminating ρ_{3j} and ρ_1, and reverting back the change of variables, the F.O.C. for region 1 becomes :

$$\lambda_{r1}^o = \frac{\lambda_r}{m} + \frac{4\mu}{3d + 4t_a}\left[\left(\frac{d + t_a}{2\mu\lambda_u} - \frac{\phi\delta(3\beta - 2\gamma)}{\beta}\right)\left(\frac{\lambda_u}{m} - \lambda_{u1}\right) + \frac{\lambda_u}{m}\left((m + 1 - 2m_M)d\nu e_b - \sum_{k\in S}\rho_{2k}\right)\right] \tag{2.48}$$

and for peripheral regions ($j \neq 1$) :

$$\lambda_{rj}^o = \frac{\lambda_r}{m} + \frac{4\mu}{3d + 4t_a}\left[\left(\frac{d + t_a}{2\mu\lambda_u} - \frac{\phi\delta(3\beta - 2\gamma)}{\beta}\right)\left(\frac{\lambda_u}{m} - \lambda_{uj}\right) + \frac{\lambda_u}{m}\left(m\rho_{2j} + (1 - 2m_M)d\nu e_b - \sum_{k\in S}\rho_{2k}\right)\right] \tag{2.49}$$

As in 2.8, $\sum_S \rho_{2k}$ is eliminated by summing Eq. (2.49) over $j \in S$:

$$\sum_{k\in S}\rho_{2k} = \frac{m}{m-m_S}\left(\frac{3d+4t_a}{4\mu\lambda_u^2}\lambda_r + \frac{d+t_a}{2\lambda_u} - \frac{\phi\delta(3\beta-2\gamma)}{\beta}\right)\left(\sum_{k\in S}\lambda_{uk} - \frac{m_S}{m}\lambda_u\right) + \frac{m_S(2m_M-1)}{m-m_S}d\nu e_b \tag{2.50}$$

The values in Eq. (2.30) are obtained by re-injecting the value of $\sum_S \rho_{2k}$ into Eq. (2.49), and using that $\rho_{2j} = 0$ for $j \in X$ and $\rho_{2j} = 2d\nu e_b$ for $j \in M\backslash\{1\}$. The threshold values $\overline{\lambda}^o$ and $\underline{\lambda}^o$ in Eq. (2.30) are then derived from the conditions $\lambda_{rj}^o < \frac{\lambda_r}{\lambda_u}\lambda_{uj}$ and $\lambda_{rj}^o > \frac{\lambda_r}{\lambda_u}\lambda_{uj}$ for $j \in M$ and $j \in X$, respectively :

$$\underline{\lambda}^o \equiv \frac{1}{m_M+m_X}\left(\sum_{k\in M}\lambda_{uk} + \sum_{k\in X}\lambda_{uk} - \frac{4\lambda_u^2\mu\nu e_b d(2m_M-1)}{(3d+4t_a)\lambda_r + 2\lambda_u\mu\left(d+t_a-2\delta\phi\frac{3\beta-2\gamma}{\beta}\right)}\right) \tag{2.51}$$

$$\overline{\lambda}^o \equiv \frac{1}{m_M+m_X}\left(\sum_{k\in M}\lambda_{uk} + \sum_{k\in X}\lambda_{uk} + \frac{4\lambda_u^2\mu\nu e_b d(2m_X+1)}{(3d+4t_a)\lambda_r + 2\lambda_u\mu\left(d+t_a-2\delta\phi\frac{3\beta-2\gamma}{\beta}\right)}\right) \tag{2.52}$$

If $\overline{\lambda}^o > \underline{\lambda}^o$, then as in 2.8, the most (least) urbanized regions are importers (exporters). We thus have for $j \neq 1$: $j \in M$ if $\lambda_{uj} > \overline{\lambda}^o$, $j \in S$ if $\underline{\lambda}^o \leq \lambda_{uj} \leq \overline{\lambda}^o$, and $j \in X$ if $\lambda_{uj} < \underline{\lambda}^o$. If $\overline{\lambda}^o < \underline{\lambda}^o$, the signs of the above inequalities change.

As for region 1, re-injecting the value of $\sum_S \rho_{2k}$ into Eq. (2.48), using Eqs. (2.51) and (2.52) and re-arranging leads to (in the case $\overline{\lambda}^o > \underline{\lambda}^o$) :

$$\lambda_{r1}^o = \begin{cases} \frac{\lambda_r}{\lambda_u}\frac{\overline{\lambda}^o+\underline{\lambda}^o}{2} + \frac{2\mu}{3d+4t_a}\left[d+t_a-2\phi\delta\frac{3\beta-2\gamma}{\beta}\right]\left(\frac{\overline{\lambda}^o+\underline{\lambda}^o}{2} - \lambda_{u1}\right) & \text{if } \lambda_{uj} > \frac{\overline{\lambda}^o+\underline{\lambda}^o}{2} \\ \frac{\lambda_r}{\lambda_u}\lambda_{uj} & \text{if } \lambda_{uj} \leq \frac{\overline{\lambda}^o+\underline{\lambda}^o}{2} \end{cases} \tag{2.53}$$

If $\overline{\lambda}^o < \underline{\lambda}^o$, region 1 can only be an exporter or self-sufficient and the signs of the inequalities in Eq. (2.53) change.

Proof of Proposition 2 If $\overline{\lambda}^o > \underline{\lambda}^o$, the proof is exactly the same as for Proposition 1. Thus, in this case we have that $\lambda_{u1} - \lambda_{um} \leq (\overline{\lambda}^o - \underline{\lambda}^o)/2$ is a necessary and sufficient condition for a pure local-food system to maximize welfare. If $\overline{\lambda}^o < \underline{\lambda}^o$, it is necessary to account for the fact that region 1 either exports or is self-sufficient, and region m either imports or is self-sufficient. Therefore the condition becomes $\lambda_{u1} - \lambda_{um} \leq (\underline{\lambda}^o - \overline{\lambda}^o)/2$. QED.

2.10 Spatial-equilibrium distribution of food production

Proof of Proposition 3 A pure local-food configuration is characterized by $\lambda_{rj} = (\lambda_r/\lambda_u)\lambda_{uj}$ for all j. Using Eq. (2.34), it is easy to see that, for such a configuration to emerge in equilibrium, we need that $\lambda_{uj} - (\lambda_u/m) = 0$ for all j and/or $\left(\frac{2\phi\delta}{t_a} - 1\right)\mu = \frac{\lambda_r}{\lambda_u}$. The analysis of the sign of the slope of λ^*_{rj} with respect to λ_{uj} in Eq. (2.34) completes the proof. QED.

2.11 Simulation results

Spatial configuration	Number of regions			Relative change in emissions w.r.t. emissions-minimizing (share of each emission category) [%]		
	Importers m_M	Self-suff. m_S	Exporters m_X	Within T_w	Between $e_b T_b$	Total E
Pure local food	0	50	0	+118	-100	+67
				(100)	(0)	(100)
Emissions-minimizing	5	11	34	-	-	-
				(77)	(23)	(100)
Spatial equilibrium						
$t_a = 0.04$	38	0	12	+235	-28	+174
				(94)	(6)	(100)
$t_a = 1$	12	0	38	-11	+81	+10
				(62)	(38)	(100)
Welfare-maximizing						
$t_a = 0.04$	5	11	34	+4	-10	+1
				(79)	(21)	(100)
$t_a = 1$	9	5	36	-10	+51	+4
				(66)	(34)	(100)

Tableau 2.2 – *Summary of the simulation results in the various spatial configurations and for two values of within-region transport costs (t_a). Relative changes in emissions are computed for each category relatively to emission levels in the emissions-minimizing configuration. The shares of the respective emission categories in total emissions for each spatial configuration are given in parentheses. Parameter values : $m = 50$, $\lambda_u \approx 0.53$, $\lambda_r \approx 0.47$, $\lambda_{u1} \approx 0.0796$, $\lambda_{uj} = \lambda_{u1}/(j^{0.79})$ for all j, $\mu \approx 0.026$, $e_b \approx 0.08$, $\nu = 4$, $\phi = 1$, $\delta = 1$, and $d = 0.5$.*

2.12 Discussion and Extensions with K_j elevators and bundling capacity τ

2.12.1 Equilibrium

We suppose there are K_j elevators within each agricultural area of region j (thus $2K_j$ elevators in region j). They are evenly spaced along the rural area [8] and located at $x_j^k = \{x_j^1, x_j^2, ..., x_j^K\}$. Without loss of generality, we set $\bar{x}_{uj} < x_j^1 < x_j^2 < ... < x_j^K$ so that the location of elevator k is given by :

$$x_j^k = \bar{x}_{uj} + \frac{\bar{x}_j - \bar{x}_{uj}}{2K_j} + (k-1)\frac{\bar{x}_j - \bar{x}_{uj}}{K_j} = \frac{\lambda_{uj}}{2} + \frac{\lambda_{rj}}{4\mu K_j} + (k-1)\frac{\lambda_{rj}}{2\mu K_j}. \tag{2.54}$$

For a given distance to an elevator, the transport cost is higher for a farmer located further away from the city. We also take into account that K_j varies with λ_{rj} since the number of elevators reacts positively to a change in agricultural production. For simplicity, we assume that

$$K_j = \kappa\lambda_{rj}/2 \tag{2.55}$$

with $0 < \kappa < 1$. Hence, increasing food production in a region induces a rise in the number of elevators in that region.

Once gathered in the elevators, food production is bundled and sent in bulk shipments to the CBD. The ability to group commodities is measured by parameter τ with $0 < \tau < 1$: if $\tau = 1$, then the production of each farmer is shipped directly to the city, whereas $\tau \to 0$ means that all the production received by a collector can be stored and carried in a single shipment. [9]

8. Note that we assume that unit per-mile freight prices between elevator and city are identical regardless of the elevator and are treated as parameters. Ideally, we would consider a game in which elevators' owners act strategically to maximize their profits. This configuration would complexity to the analysis without adding new significant results.

9. In practice, low values of τ are adapted to the case of commodities such as cereals, while values of τ close to 1 are more adapted to the case of fresh fruits and vegetables.

The individual cost associated with the distribution of farmers' output is now given by :

$$C_{aj}(x,k) = f + t_a \left| x - x_j^k \right| + t_a x_j^k \tau \tag{2.56}$$

At given prices and locations of the urban population, each farmer chooses a location that maximizes his/her utility. Let $V_{rj}(x,k)$ be the indirect utility of a farmer located at x in region j and carrying his output to elevator k. An equilibrium is reached when no farmer wants to change his location so that $V_{rj}(x,1) = ... = V_{rj}(x,k) = ...V_{rj}(x,K)$.

The bid rent at the equilibrium must solve $\partial V_{rj}^i(x,k)/\partial x = 0$ (or equivalently, $\frac{\partial R_j(x,k)}{\partial x} + \mu t_a = 0$) and verify $R_j(x,1) + C_{aj}(x,1) = ... = R_j(x,K) + C_{aj}(x,K)$. As a consequence, the land rent capitalizes not only the cost of the distance between farmers and the elevator but also the transport costsx between the latter and the city. Because the opportunity cost of land is equal to zero, we have $R_j(\bar{x}_j) = 0$ and the equilibrium agricultural land rent is given by :

$$R_j^*(x,k) = \mu t_a \left[\frac{\lambda_{rj}}{4\mu K_j} - \left| x - x_j^k \right| + \tau \frac{\lambda_{rj}}{2\mu K_j} (K_j - k) \right] \tag{2.57}$$

Finally, using (2.55), (2.56) and (2.57), the net income received by a farmer becomes :

$$\pi_j(x) = (a - b\lambda_r) - f - t_a \tau \left(\frac{\lambda_{rj}}{2\mu} + \frac{\lambda_{uj}}{2} \right) - \frac{(1-\tau)t_a}{2\mu\kappa} \equiv \pi_j^*. \tag{2.58}$$

2.12.2 Intra-regional transport flows

To evaluate the distance traveled by commodities, we need to know the allocation of farmers between elevators. Farmers choose the elevator minimizing his total cost. Let $\widehat{x}_j^{k,k+1}$ be the farmer who is indifferent between elevator k and $k+1$:

$$\widehat{x}_j^{k,k+1} = \frac{x_j^k + x_j^{k+1}}{2} + \frac{\tau(x_j^{k+1} - x_j^k)}{2} = \frac{\lambda_{uj}}{2} + \frac{\lambda_{rj} k}{2\mu K_j} + \frac{\tau \lambda_{rj}}{4\mu K_j}.$$

The distance to the city differs from one elevator to another. Transportation costs differ accordingly, implying that farmers cannot be evenly distributed among elevators. The mass of farmers residing in region j and shipping their output to elevator 1 and K

are respectively

$$\left|\widehat{x}_j^{1,2} - \bar{x}_{uj}\right| \mu = \frac{\lambda_{rj}(2+\tau)}{4K_j} \quad \text{and} \quad \left|\bar{x}_j - \widehat{x}_j^{K,K-1}\right| \mu = \frac{\lambda_{rj}(2-\tau)}{4K_j}.$$

As for the other $K-2$ elevators, we have

$$\left|\widehat{x}_j^{k,k+1} - \widehat{x}_j^{k,k-1}\right| \mu = \frac{\lambda_{rj}}{2K_j} \qquad \text{with } k \in \{2, ..., K-1\}.$$

Considering this organization of intra-regional freight, the sum of agricultural flows within each region becomes :

$$T_{wj} = 2\sum_{k=1}^{K} \int_{\widehat{x}_j^{k,k-1}}^{\widehat{x}_j^{k,k+1}} \mu \left|x - x_j^k\right| \mathrm{d}x + 2\sum_{k=1}^{K} x_j^k \left(\widehat{x}_j^{k,k+1} - \widehat{x}_j^{k,k-1}\right) \mu\tau$$

2.12.3 Ton-mileage

In region j, the sum of agricultural flows from farms to elevators, and from elevators to the CBD are given respectively by :

$$\begin{aligned}
\sum_{k=1}^{K_j} \int_{\widehat{x}_j^{k,k-1}}^{\widehat{x}_j^{k,k+1}} \left|x - x_j^k\right| \mathrm{d}x &= \left(\frac{\lambda_{rj}}{4\mu K_j}\right)^2 + \frac{K_j - 1}{2}\left\{\left[\frac{\lambda_{rj}(1+\tau)}{4\mu K_j}\right]^2 + \left[\frac{\lambda_{rj}(1-\tau)}{4\mu K_j}\right]^2\right\} \\
&= \left(\frac{\lambda_{rj}}{4\mu K_j}\right)^2 + (K_j - 1)\left(\frac{\lambda_{rj}}{4\mu K_j}\right)^2 (1+\tau^2) \\
&= \left(\frac{\lambda_{rj}}{4\mu K_j}\right)^2 \left[K_j + (K_j - 1)\tau^2\right]
\end{aligned}$$

and

$$\begin{aligned}
\sum_{1}^{K_j} x_j^k \left(\widehat{x}_j^{k,k+1} - \widehat{x}_j^{k,k-1}\right) &= \frac{\lambda_{uj}}{2}\frac{\lambda_{rj}}{2\mu} + \left(\frac{\lambda_{rj}}{4\mu K_j}\right)^2 (2+\tau) + \frac{K-2}{2}\frac{\lambda_{rj}}{2\mu K_j}\frac{\lambda_{rj}}{2\mu K_j} \\
&\quad + \frac{(K_j - 2)(K_j - 1)}{2}\frac{\lambda_{rj}}{2\mu K_j}\frac{\lambda_{rj}}{2\mu K_j} + \left[\frac{\lambda_{rj}}{4\mu K_j} + 2(K-1)\frac{\lambda_{rj}}{4\mu K_j}\right]\frac{\lambda_{rj}(2-\tau)}{4\mu K_j} \\
&= \frac{\lambda_{uj}}{2}\frac{\lambda_{rj}}{2\mu} + \left(\frac{\lambda_{rj}}{4\mu K_j}\right)^2 (2+\tau) + 2(K_j - 2)K\left(\frac{\lambda_{rj}}{4\mu K_j}\right)^2 \\
&\quad + (2K_j - 1)(2-\tau)\left(\frac{\lambda_{rj}}{4\mu K_j}\right)^2 \\
&= \frac{\lambda_{uj}}{2}\frac{\lambda_{rj}}{2\mu} + \left(\frac{\lambda_{rj}}{4\mu K_j}\right)^2 \left[2K_j^2 - 2\tau(K_j - 1)\right]
\end{aligned}$$

Hence, the sum of agricultural flows within region j is :

$$T_{wj} = \frac{\lambda_{rj}^2}{4\mu}\left[\frac{\tau^2 + K_j(1-\tau^2) + 2\tau K_j^2}{2K_j^2}\right] + \frac{\lambda_{uj}\lambda_{rj}}{2}\tau.$$

Because $K_j = \kappa\lambda_{rj}/2$, we finally obtain

$$T_{wj} = \frac{\lambda_{rj}^2\tau}{4\mu} + \frac{\lambda_{rj}(1-\tau^2)}{4\kappa\mu} + \frac{\tau^2}{2\kappa^2\mu} + \frac{\lambda_{uj}\lambda_{rj}}{2}\tau$$

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Chapitre 3

Conventional vs. Alternative Farming : Assessing the Sustainability of a Regional Food Supply Pattern.

Feeding the world's expanding population in a sustainable way is among the main challenges in the coming decades. In this chapter, we examine whether promoting alternative farming leads to improve the sustainability of the food supply chain at a regional scale. Using a spatial model describing the regional land allocation between two types of agricultural practices, we show that alternative farming is more likely to develop and thrive in regions hosting an intermediate-size city. We highlight that promoting alternative farming can lead to a welfare improvement compared to the market, provided that the marginal opportunity cost of urban land remains low enough. However, we find that the conversion from conventional to alternative farming does not necessarily reduce GHG emissions and may, as a consequence, offset the positive effect on welfare.

Keywords : Food supply, Agriculture, Land allocation, Sustainability

JEL Classification : F12 ; Q10 ; Q54 ; Q56 ; R12

3.1 Introduction

Today's global food system is characterized by two major features : (i) food production rests on intensive agricultural practices and (ii) populations depend increasingly on food from distant sources [1]. Long-distance food supply has become the norm in most of the world, particularly in highly urbanized regions where farmland has greatly declined, forcing the cities that cannot rely on local production to expand the boundaries of their foodshed [Kloppenburg et al., 1996].

The sustainability of this system is however questioned This organization of the global food system has attracted increasing attention and raises questions with regard to its sustainability. The depletion of fossil energy resources and energy-related environmental damages lead the cities to account for factors that were, until recently, neglected. At the same time, urban dwellers have more and more demanding expectations with respect to the social and ecological implications of food they consume. In affluent cities notably, the primary issue related to food is no longer one of inadequate supply but rather one of quality and ethical concerns [Deutsch et al., 2013].

In this context, "eating local and organic" has become one of the main watchwords for food supply planning. Cities are increasingly considering the relevance of developing policies to explicitly support alternative production and reduce their inter-regional dependencies [Peters et al., 2009]. From a practical standpoint, improving the sustainability of their current food supply chain would broadly fall into two sets of measures :

i) Reorienting incentives towards less intensive agricultural practices, including organic food development and reduced reliance on chemical inputs (Pimentel et al. [2005] and Niggli et al. [2009]).

ii) Rebuilding the foodshed boundaries so as to reduce the reliance on food imports

1. In the United States, food travels between 2,500 and 4,000 kilometers from farm to plate, as much as 25 percent farther than in 1980's. In the UK, food travels 50 percent farther than it did two decades ago [Halweil, 2002].

(local vs imported production).

Alternative food systems – *i.e., systems that rely on both local food production and organic farming* – are, in this respect, commonly viewed to be inherently more sustainable than conventional ; from the ecological standpoint first, low-input practices and shorter distances associated with alternative farming are purported to reduce the amount of energy used and greenhouse gas emissions released in food transportation [Hinrichs, 2003]. Regarding the economic and the social dimensions then, goods from alternative systems are presumed to be sold at higher prices, enabling farmers to generate a greater profit and, thereby, improve the economic viability of rural communities.

In practice however, these assertions are being challenged ; a growing body of research questions the assumption that local food systems are intrinsically more fair or sustainable (Bellows and Hamm [2001] ; Born and Purcell [2006]) and supports the idea that "localness" is not necessarily environmentally-friendlier [Pirog et al., 2001] [2]. In the end, the debate over the sustainability of alternative systems remains an open issue [Edwards-Jones et al., 2008].

In this chapter, we develop a theoretical spatial model describing the regional land allocation between two types of agricultural practices (alternative and conventional) and we examine whether promoting alternative farming lead to improve the sustainability of the food supply chain at a regional scale. Exploring the conditions that enable alternative farming to exist viably, we show that it is more likely to develop and thrive in regions hosting an intermediate-size city, insufficient market opportunities and expensive food transportation hindering respectively its development in rural areas surrounding small and large cities. Regarding the optimality of the market outcome,

2. Comparing the carbon footprint of local versus imported foodstuffs, Pirog et al. [2001] state that the higher weight capacities of transportation vehicles used in the global food system are usually more efficient due to scale. Since farmers involved in local alternatives are most often not part of a distribution network that offers more organized and efficient transport logistics for delivering food, the environmental benefit is not obvious.

we highlight that fostering alternative farming can lead to a welfare improvement provided that the marginal opportunity cost of urban land remains low enough. However, when looking at the environmental aspects, we find that the conversion from conventional to alternative farming does not necessarily reduce GHG emissions and may, as a consequence, counterbalance the positive effect on the regional welfare.

The chapter proceeds as follows. Section 4.2 presents the model that we use in Section 3.3 to determine the farming pattern that occurs at the equilibrium. In Section 3.4 and 3.5, we discuss the optimality of the market outcome and we wonder whether fostering alternative farming can concomitantly improve the regional welfare and the carbon footprint of the food supply chain. Section 3.6 finally offers a comparative-static analysis focused on the impacts of rising energy prices.

3.2 The Model

Consider an economy formed by an open region and two sectors (agriculture and urban sector). The agricultural activity can be of two types : conventional farming, where commodities are gathered to be sold in the global integrated market, and alternative farming where goods are exclusively sold in the region where they have been grown. The region hosts a population exogenously divided into λ_u urban households and λ_r farmers, $\lambda_u/(\lambda_u + \lambda_r)$ measuring the urbanization rate.

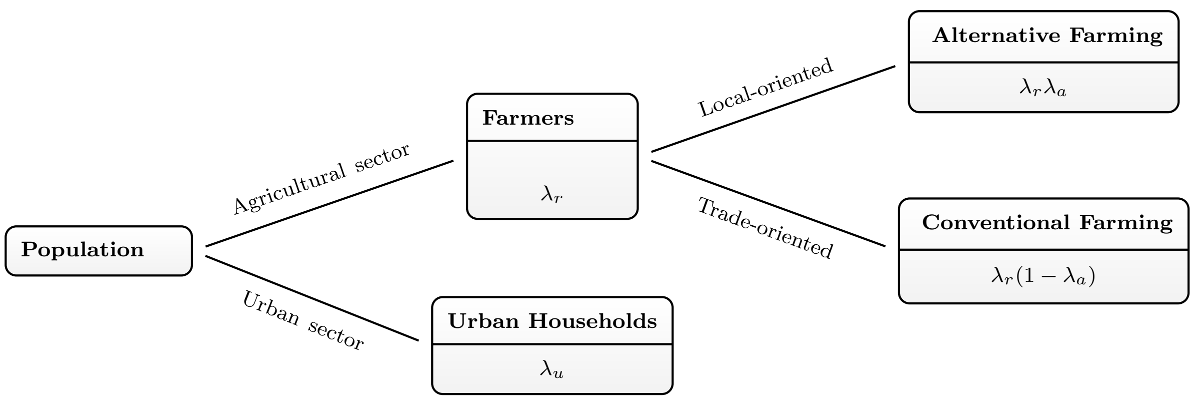

Figure 3.1 – *The sectoral organization of the region*

3.2.1 The spatial structure

The regional space is made of an urban area including a CBD located at $x = 0$ and urban households' lots, and a rural area where farmers live and produce agricultural goods. Soil quality is assumed to be homogeneous over all available land. Without loss of generality, we focus on the right-hand side of the region, the left-hand side being perfectly symmetrical. Distances and locations are expressed by the same variable x, measured from the city center.

Each urban dweller consumes a residential plot of fixed size $1/\delta$ (where $\delta > 1$ is the density of the city) so that the right endpoint of the city is given by

$$\bar{x}_u = \frac{\lambda_u}{2\delta} \tag{3.1}$$

Farmers settles at the periphery of the urban area. They produce either conventional or alternative goods. Assuming that each farmer uses one unit of land for cultivation, the right endpoint of the region is :

$$\bar{x} = \frac{\lambda_u}{2\delta} + \frac{\lambda_r}{2} \tag{3.2}$$

We also suppose the mass of land units is large enough to accommodate both urban and farming activities at the equilibrium. This assumption does not affect our conclusions on land allocation because alternative and conventional farming use the same quantity of land, and the regional distribution between urban and agriculture (λ_u/λ_r) is fixed.

3.2.2 Preferences and demand

Preferences are defined over three consumption goods : an alternatively-grown agricultural product, a conventional agricultural product, and a homogeneous aggregate good Q, chosen as the numéraire. The latter represents the consumption of all goods other than agricultural commodities. In order to abstract from income effects, we assume that the marginal utility with respect to the numéraire is constant. Consumers do not differentiate conventional goods produced in the region they live from imported goods. We further assume that the utility function is additive with respect to the consumed quantity of agricultural goods (q_a and q_c) and the composite good (Q) and given by [3]

$$U(Q; q_c; q_a) = Q + \left(\alpha_c - \frac{q_c}{2}\right) q_c + \left(\alpha_a - \frac{q_a}{2}\right) q_a - \gamma q_a q_c \tag{3.3}$$

The parameters α_a, α_c and γ are positive and we posit $\gamma < 1$ to ensure the quasi-concavity of the utility function. γ measures the substitutability between the two agricultural varieties, ranging from zero when alternative and conventional goods are independent, to values close to one when they are perfect substitutes. α_a and α_c represent the intrinsic quality of alternatively-grown and conventional goods, respectively. The gap between α_a and α_c is therefore a measure of the quality differentiation between the two agricultural goods and reflects the consumers' willingness to buy products identified as alternatively-grown ; the larger $\alpha_a - \alpha_c$, the greater the consumers' sensitivity towards the farming practices.

Consumers live in the urban area and work in the CBD. They bear urban costs, given by the sum of the commuting costs and the land rent. Denoting t_u and R_u as the per-mile commuting cost and the (urban) land rent, the budget constraint of a urban dweller residing at x is :

$$q_c p_c + q_a p_a + Q + \frac{R_u(x)}{\delta} + t_u x = w_u + \overline{Q} \tag{3.4}$$

where p_c and p_a are the prices of the conventional and the alternative good, and w_u is the urban wage prevailing in the city. The initial endowment in numéraire $\overline{Q}$ is supposed to be large enough to ensure strictly positive consumption in equilibrium. Maximizing the utility (3.3) subject to the budget constraint (4.7) leads to the following individual demand functions :

$$q_a^d = \frac{\alpha_a - \gamma\alpha_c}{1-\gamma^2} - \frac{p_a}{1-\gamma} + \frac{\gamma}{1-\gamma^2}(p_a + p_c) \tag{3.5}$$

$$q_c^d = \frac{\alpha_c - \gamma\alpha_a}{1-\gamma^2} - \frac{p_c}{1-\gamma} + \frac{\gamma}{1-\gamma^2}(p_a + p_c) \tag{3.6}$$

3. This specification is similar to that used by Singh and Vives [1984] with the simplification $\beta_i = \beta_j = 1$.

3.2.3 Technologies and agricultural profits.

Alternative food production Products from alternative farming are intended for regional consumption only. Farmers operating in this sector only use organic fertilizer and one unit of land to produce. Denoting by $\bar{q}$ the natural ability of soils to grow crops in the region, the individual production in alternative goods is given by :

$$q_a^s = \bar{q}\kappa \tag{3.7}$$

where κ is a positive coefficient that can be interpreted as the agricultural labor efficiency.

The costs to transport the goods from the farm to the city are borne by the farmer and are supposed to be linear in weight and distance. Letting t_a be the transportation cost per unit of good and distance and $R_a(x)$, the land rent paid by a farmer involved in alternative farming, the profits of a farmer located at x are :

$$\pi_a(x) = (p_a^* - t_a x)\bar{q}\kappa - R_a(x). \tag{3.8}$$

As alternative farmers produce for the domestic market only, the equilibrium price is determined at the regional scale. Denoting by λ_a the share of farmers involved in alternative production, the total amount of goods produced is such that $Q_a^s = \bar{q}\kappa\lambda_r\lambda_a$. Using (3.5) and the expression of Q_a^s, the market clearing condition for alternatively-grown goods leads to

$$p_a^* = [\alpha_a - \gamma(\alpha_c - p_c)] - \left(1 - \gamma^2\right)\frac{\lambda_a\lambda_r\bar{q}\kappa}{\lambda_u} \tag{3.9}$$

The term in square brackets captures the maximum willingness to pay for alternatively-grown goods, while the last term in RHS of (3.9) encompasses both the effect of the competition between farmers ($\lambda_a\lambda_r\bar{q}\kappa$) and that of regional market opportunities (through the inverse measure of the demand sensitivity to price $\frac{1-\gamma^2}{\lambda_u}$).

Conventional food production In conventional farming, production requires one unit of land and an amount z of synthetic fertilizer. The yield response to synthetic fertilizer application is assumed to be positive, increasing and concave. The individual supply in conventional goods can be written as $q_c^s \equiv \bar{q}\kappa F(z)$ with $F'(z) > 0$ and $F''(z) < 0$. For the ease of calculation, we retain a Cobb-Douglas specification as in Beckmann [1972], so that

$$q_c^s = \bar{q}\kappa\sqrt{z+1} \qquad \forall z \geq 0 \tag{3.10}$$

Note that when no synthetic fertilizer is used ($z = 0$), yields in conventional farming equals those of alternative farming ($q_c^s(0) = q_a^s = \bar{q}\kappa$).

Regarding the food transportation, commodities are first gathered in a regional grain elevator located at the border of conventional fields $\hat{x}$, before being brought to the central market by larger vehicles [4]. To send its production to the elevator, the farmer has to pay t_c per unit of product and distance covered. We further assume $t_c < t_a$, meaning that conventional farmers benefit from lower transportation costs than alternative farmers [5]. Let p_z and R_c be the unit cost of synthetic fertilizer and the land rent paid by conventional farmers. The profits of a farmer located at x are then given by :

$$\pi_c(x) = (p_c - t_c|x - \hat{x}|)q_c^s(x) - p_z z - R_c(x) \tag{3.11}$$

For simplicity, we suppose that p_c and p_z are exogenously fixed ; the regional supply in conventional goods is assumed to be small enough to not significantly impact the equilibrium price p_c determined on the global market.

Conventional farmers choose the amount of synthetic fertilizer to be applied so as to maximize their profit $\pi_c(x)$, leading to :

$$z^*(x) = \begin{cases} \left(\dfrac{p_c - t_c|x - \hat{x}|}{2p_z}\bar{q}\kappa\right)^2 - 1 > 0 & \text{if } \hat{x} < x \leq \tilde{x} \\ 0 & \text{if } \tilde{x} < x < \bar{x} \end{cases} \tag{3.12}$$

4. Although other locations can be envisaged, this option offers the advantage to abstract from the effects of the location strategy within the conventional agricultural area.

5. This assumption is consistent with the reality, the higher transport costs in the organic sub-sector being mainly due to the lack of economies of scale [CEC, 2004].

and

$$q_c^{s^*}(x) = \begin{cases} \dfrac{p_c - t_c|x-\hat{x}|}{2p_z}(\bar{q}\kappa)^2 & \text{if } \hat{x} < x \leq \tilde{x} \\ \bar{q}\kappa & \text{if } \tilde{x} < x < \bar{x} \end{cases} \tag{3.13}$$

where $\tilde{x} \equiv \hat{x} + \dfrac{p_c}{t_c} - \dfrac{2p_z}{\bar{q}\kappa t_c}$. As shown by (4.13), the amount of synthetic fertilizer used by conventional farmers is decreasing with the distance from the regional grain elevator, and increasing with the natural ability of land $\bar{q}$. Moreover, the expression of $\tilde{x}$ suggests that the spatial extent of the high input conventional farming area depends only on exogenous parameters. This result is of particular importance as it implies that conversion to alternative farming does not systematically lead to a decrease in synthetic fertilizer use (Fig. 3.2.2) [6].

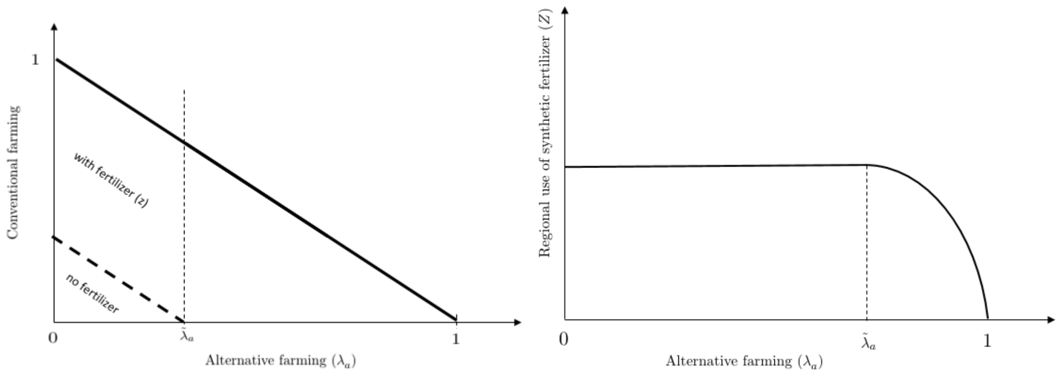

Figure 3.2 – *Farming conversion and regional use of synthetic fertilizer*

A closer look at the nature of the conventional farming reveals that three cases can be envisaged. First, all the conventional farmers use synthetic fertilizer if $\bar{x} < \tilde{x}$ that is, if the transportation cost per unit of good supported by the farmer located at the limit of the region is small enough. Using (3.2) and the expression of $\tilde{x}$, we show that this condition can be written as $\frac{(1-\lambda_a)\lambda_r}{2}t_c < p_c - \frac{2p_z}{\bar{q}\kappa}$ or equivalently :

$$\lambda_a > \tilde{\lambda}_a \equiv 1 - \frac{2}{\lambda_r}\frac{\bar{q}\kappa p_c - 2p_z}{\bar{q}\kappa t_c}. \tag{3.14}$$

Second, if $\tilde{x} \leq \hat{x}$, or equivalently, if $\bar{q} \leq \frac{2p_z}{\kappa p_c}$, none of the conventional farmers

6. Observe that this result stems from the assumption that the transportation cost from the grain elevator to the CBD in conventional farming is sufficiently low to be neglected.

use synthetic fertilizer[7] ; in this case, the natural ability of soil is not high enough to make the use of synthetic fertilizer economically beneficial. Finally, conventional farming includes both farmers who use fertilizer and others who do not use fertilizer if $\hat{x} < \tilde{x} < \bar{x}$ (that is, if $\bar{q} > \frac{2p_z}{\kappa p_c}$ and $\lambda_a < \tilde{\lambda}_a$).

Summing up, the share of conventional farmers using synthetic fertilizer ($\lambda_{c|_{z>0}}$) is such :

$$\lambda_{c|_{z>0}} = \begin{cases} 0 & \text{if} \quad \bar{q} \leq \dfrac{2p_z}{\kappa p_c} \\ \dfrac{2}{(1-\lambda_a)\lambda_r} \dfrac{\bar{q}\kappa p_c - 2p_z}{\bar{q}\kappa t_c} & \text{if} \quad \bar{q} > \dfrac{2p_z}{\kappa p_c} \quad \text{and} \quad \lambda_a < \tilde{\lambda}_a \\ 1 & \text{if} \quad \bar{q} > \dfrac{2p_z}{\kappa p_c} \quad \text{and} \quad \lambda_a > \tilde{\lambda}_a \end{cases} \tag{3.15}$$

$\lambda_{c|_{z>0}}$ increases with the share of alternative farming (λ_a) provided that the natural ability of soils is high enough. Plugging (4.13) and (3.13) into (3.11), the profits for farmers involved in conventional production are finally given by :

$$\pi_c(x) = \begin{cases} \dfrac{(p_c - t_c|x-\hat{x}|)^2}{4p_z}(\bar{q}\kappa)^2 - R_{c|_{z>0}}(x) + p_z & \text{if } \hat{x} < x \leq \tilde{x} \\ (p_c - t_c|x-\hat{x}|)\bar{q} - R_{c|_{z=0}}(x) & \text{if } \tilde{x} < x < \bar{x} \end{cases} \tag{3.16}$$

3.3 The equilibrium pattern of agricultural land use

We now determine the agricultural pattern that would emerge at the market equilibrium.

3.3.1 Equilibrium land allocation

As in Von Thünen models, the regional land allocation is derived from the equilibrium rent function. Bid rent functions are obtained by equating the location costs (transportation and land cost) within each area (see Appendix B.1). Each plot of land being allocated to the highest bidder, the equilibrium land rent is such that :

$$R^*(x) = \max\{R_u(x), R_a(x), R_{c|_{z>0}}(x), R_{c|_{z=0}}(x)\} \tag{3.17}$$

7. Under this threshold value of $\bar{q}$, $\tilde{\lambda}_a$ is always higher than one, so that $\lambda_a < \tilde{\lambda}_a$.

Depending on the bid rent curves' ranking, several land use configurations can occur (Fig. 3.3). In order to ease the discussion, we concentrate on the following configuration : a CBD surrounded by a residential urban area, followed by a zone dedicated to alternative farming, finally bordered by a conventional farming area (See. Fig. 3.3.A1, A2 and A3). We show in Appendix B.2 that this spatial configuration occurs if and only if the share of alternative farmers is not to high, that is, for $\lambda_a < \hat{\lambda}_a$ with $\hat{\lambda}_a = \frac{4(2p_z t_a - \bar{q}\kappa p_c t_c)}{\bar{q}\kappa t_c^2 \lambda_r} > 0$[8]. In this case, the equilibrium land rent is given by :

$$R^*(x) = \begin{cases} R_u^*(x) = \delta t_u |\bar{x}_u - x| + R_a^*(\bar{x}_u) & \text{if } 0 < x \leq \bar{x}_u \\ R_a^*(x) = t_a |\hat{x} - x| \bar{q}\kappa + R_{c|_{z>0}}^*(\hat{x}) & \text{if } \bar{x}_u < x \leq \hat{x} \\ R_{c|_{z>0}}^*(x) = \dfrac{p_c + t_c\left(\hat{x} - \frac{x+\tilde{x}}{2}\right)}{2p_z} t_c |\tilde{x} - x| \bar{q}^2\kappa^2 + R_{c|_{z=0}}^*(\tilde{x}) & \text{if } \hat{x} < x \leq \tilde{x} \\ R_{c|_{z=0}}^*(x) = t_c |\bar{x} - x| \bar{q}\kappa & \text{if } \tilde{x} < x < \bar{x} \end{cases} \tag{3.18}$$

If the above condition is not met (i.e. if $\lambda_a > \hat{\lambda}_a$), a spatial pattern where the land allocated to alternative farming is enclosed in the conventional farming area occurs (Fig. 3.3.B).

Equilibrium incomes in alternative and conventional farming are obtained by plugging (3.18) into (3.8) and (3.16) :

$$\pi_a^* = \left[p_a^* - t_a \left(\frac{\lambda_u}{2\delta} + \frac{\lambda_a \lambda_r}{2} \right) - \frac{(\bar{q}\kappa p_c - 2p_z)^2}{4\bar{q}\kappa p_z} - \frac{(1-\lambda_a)\lambda_r}{2} t_c \right] \bar{q}\kappa \tag{3.19}$$

$$\pi_c^* = \left[p_c - t_c \frac{(1-\lambda_a)\lambda_r}{2} \right] \bar{q}\kappa \tag{3.20}$$

The price of alternatively-grown goods decreases with respect to the share of alternative farmers (Eq.(3.9)). Therefore, profits in alternative farming are decreasing with λ_a while they are increasing in conventional farming. Consequently, starting from a very low share of alternative farming (i.e. λ_a close to 0), there can be an interior solution for the regional distribution of farmers between conventional and alternative activities at

8. Note that for values of t_c sufficiently low compared with t_a, this condition is always met.

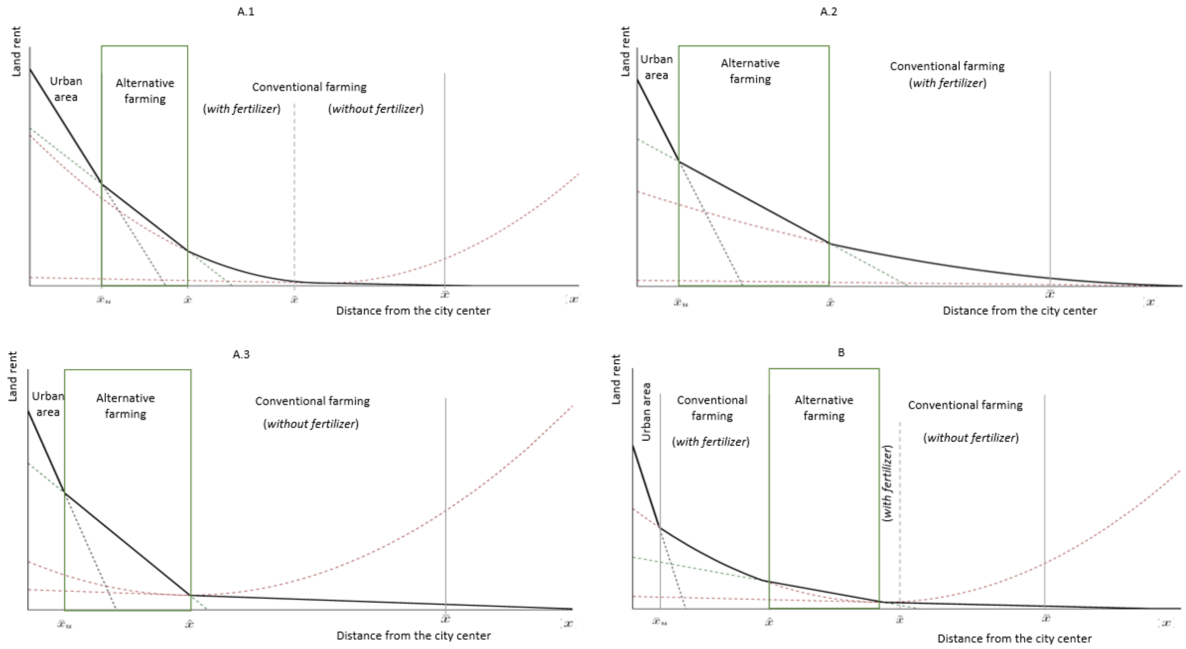

Figure 3.3 – *Bid-rent functions and regional land allocation*

the equilibrium. Such an equilibrium occurs when no farmer can be better off by converting to the other farming practice. Solving $\pi_c^* = \pi_a^*$ for λ_a, we derive the equilibrium share of farmers involved in alternative farming :

$$\lambda_a^* = \frac{\alpha_a - \gamma(\alpha_c - p_c) - t_a \frac{\lambda_u}{2\delta} - \left(\frac{p_z}{\bar{q}\kappa} + \frac{p_c^2 \bar{q}\kappa}{4p_z}\right)}{\lambda_r \left(\bar{q}\kappa \frac{1-\gamma^2}{\lambda_u} + \frac{t_a}{2}\right)} \tag{3.21}$$

Since the profit differential between alternative and conventional farming decreases monotonically with respect to the share of alternative farmers, this equilibrium is unique and stable. Moreover, we show in Appendix C that λ_a^* varies from 0 to 1 for intermediate values of t_a.

3.3.2 Urbanization and agricultural practices

According to (3.21), the share of alternative farming describes a concave function with respect to the urban population' size (λ_u). This inverted U-shaped relation stems from the interplay of two competing effects, namely, the market size effect ($\frac{1-\gamma^2}{\lambda_u}$) and the transportation bill effect ($-t_a \frac{\lambda_u}{2\delta}$). In a first step, the larger the urban population, the stronger the market size effect. Farmers are thus encouraged to convert to alternative production so as to benefit from additional outlets. However, a larger urban population is also equivalent to a more extended residential area, resulting in higher transportation costs for farmers. Since the marginal impact of the market size effect is decreasing with the urban population' size while that of the transportation bill is constant, there is a threshold level of urbanization $\bar{\lambda}_u$ at which the equilibrium share of alternative farming achieves a maximum (thereafter referred as $\bar{\lambda}_a$) :

$$\bar{\lambda}_u = \frac{2\bar{q}\kappa\,(1-\gamma^2)}{t_a}\left[\sqrt{1+\frac{\delta}{(1-\gamma^2)\,\bar{q}\kappa}\left(\alpha_a-\gamma(\alpha_c-p_c)-\frac{4p_z^2+p_c^2\bar{q}^2\kappa^2}{4\bar{q}\kappa p_z}\right)}-1\right] \quad (3.22)$$

Beyond $\bar{\lambda}_u$, transportation costs outweigh the market size effect so that farmers have incentives to return to conventional production.

Proposition 4 *Alternative farming is more likely to thrive in a region hosting a city which population is neither too large nor too small (other things being equal).*

The shape of the relationship between alternative farming and urbanization and the value of $\bar{\lambda}_u$ are strongly influenced by the parameters defining the consumers' preferences. First, the quality differentiation between conventional and alternatively-grown goods affects the equilibrium farming pattern as follows : the greater $\alpha_a - \alpha_c$, the larger the share of alternative farming regardless the level of urbanization. Second, as illustrated by Figure 3.4, the maximum alternative share $\bar{\lambda}_a$ is positively (resp. negatively) related to the degree of agricultural goods' substituability provided that the quality of the alternatively-grown good valuated by the consumers is high (resp. low).

Last, agricultural goods' substituability also determines the level of $\bar{\lambda}_u$. When agricultural goods are almost-perfect substitutes (γ close to one), the market effect is weak and more likely offset by the transportation bill, so that alternative farming can only develop in very low urbanized regions. As γ decreases, the market effect plays more significantly, allowing alternative farming to become economically viable in regions hosting a larger city.

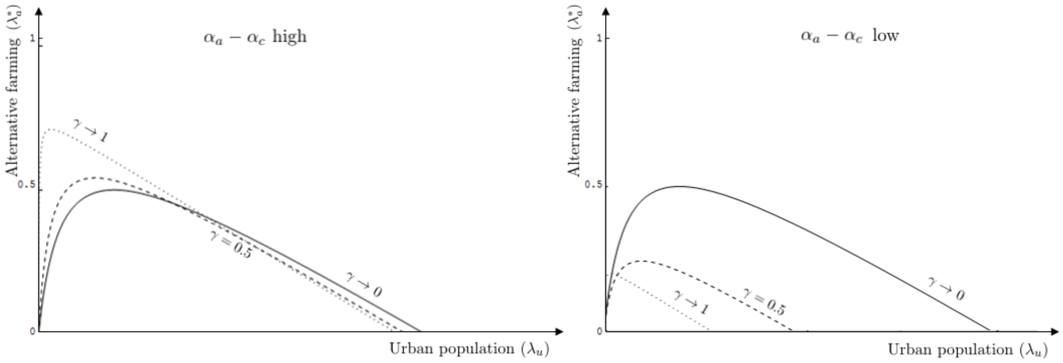

Figure 3.4 – *Alternative farming share (λ_a^*) and urban population' size (λ_u) for different level of goods' substituability.*

3.3.3 Soil quality and fertilizer use at the equilibrium

The use of synthetic fertilizer in conventional farming varies in space and depends on the natural ability of the regional soils ($\bar{q}$). As a consequence, both the individual and the total amount of fertilizer use in conventional farming in equilibrium vary according to this characteristic (Fig. 3.5).

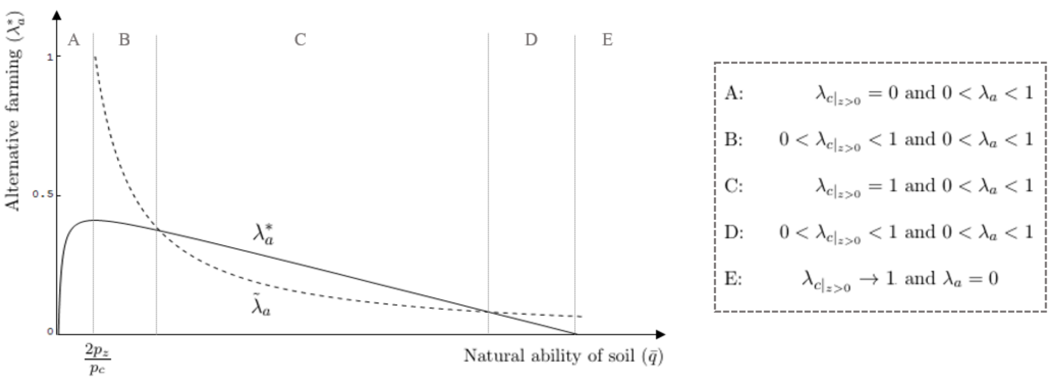

Figure 3.5 – *The regional farming pattern at the equilibrium*

For a very low natural ability of soils, the region hosts mainly synthetic-free conventional farming. As the quality rises (while remaining below $\frac{2p_z}{\kappa p_c}$), the share of alternative farming increases. From the threshold $\bar{q} > \frac{2p_z}{\kappa p_c}$, using synthetic fertilizer in conventional production becomes economically beneficial. As a consequence, any further soils' quality increase results in the development of high-input conventional farming at the expense of both alternative and synthetic-free conventional farming. Finally, for a very large value of $\bar{q}$, farmers are all engaged in conventional production and mainly use synthetic fertilizer.

3.4 Agricultural pattern and regional welfare

We now evaluate the optimality of the equilibrium farming pattern. We start by assessing the impact of alternative farming on the indirect utility of urban households. In a second step, we define the farming pattern that maximizes the regional social welfare and we discuss the conditions for which fostering alternative farming leads to a welfare improvement.

3.4.1 *Urban households utility and alternative farming.*

Let V_u be the indirect utility of a urban household living in the region given by :

$$V_u(\lambda_a) = w_u - \frac{R_u^*(x)}{\delta} - t_u x + \overline{Q} + \underbrace{\left(\alpha_c - p_c - \gamma\frac{\bar{q}\kappa\lambda_a\lambda_r}{\lambda_u}\right)^2 \frac{1-\gamma^2}{2}}_{CS_c} + \underbrace{\left(\frac{\bar{q}\kappa\lambda_a\lambda_r}{\lambda_u}\right)^2 \frac{1-\gamma^2}{2}}_{CS_a} \tag{3.23}$$

CS_c and CS_a are the consumers' surpluses evaluated at the equilibrium prices associated with the consumption of the conventional and the alternatively-grown goods, respectively. For the range of values of p_c that allows the individual demand of conventional goods q_c^d to be positive, we have $\frac{\partial CS_a}{\partial\lambda_a} > 0$, $\frac{\partial CS_c}{\partial\lambda_a} < 0$ and $\frac{\partial^2 CS_a}{\partial\lambda_a^2} > \frac{\partial^2 CS_c}{\partial\lambda_a^2}$.

Replacing $R_u^*(x)$ by its expression in (3.23) and rearranging, the indirect utility becomes :

$$V_u(\lambda_a) = C - \bar{q}\kappa\left(\frac{t_a - t_c}{2\delta} + \frac{(\alpha_c - p_c)\gamma\left(1-\gamma^2\right)}{\lambda_u}\right)\lambda_r\lambda_a + \frac{\bar{q}^2\kappa^2\left(1-\gamma^4\right)\lambda_r^2}{2\lambda_u^2}\lambda_a^2 \tag{3.24}$$

where C is a constant that only depends on exogenous parameters. The relationship between $V_u(\lambda_a)$ and λ_a being convex, the share of alternative farming that would maximize the indirect utility of urban households is a corner solution. Stated differently, the utility of urban households is maximized under full specialization only, be it either alternative or conventional.

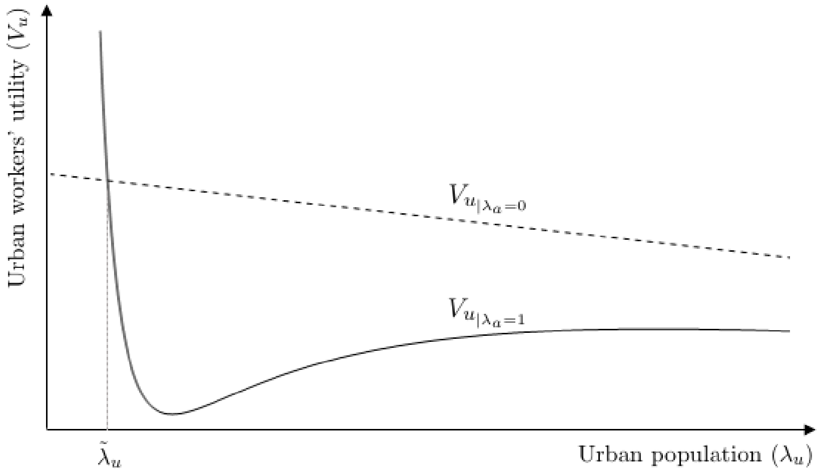

Figure 3.6 – *Urban households' utility under fully-alternative and fully-conventional farming patterns.*

Figure 3.6 depicts the relationship between the indirect utility of urban households and the level of urbanization. The plain and the dashed lines represent respectively the cases where the regional agriculture is exclusively alternative ($\lambda_a = 1$) and exclusively conventional ($\lambda_a = 0$). As seen from (3.24), $V_{u|\lambda_a=0}$ decreases at a constant rate of $\frac{-t_u}{2\delta}$ while $V_{u|\lambda_a=1}$ describes an inverted N-shaped curve. Furthermore, since $\lim_{\lambda_u \to 0} V_{u|\lambda_a=1} = +\infty$ and $\lim_{\lambda_u \to +\infty} (V_{u|\lambda_a=0} - V_{u|\lambda_a=1}) = \frac{\bar{q}\kappa(t_a - t_c)\lambda_r}{2\delta} > 0$, the two curves always intersect once and only once, implying that alternative farming improves the utility of urban households only in regions hosting a city not too crowded (i.e. $\lambda_u < \tilde{\lambda}_u$).

From the urban households standpoint, alternative farming has two opposite effects. On the one hand, more farmers involved in alternative production implies both a lower price and a higher individual consumption level, leading to a larger consumers' surplus. On the other hand, alternative farming causes a rise in urban land prices ; differentiating $R_u^*(\bar{x}_u)$ with respect to λ_a in (3.18), we show that the marginal opportunity cost of urban land –*that is, the extra land cost that urban households have to pay for each additional alternative farmer*– is given by $\frac{\bar{q}\kappa(t_a - t_c)\lambda_r}{2\delta}$. Thus, alternative farming can either improve or reduce the urban households' utility, depending on which effect outweighs the other. Since the land costs plays with even more weight in highly urbanized regions, the development of alternative farming near large cities leads to a rise in urban land prices that cannot be positively compensated by the consumers' surplus. This explains why promoting alternative farming in the most urban-crowded may be detrimental to urban households.

3.4.2 The welfare-maximizing solution

We finally broaden the discussion on the optimality of the market equilibrium by including the farmers' well-being. To this end, we define the regional social welfare function as :

$$SW(\lambda_a) = \lambda_u V_u(\lambda_a) + \lambda_a \lambda_r \pi_a^*(\lambda_a) + (1-\lambda_a)\lambda_r \pi_c^*(\lambda_a) \tag{3.25}$$

with $\frac{\partial^2 SW}{\partial \lambda_a^2} < 0$ [9]. Solving $\frac{\partial SW}{\partial \lambda_a} = 0$ for λ_a, the optimal share of farmers involved in alternative farming is given by :

$$\lambda_a^o = \frac{\alpha_a - \gamma(\alpha_c - p_c)(2-\gamma^2) - t_a \frac{\lambda_u}{2\delta} - \left(\frac{p_z}{\bar{q}\kappa} + \frac{p_c^2 \bar{q}\kappa}{4p_z}\right) + t_c\left(\frac{\lambda_u}{2\delta} + \frac{\lambda_r}{2}\right)}{\lambda_r\left(\bar{q}\kappa \frac{(1-\gamma^2)^2}{\lambda_u} + t_a\right)} \tag{3.26}$$

Comparing (3.21) to (3.26), we can derive the conditions under which the market lead to a farming pattern close to the optimal solution. As for the equilibrium, we show in Appendix D that the shape of the relationship between the optimal farming pattern and the size of the urban population (λ_u) is concave. Therefore, plotting λ_a^* and λ_a^o as a function of λ_u, curves can either cross once, twice or never cross.

From (3.21) and (3.26), we get the following properties :

$$\lim_{\lambda_u \to +\infty} \lambda_a^o = -\infty \text{ and } \lim_{\lambda_u \to +\infty} \lambda_a^* = -\infty \tag{3.27}$$

$$\lim_{\lambda_u \to 0} \lambda_a^o = 0 \text{ and } \lim_{\lambda_u \to 0} \lambda_a^* = 0 \tag{3.28}$$

$$\lim_{\lambda_u \to +\infty} (\lambda_a^o - \lambda_a^*) = +\infty \tag{3.29}$$

$$\lim_{\lambda_u \to 0} \left(\frac{\partial \lambda_a^o}{\partial \lambda_u} - \frac{\partial \lambda_a^*}{\partial \lambda_u}\right) > 0 \tag{3.30}$$

9. Recalling that alternative and conventional profits are respectively decreasing and increasing with the share of alternative farmers and knowing that $\pi_a^*(0) > \pi_c^*(0)$, we can show that SW is a concave function of λ_a.

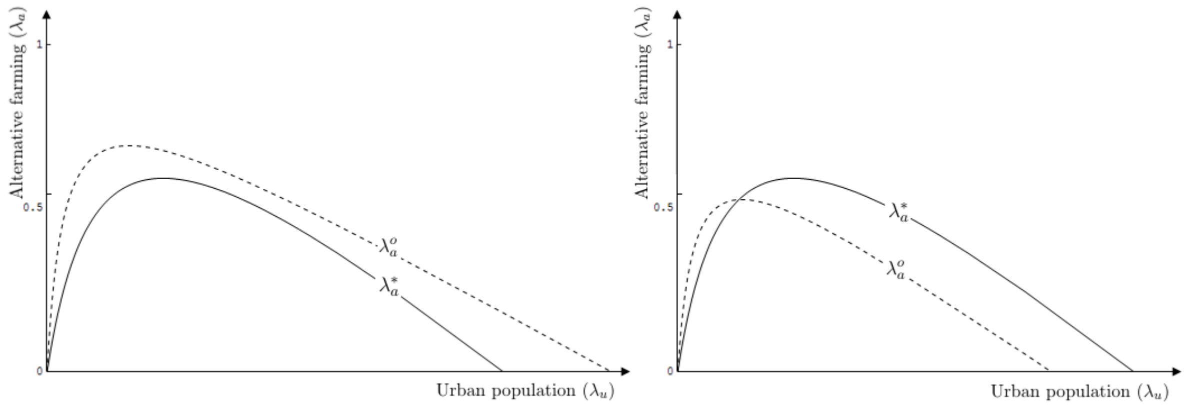

Figure 3.7 – *Equilibrium and Optimal farming pattern in function of the urban population' size*

We derive from (3.27) that the market always leads to an optimal situation for the most-urbanized regions, where no alternative farming can develop. Moreover, (3.28) and (3.30) suggest that the market never allows enough alternative farming to establish itself in the regions hosting a very small city. This situation can even be observed for intermediate and large cities if the marginal opportunity cost of urban land is sufficiently low (see Fig.3.7.1). On the contrary, if this cost is high, we have previously shown that alternative farming is detrimental to the utility of large-cities dwellers. In this situation, the two curves intersect and we draw from (3.27)–(3.30) that λ_a^o is always higher than λ_a^* for small values of λ_u and lower than λ_a^* for intermediate values of λ_u. Hence, from the welfare standpoint, alternative farming is not enough developed in low urbanized regions and too much developed in high urbanized regions (see Fig.3.7.2) [10].

Proposition 5 *Fostering the development of alternative farming always leads to a welfare improvement in low-urbanized regions. This result can be extended to more urbanized regions provided that the marginal opportunity cost of urban land remains low enough.*

10. Note that λ_a^o and λ_a^* can also intersect twice before crossing the x-axis. In this case, alternative farming is not enough developed low urbanized and high urbanized regions, and too much developed in regions hosting an intermediate-size city.

3.5 Does alternative farming development lead to a decrease in GHG emissions ?

Suppose the region seeks to meet its population' food needs whilst reducing the GHG emissions stemming from the whole supply chain. As emissions come from both production and transportation, the region faces a trade-off between (i) fostering alternative farming so as to lessen the emissions due to the use of synthetic fertilizer and (ii) sharing its land between alternative and conventional production so as to curb the emissions due to the transportation flows.

In this section, we assess the way the emissions from the regional food supply vary according to the share of alternative farming and we determine the conditions for which, modifying the equilibrium pattern so as to improve the social welfare contributes to a concomitant decrease in GHG emissions. It is worth noting that the emissions accounting we propose in this work differs somewhat from an environmental assessment of the food supply system of the city, as we do not include the emissions due to conventional goods grown abroad and consumed in the region. Although analytically feasible, doing so would require additional calculations to determine the share of goods produced and consumed locally and would, thereby, complicate the analysis. Instead, we focus on the volume of GHG emissions at the regional scale ; we account for the emissions stemming from conventional and alternative production, food transportation within the region but also for the emissions due to incoming or out-coming flows in conventional goods (i.e. inter-regional trade, be it exports or imports). Besides, in order to avoid double-counting of emissions, we assume that the region takes into account only half of the inter-regional trade flow. Hence, summing the flows on all the regions that belong to the geographical unit we consider would give the aggregate level of emissions from the whole food supply chain.

3.5.1 Synthetic fertilizer use and agricultural production

As previously mentioned and illustrated by Figure 3.2, promoting alternative farming does not necessarily involve less fertilizer. According to the characteristics of the region, there may be cases where converting to alternative practices does not provide any GHG benefit in the production stage. This is readily verified by calculating the use of synthetic fertilizer and the supply in conventional goods in the region. Using (4.13) and (3.13), we have :

$$Z = \begin{cases} \dfrac{(\bar{q}\kappa p_c + 4p_z)(\bar{q}\kappa p_c - 2p_z)^2}{6\bar{q}\kappa p_z^2 t_c} & \text{if } \lambda_a < \tilde{\lambda}_a \\ \left[p_c^2 - \dfrac{4p_z^2}{\bar{q}^2\kappa^2} + \dfrac{t_c(1-\lambda_a)\lambda_r}{2}\left(\dfrac{t_c(1-\lambda_a)\lambda_r}{6} - p_c\right)\right]\dfrac{(1-\lambda_a)\lambda_r}{4p_z^2}\bar{q}^2\kappa^2 & \text{if } \lambda_a > \tilde{\lambda}_a \end{cases} \tag{3.31}$$

and

$$Q_c^s = 2\int_{\hat{x}}^{\bar{x}} q_c^{s*}(x)dx = \begin{cases} \dfrac{(\bar{q}\kappa p_c - 2p_z)^2}{2p_z t_c} + \bar{q}\kappa(1-\lambda_a)\lambda_r & \text{if } \lambda_a < \tilde{\lambda}_a \\ \dfrac{\bar{q}^2\kappa^2}{p_z}\left(p_c - \dfrac{t_c(1-\lambda_a)\lambda_r}{4}\right)\dfrac{(1-\lambda_a)\lambda_r}{2} & \text{if } \lambda_a > \tilde{\lambda}_a \end{cases} \tag{3.32}$$

As suggested by (3.31), a decrease in conventional farming results in a lower use of synthetic fertilizer only if the share of alternative farming is already sufficiently high (i.e. $\lambda_a^* > \tilde{\lambda}_a$), or if the conversion from conventional to alternative farming is large enough. Regarding the regional production in conventional goods, it decreases linearly with the share of alternative farming as long as the conversion involves conventional farmers who do not use synthetic fertilizer. Then, from $\lambda_a^* > \tilde{\lambda}_a$, the production falls more rapidly with increasing λ_a.

For simplicity, we limit the rest of the analysis to the most relevant and realistic case, that is the situation where all the conventional farmers use synthetic fertilizer to produce their goods ($\lambda_a > \tilde{\lambda}_a$). Hence, assuming that GHG emissions are linear with the production, the flow of emissions arising from food production is given by :

$$\begin{aligned} E_P(\lambda_a) &= e_a Q_a^s + e_c Q_c^s \\ &= e_a\lambda_a\lambda_r\bar{q}\kappa + e_c\frac{\bar{q}^2\kappa^2}{p_z}\left(p_c - \frac{t_c(1-\lambda_a)\lambda_r}{4}\right)\frac{(1-\lambda_a)\lambda_r}{2} \quad (\text{ with } \lambda_a > \tilde{\lambda}_a) \end{aligned} \tag{3.33}$$

where e_c and e_a are the emission factors associated with the conventional and the alternative practices, respectively. e_c is assumed to be higher than e_a. As for the production in conventional goods, the emission flow stemming from agricultural production in the region decreases concavely as the share of alternative farming increases (Fig. 3.9.2).

3.5.2 Intra-regional food transportation and trade

Intra-regional food transport Alternative goods are transported to the central market located at $x = 0$ by each farmer involved in alternative production. Recalling that alternative fields are located from $\bar{x}_u$ to $\hat{x}$, the sum of alternative freight flows within the region is given by :

$$T_a = 2\bar{q}\kappa \left(\int_{\bar{x}_u}^{\hat{x}} |x - \bar{x}_u| dx + \lambda_a^* \lambda_r \bar{x}_u \right) = \frac{\lambda_a \lambda_r}{2} \left(\frac{\lambda_a \lambda_r}{2} + \frac{\lambda_u}{\delta} \right) \bar{q}\kappa \tag{3.34}$$

Not surprisingly, intra-regional transport flows of alternative goods increase with the regional share of alternative farming (Fig. 3.8.2).

In conventional farming, transportation is organized in two stages. In a first step, farmers carry their goods to the regional grain elevator located at $\hat{x}$:

$$T_c^{x \to \hat{x}} = 2 \int_{\hat{x}}^{\bar{x}} q_c^{s^*}(x) |x - \hat{x}| dx = \frac{3p_c - t_c \bar{q}\kappa(1 - \lambda_a)\lambda_r}{6p_z} \times \frac{\bar{q}\kappa(1 - \lambda_a)^2 \lambda_r^2}{4} \tag{3.35}$$

The production from all the conventional farmers operating in the region is then collected and bundled in order to be sent, in a second step, to the central market :

$$T_c^{\hat{x} \to CBD} = Q_c^s \hat{x} = \left[\frac{\bar{q}^2 \kappa^2}{p_z} \left(p_c - \frac{t_c (1 - \lambda_a)\lambda_r}{4} \right) \frac{(1 - \lambda_a)\lambda_r}{2} \right] \left(\frac{\lambda_u}{\delta} + \lambda_a \lambda_r \right) \tag{3.36}$$

Because fostering the development of alternative farming has an impact on both the distance covered by farmers and the volume of agricultural goods transported from farms to the CBD, its final effect on intra-regional conventional transportation is ambiguous. Focusing on the volume effect first, raising the share of alternative farmers implies mechanically less conventional production. Recalling that $\lambda_a > \tilde{\lambda}_a$, the volume of goods transported decreases concavely as λ_a increases. Regarding the distance covered, trips decrease from conventional farms to the grain elevator, but increase from the elevator to the CBD. In the end, since both the volume and the distance fall in the first step of the conventional freight, $T_c^{x \to \hat{x}}$ is always decreasing with the share of alternative farming. In contrast, $T_c^{\hat{x} \to CBD}$ may either increase or decrease, depending on which effect outweighs the other (Fig. 3.8.1).

Inter-regional food trade. We finally account for the trade in conventional goods between the region and its trade partner. The perfect competition on the conventional agricultural markets implies unidirectional flows ; the region is either importer, exporter, or self-reliant and the volume of trade flows can be expressed as :

$$|Q_c^s - Q_c^d| = \left| \int_{\hat{x}}^{\bar{x}} q_c^{s^*}(x)dx - q_c^d \lambda_u \right| \tag{3.37}$$

Letting ν be the distance between the region and its trade partner, the inter-regional flow of conventional goods is such that

$$T_c^{Trade} = \begin{cases} \left[\frac{\bar{q}^2 \kappa^2 [4p_c - t_c(1-\lambda_a)\lambda_r](1-\lambda_a)\lambda_r}{8p_z} - \left(\alpha_c - p_c - \frac{\gamma \bar{q} \kappa \lambda_a \lambda_r}{\lambda_u} \right) \lambda_u \right] \nu & \text{if } \lambda_a < \lambda_a^{X|M} \\ 0 & \text{if } \lambda_a = \lambda_a^{X|M} \\ \left[\left(\alpha_c - p_c - \frac{\gamma \bar{q} \kappa \lambda_a \lambda_r}{\lambda_u} \right) \lambda_u - \frac{\bar{q}^2 \kappa^2 [4p_c - t_c(1-\lambda_a)\lambda_r](1-\lambda_a)\lambda_r}{8p_z} \right] \nu & \text{if } \lambda_a > \lambda_a^{X|M} \end{cases} \tag{3.38}$$

where

$$\lambda_a^{X|M} = 1 - \frac{2\bar{q}\kappa p_c - 4\gamma p_z}{\bar{q}\kappa t_c \lambda_r} + \frac{2p_c}{t_c \lambda_r} \sqrt{\left(1 - \frac{2\gamma p_z (2p_c - t_c \lambda_r)}{\bar{q}\kappa p_c^2} + \frac{4\gamma^2 p_z^2}{\bar{q}^2 \kappa^2 p_c^2} - \frac{2(\alpha_c - p_c) p_z t_c \lambda_u}{\bar{q}^2 \kappa^2 p_c^2} \right)} > \tilde{\lambda}_a \tag{3.39}$$

is the alternative-conventional distribution for which the region is self-reliant in conventional goods.

As illustrated by Figure 3.8.3, the impact of farming conversion on inter-regional flows depends on the trade status of the region : if the region is exporter, promoting alternative farming leads to decrease the trade flows since less farmers in the conventional activity is equivalent to less regional production (Equation (3.38.1)). On the contrary, if the region is importer, raising the share of alternative farming would widen the gap between the regional supply and the demand, inducing a rise in inter-regional trade flows (Equation (3.38.3)).

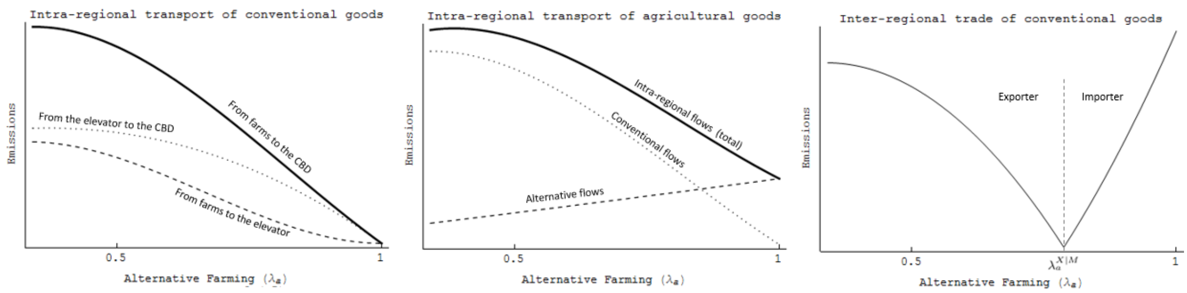

Figure 3.8 – *GHG emissions from food transportation*

Emissions from food delivery We finally convert all these flows (expressed in weight×distance) into emissions. Let e_{ih}, e_{bh} and e_t be the emission factors associated with individual haulage, bundling haulage, and inter-regional trade flows respectively. Consistently with the reality, we further assume that the transport modes used for consolidated shipments and inter-regional trade are less emission-intensive than that used for individual transportation (i.e. $e_{bh} < e_{ih}$ and $e_t < e_{ih}$). Using (3.34)–(3.38), the total emissions stemming from food transportation are :

$$E_T(\lambda_a) = e_{ih}[T_a(\lambda_a) + T_c^{x\rightarrow\hat{x}}(\lambda_a)] + e_{bh}T_c^{\hat{x}\rightarrow CBD}(\lambda_a) + e_t\frac{T_c^{Trade}(\lambda_a)}{2} \quad (3.40)$$

3.5.3 Emissions from the regional food supply chain

Emissions and agricultural pattern Combining (3.33) and (3.40), we finally obtain the total emissions stemming from the regional food supply system. For the sake of readability, its expression has been reported in Appendix E and we only discuss its graphical representation provided in Figure 3.9.

As illustrated by the graphs, fostering alternative farming could alternately induce less or more emissions at the regional scale. The first graph illustrates the case where emissions from inter-regional trade are negligible. Under this condition, the emissions

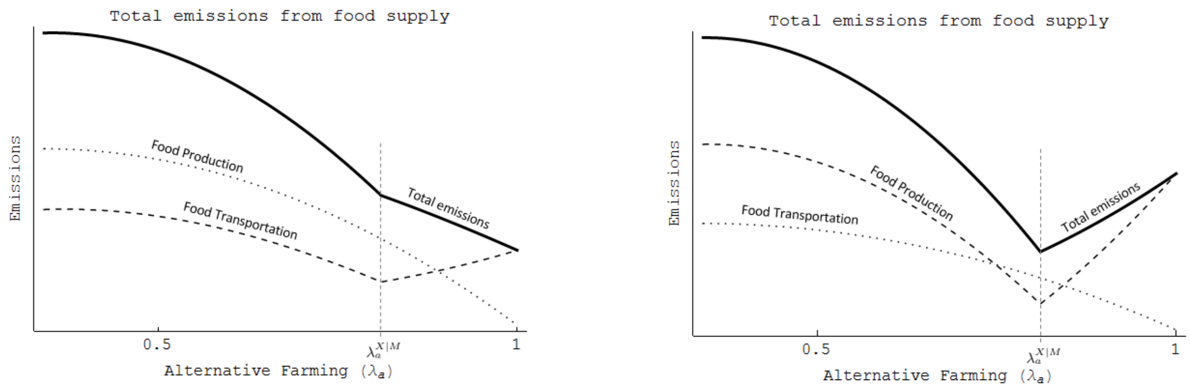

Figure 3.9 – *Total GHG emissions from the regional food supply*

due to conventional goods imports are more than compensated by the cut in emissions stemming from the lower use of synthetic fertilizer, so that the development of alternative farming always leads to a decrease in GHG emissions (Fig. 3.9.1). By contrast, if trade in conventional goods accounts for a significant part in emissions, the region is wise to limit inter-regional flows and even tend toward self-reliance. As a consequence, promoting alternative farming would induce lower emissions as long as the region is exporter in conventional goods (Fig. 3.9.2). In this situation, fostering the development of alternative farming so as to improve the regional welfare induces a concomitant cut in GHG emissions only provided that $\lambda_a^* < \lambda_a^o < \lambda_a^{X|M}$.

Emissions and urbanization   As regards to the impact of urbanization, we can show that emissions are always increasing with the size of the urban population when the region is importer, and can either increase or decrease otherwise. The effect of λ_u on emissions is twofold, playing both on intra-regional flows through the extent of the urban area, and on inter-regional trade through a demand effect. Hence, comparing the emissions of two exporting regions hosting a city of different size, the impact of alternative farming development is not clear ; on the hand, it would increase the emissions due to intra-regional flows to a greater extent in the most-urbanized region. On the other hand, the emissions stemming from inter-regional trade would also decrease more significantly in this region. The total effect is thus always conditional upon the relative importance of these two variations.

3.6 Assessing the impact of an energy price rising.

We finally use our model to evaluate the effects of a rise in energy prices on the regional farming pattern at the equilibrium. To do so, we assume that such an increase can affect both the fertilizer price (p_z) and the transportation costs (t_c and t_a). Moreover, we suppose that technology is given, so that farmers can neither avoid nor lessen the impact of the increase in energy prices by changing their production behavior.

3.6.1 The impact of a fertilizer price rising

Suppose that the energy price rising leads to increase the fertilizer price (p_z). Using the results from Section 1 and 2, a basic comparative static analysis allows to draw the implications on the equilibrium farming pattern.

Assuming first that $\bar{q} > \frac{2p_z}{p_c\kappa}$, we know from (3.15) that farmers distribute themselves between alternative production, intensive conventional production, and synthetic-free conventional production. Starting from this farming pattern, any rise of p_z leads to an increase of λ_a^* – as π_a^* increases while π_c^* stays constant (Eqs. (3.19) and (3.20)) – and consequently, to an increase of the equilibrium value of $\hat{x}$. In the same time, as p_z rises, the equilibrium value of $\tilde{x}$ diminishes, so that the spatial extent of lands where the use of synthetic fertilizer is economically viable ($\tilde{x} - \hat{x}$) becomes smaller. Furthermore, as producing goods becomes more expensive, conventional farmers tend to lessen their use of synthetic fertilizer whatever their location (Eq. (4.13)). In the end, the regional use of fertilizer in conventional farming decreases because of the reduction of both the individual use $z^*(x)$ and the share of conventional farmers using fertilizer $\lambda_{c|_{z>0}}$.

The share of alternative farming keeps rising with p_z and achieves a maximum value when $\bar{q} = \frac{2p_z}{p_c\kappa}$. From this specific value, any further rise in p_z leads to a decrease in λ_a^*; alternative farmers convert to synthetic-free conventional production.

Proposition 6 *A rise in the synthetic fertilizer price would favor the conversion to alternative farming while transforming conventional farming from high-input to reduced-input practices.*

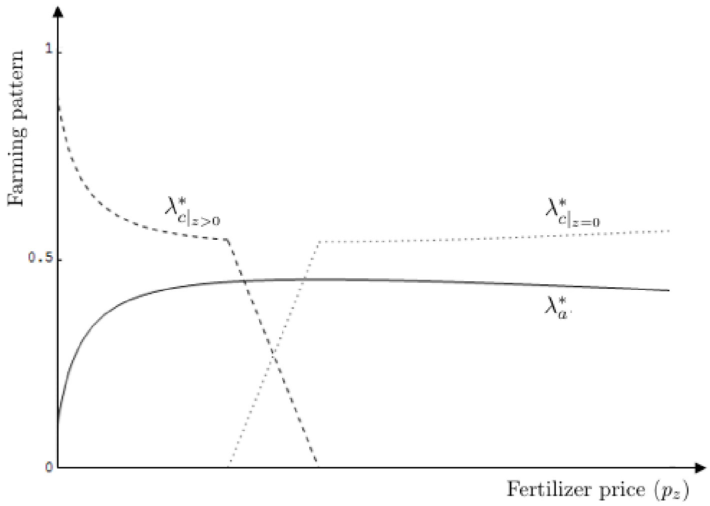

Figure 3.10 – *The impact of a fertilizer price rising on the equilibrium farming pattern.*

3.6.2 The impact of an agricultural transport cost rising

Suppose now that the energy price rising results in higher costs of agricultural transportation for both conventional and alternative farmers (i.e. t_a and t_c). According to (3.21), the equilibrium share of alternative farming is decreasing with the transportation cost t_a. Hence, any measure involving a rise in t_a induces a decrease in λ_a^*. This results stems from the fact that, even though the rise in transportation costs affects both conventional and alternative farmers, profits in conventional activity decrease less sharply than those in alternative farming.

Regarding the conventional activity, we easily show from (4.13) that farmers use less synthetic fertilizer as t_c increases ; since transporting goods becomes more expensive, conventional farmers have incentives to maintain their production $q_c^s(x)$ at a low level whatever their location x. In the same time, the share of farmers using fertilizer $\lambda_{c|_{z>0}}$ decreases as a result of the transportation cost increase. Hence, a transportation costs rising has the effect of reducing both the share of alternative agriculture and that of conventional agriculture using fertilizers. For a very sharp cost increase, agriculture in the region becomes predominantly synthetic-free conventional farming ($\lambda_{c|_{z=0}} \to 1$).

3.7 Conclusion

Feeding the population in a sustainable way has emerged as a growing concern for public authorities in most of developed countries. Although the trade-off is quite trivial, solutions to implement are not nearly that obvious. First, because current food supply chains have reached a high level of sophistication. Hence, when considering the environmental impact of food travels, the question of "how far ?" is as important as that of "how ?". Second, because of the tight economic linkages between countries, implying that addressing a sustainability issue occurring at a regional scale requires to adopt a much broader approach than a local-focused one. Finally, because one viable solution for some regions may not be generalizable to all, making it necessary to take into account economic and demographic characteristics such as the level of urbanization or the regional soils' quality.

In this chapter, we have developed a model that allows accounting for the land allocation between conventional and alternative farming systems. Focusing on the market outcome, we find that, even though urbanization may promote the development of alternative goods production through a market size effect, it is more likely to foster a growth in conventional agriculture ; given our spatial specification, the share of farmers involved in alternative agriculture tends to decline significantly, due to urban pressure and a fiercer competition on land market, making its development more likely in regions hosting an intermediate-size city. Regarding the optimality of the farming pattern at the equilibrium, we highlight that fostering the development of alternative farming always leads to a welfare improvement in low-urbanized regions. Moreover, we show that this result can be extended to more urbanized regions provided that the marginal opportunity cost of urban land remains low enough.

Finally, when looking at the environmental aspects, we find that fostering alternative farming does not necessary lead to a cut in GHG emissions. In particular, we stress that promoting alternative farming when inter-regional trade in conventional goods accounts for a large part in emissions may increase the emissions through spillover effects ; if the region is already importer in conventional goods, raising the share of alternative farming will strengthen the food dependency of the region and result in a rise in emissions due to trade.

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Appendix A : Fertilizer use in conventional farming

Appendix B.1 : Equilibrium land rent

Bid rents are derived by equating the location costs (transportation and land cost) within each area. For conventional farmers, the equilibrium land rent must solve $\frac{\partial \pi_c(x)}{\partial x} =$

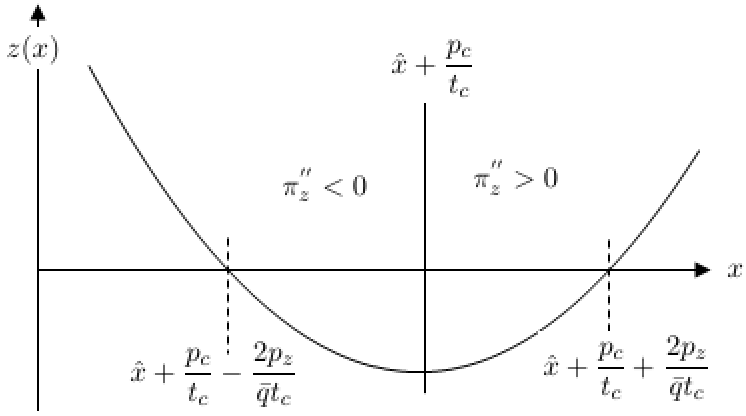

Figure 3.11 – *Variation of synthetic fertilizer use in space*

0 or, equivalently

$$\begin{cases} \dfrac{\partial R_{c|_{z>0}}(x)}{\partial x} + \dfrac{\bar{q}^2\kappa^2 t_c(pc - tc|x-\hat{x}|)}{2p_z} = 0 \text{ if } x < \tilde{x} \\ \dfrac{\partial R_{c|_{z=0}}(x)}{\partial x} + \bar{q}\kappa t_c = 0 \text{ if } x \geq \tilde{x} \end{cases}$$

As a consequence, the bid rents of conventional farmers are such that

$$\begin{cases} R_{c|_{z>0}}(x) = \bar{r}_{c|_{z>0}} - \dfrac{\bar{q}^2\kappa^2 t_c(pc - tc|x-\hat{x}|)}{2p_z} x \text{ if } x < \tilde{x} \\ R_{c|_{z=0}}(x) = \bar{r}_{c|_{z=0}} - \bar{q}\kappa t_c x \text{ if } x \geq \tilde{x} \end{cases}$$

where $\bar{r}_{c|_{z>0}}$ and $\bar{r}_{c|_{z=0}}$ are constants. Similarly, the equilibrium land rent for alternative farmers must satisfy $\frac{\partial \pi_a(x)}{\partial x} = 0$ or, equivalently, $\frac{\partial R_a(x)}{\partial x} + \bar{q}\kappa t_a = 0$, which solution is $R_a(x) = \bar{r}_a - \bar{q}barq\kappa t_a x$, where $\bar{r}_a$ is a constant. Assuming that $R_a(x) > R_{c|_{z>0}}(x)$ for $x \in [0; \hat{x}[$ the (right-hand side) conventional farmers locate in the land strip $]\hat{x}, \bar{x}]$ where $\hat{x}$ is the boundary between alternative and conventional fields, and $\bar{x} = \lambda_u/(2\delta)$ is the region limit, whereas alternative farmers locate in $]\bar{x}_u, \hat{x}]$. Because the opportunity cost of land is equal to zero, the land rent at the region limit is zero, i.e. $R_c^*(\bar{x}) = 0$. This implies that $\bar{r}_{c|_{z=0}} = \bar{q}\kappa t_c \bar{x}$.

Land rents of conventional farmers using synthetic fertilizer and those who do not use fertilizer must be equal at $\tilde{x}$ (i.e., $R_{c|_{z>0}}(\tilde{x}) = R_{c|_{z=0}}(\tilde{x})$), so that $\bar{r}_{c|_{z>0}} = \bar{q}\kappa t_c(\bar{x} - \tilde{x}) + \frac{\bar{q}^2\kappa^2 t_c \tilde{x}\left[p_c - t_c\left(\frac{\tilde{x}}{2} - \hat{x}\right)\right]}{2p_z}$. In the same way, land rents between conventional farmers and alternative farmers must be equal at $\hat{x}$ (i.e., $R_a(\hat{x}) = R_{cz}(\hat{x})$), so that $\bar{r}_a = \bar{q}\kappa t_a \hat{x} + \bar{q}\kappa t_c(\bar{x} - \tilde{x}) + \frac{\bar{q}^2\kappa^2 t_c[2p_c - t_c(\tilde{x} - \hat{x})](\tilde{x} - \hat{x})}{4p_z}$.

As for urban households, they choose their location so as to maximize their utility under the budget constraint. Because of the fixed lot size assumption, the value of the consumption of the non-spatial goods $q_c p_c + q_a p_a + Q$ at the residential equilibrium is the same regardless of the urban worker's location. Denoting by t_u the commuting cost, the equilibrium urban land rent must solve $\frac{\partial V_u(x)}{\partial x} = 0$ or, equivalently, $\frac{\partial R_u(x)}{\partial x} + \delta t_u = 0$, which solution is $R_u(x) = \bar{r}_u - \delta t_u x$, where $\bar{r}_u$ is a constant. At the equilibrium, urban and agricultural land rents must be equal at the city limit $\bar{x}_u$, leading to $\bar{r}_u = \delta t_u \bar{x}_u + R_a(\bar{x}_u)$. As a result, the equilibrium land rent in the region is given by :

$$R^*(x) = \begin{cases} R^*_u(x) = \delta t_u|\bar{x}_u - x| + t_a(\hat{x} - \bar{x}_u)\bar{q}\kappa + \dfrac{\bar{q}^2\kappa^2(p_c - t_c\hat{x})^2}{4p_z} + p_z - (p_c - t_c\bar{x})\bar{q}\kappa & \text{if } 0 < x \leq \bar{x}_u \\ R^*_a(x) = t_a(\hat{x} - x)\bar{q}\kappa + \dfrac{\bar{q}^2\kappa^2(p_c - t_c\hat{x})^2}{4p_z} + p_z - (p_c - t_c\bar{x})\bar{q}\kappa & \text{if } \bar{x}_u < x \leq \hat{x} \\ R^*_{c|_{z>0}}(x) = \dfrac{\bar{q}^2\kappa^2(p_c - t_c x)^2}{4p_z} + p_z - (p_c - t_c\bar{x})\bar{q}\kappa & \text{if } \hat{x} < x \leq \tilde{x} \\ R^*_{c|_{z=0}}(x) = t_c|\bar{x} - x|\bar{q}\kappa & \text{if } \tilde{x} < x < \bar{x} \end{cases}$$

Appendix B.2 : Intra-regional spatial patterns

Let $x_{u|a}$, $x_{u|c}$ and $x_{a|c}$ be the abscissa of the intersection point between $R^*_u(x)$ and $R^*_a(x)$, $R^*_u(x)$ and $R^*_{c|_{z>0}}(x)$, and $R^*_a(x)$ and $R^*_{c|_{z>0}}(x)$, respectively. Since $R^*_{c|_{z>0}}(x)$ is a convex function of x, alternative and conventional bid rents can intersect once or twice. Hence, two spatial configurations can occur :

i) Alternative farming develops near the urban fringe which occurs if $R^*_{c|_{z>0}}(0) < R^*_a(0)$ (implying that $R^*_a(x)$ and $R^*_{c|_{z>0}}(x)$ intersect once) or, if the first intersection between $R^*_a(x)$ and $R^*_{c|_{z>0}}(x)$ occurs before the intersection between $R^*_u(x)$ and $R^*_a(x)$ (i.e. $x^1_{a|c} < x_{u|a} < x^2_{a|c}$).

ii) The land allocated to alternative farming is enclosed in the conventional farming area which occurs if $R^*_{c|_{z>0}}(0) > R^*_a(0)$ and $x_{u|a} < x^1_{a|c} < x^2_{a|c}$.

From these conditions, we draw that alternative farming takes place at the city boundary provided that $x^1_{a|c} < x_{u|a} < x^2_{a|c}$ which leads $\lambda_a < \frac{4(2p_z t_a - p_c\bar{q}\kappa t_c)}{\bar{q}\kappa t_c^2 \lambda_r}$.

Profits in alternative and conventional farming are given by :

$$\pi_a^* = \left[p_a^* - t_a\left(\frac{\lambda_u}{2\delta} + \frac{\lambda_a\lambda_r}{2}\right) - \frac{(\bar{q}\kappa p_c - 2p_z)^2}{4\bar{q}\kappa p_z} - \frac{(1-\lambda_a)\lambda_r}{2}t_c\right]\bar{q}\kappa$$

$$\pi_c^* = \left[p_c^* - t_c\frac{(1-\lambda_a)\lambda_r}{2}\right]\bar{q}\kappa$$

with $\frac{\partial\pi_a^*}{\partial\lambda_a} < 0$ and $\frac{\partial\pi_c^*}{\partial\lambda_a} > 0$. At the equilibrium, the farmers distribution (λ_a^*) is such that profits in conventional and alternative farming are the same. Solving $\pi_a^* = \pi_c^*$ leads to :

$$\lambda_a^* = \frac{\alpha_a - \gamma(\alpha_c - p_c) - t_a\frac{\lambda_u}{2\delta} - \left(\frac{p_z}{\bar{q}\kappa} + \frac{p_c^2\bar{q}\kappa}{4p_z}\right)}{\lambda_r\left(\bar{q}\kappa\frac{1-\gamma^2}{\lambda_u} + \frac{t_a}{2}\right)} \tag{3.41}$$

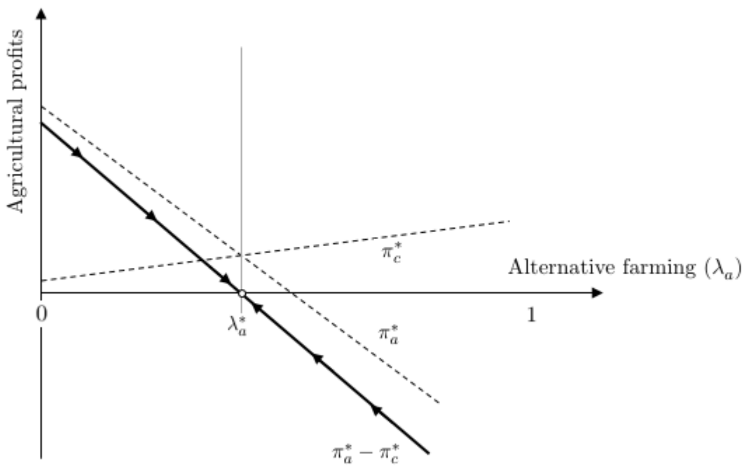

Figure 3.12 – *Net incomes differential and equilibrium*

From (3.41), we derive the conditions on parameter t_a for λ_a^* to be positive and lower than 1 :

$$\begin{cases} \lambda_a^* > 0 \quad \text{if} \quad t_a < \bar{t}_a \equiv \dfrac{\alpha_a - (\alpha_c - p_c)\gamma - \left(\frac{p_z}{\bar{q}\kappa} + \frac{p_c^2\bar{q}\kappa}{4p_z}\right)}{\frac{\lambda_u}{2\delta}} \\ \lambda_a^* < 1 \quad \text{if} \quad t_a > \underline{t}_a \equiv \dfrac{\alpha_a - (\alpha_c - p_c)\gamma - \left(\frac{p_z}{\bar{q}\kappa} + \frac{p_c^2\bar{q}\kappa}{4p_z} + \frac{\bar{q}\kappa(1-\gamma^2)\lambda_r}{\lambda_u}\right)}{\frac{\lambda_r}{2} + \frac{\lambda_u}{2\delta}} \end{cases} \tag{3.42}$$

Appendix D : The optimal farming pattern

Solving $\frac{\partial SW}{\partial \lambda_a} = 0$ for λ_a, the optimal share of farmers involved in alternative farming is given by :

$$\lambda_a^o = \frac{\alpha_a - \gamma(\alpha_c - p_c)(2-\gamma^2) - t_a \frac{\lambda_u}{2\delta} - \left(\frac{p_z}{\bar{q}\kappa} + \frac{p_c^2 \bar{q}\kappa}{4p_z}\right) + t_c\left(\frac{\lambda_u}{2\delta} + \frac{\lambda_r}{2}\right)}{\lambda_r\left(\bar{q}\kappa\frac{(1-\gamma^2)^2}{\lambda_u} + t_a\right)} \tag{3.43}$$

Let denote by N^o and D^o the numerator and the denominator of λ_a^o. Since $D^o > 0$, we posit $N^o > 0$, as the pertinent range for the study of λ_a^o is $[0;1]$. Recalling $t_a > t_c$, we get from (3.43) $\frac{\partial N^o}{\partial \lambda_u} < 0$, $\frac{\partial D^o}{\partial \lambda_u} > 0$, $\frac{\partial^2 N^o}{\partial \lambda_u^2} = 0$ and $\frac{\partial^2 D^o}{\partial \lambda_u^2} < 0$ so that

$$\frac{\partial^2 \lambda_a^o}{\partial \lambda_u^2} = \frac{\partial^2 D^o}{\partial \lambda_u^2} \times N^o + 2 \times \frac{\partial D^o}{\partial \lambda_u} \times \frac{\partial N^o}{\partial \lambda_u} + \frac{\partial^2 N^o}{\partial \lambda_u^2} \times D^o < 0 \tag{3.44}$$

As for the equilibrium, the optimal share of alternative farming is concavely related to the urban population' size.

Appendix E : The GHG emissions from the regional food supply chain

Combining (3.33) and (3.40), the total GHG emissions are given by :

$$\begin{aligned} E(\lambda_a) =& e_a\left(\bar{q}\kappa\lambda_a\lambda_r\right) + e_c\left[\frac{\bar{q}^2\kappa^2}{p_z}\left(p_c - \frac{t_c(1-\lambda_a)\lambda_r}{4}\right)\frac{(1-\lambda_a)\lambda_r}{2}\right] + \\ & e_{ih}\left[\bar{q}\kappa\left(\frac{\lambda_a^2\lambda_r^2}{4} + \bar{q}\kappa\left(\frac{p_c}{2p_z} - \frac{t_c(1-\lambda_a)\lambda_r}{6p_z}\right)\frac{(1-\lambda_a)^2\lambda_r^2}{4}\right) + \frac{\lambda_u}{2\delta}\bar{q}\kappa\lambda_a\lambda_r\right] + \\ & e_{bh}\left[\frac{\bar{q}^2\kappa^2}{p_z}\left(p_c - \frac{t_c(1-\lambda_a)\lambda_r}{4}\right)\frac{(1-\lambda_a)\lambda_r}{2}\left(\frac{\lambda_a\lambda_r}{2} + \frac{\lambda_u}{2\delta}\right)\right] + \\ & \frac{e_t}{2}\left|\frac{\bar{q}^2\kappa^2}{p_z}\left(p_c - \frac{t_c(1-\lambda_a)\lambda_r}{4}\right)\frac{(1-\lambda_a)\lambda_r}{2} - (\alpha_c - p_c)\lambda_u + \gamma\bar{q}\kappa\lambda_a\lambda_r\right|\nu \end{aligned} \tag{3.45}$$

with $\lambda_a > \tilde{\lambda}_a$.

where

$$\lambda_a^{\hat{x}\to CBD} = \frac{2}{3} + \frac{4}{3\lambda_r}\left(\sqrt{\left(\frac{p_c}{t_c} - \frac{\delta\lambda_r + \lambda_u}{4\delta}\right)^2 + \frac{p_c(\delta\lambda_r + \lambda_u)}{4t_c\delta}} - \frac{p_c}{t_c}\right)$$

and

$$\lambda_a^{X|M} = 1 - \frac{2\bar{q}\kappa p_c - 4\gamma p_z}{\bar{q}\kappa t_c\lambda_r} + \frac{2p_c}{t_c\lambda_r}\sqrt{\left(1 - \frac{2\gamma p_z(2p_c - t_c\lambda_r)}{\bar{q}\kappa p_c^2} + \frac{4\gamma^2 p_z^2}{\bar{q}^2\kappa^2 p_c^2} - \frac{2(\alpha_c - p_c)p_z t_c\lambda_u}{\bar{q}^2\kappa^2 p_c^2}\right)}$$

	T_a	$T_c^{x\to\hat{x}}$	$T_c^{\hat{x}\to CBD}$	T^{Trade}
λ_a	$\uparrow$	$\downarrow$	$\uparrow$ if $\lambda_a < \lambda_a^{\hat{x}\to CBD}$ $\downarrow$ if $\lambda_a > \lambda_a^{\hat{x}\to CBD}$	$\downarrow$ if $\lambda_a < \lambda_a^{X\vert M}$ $\uparrow$ if $\lambda_a > \lambda_a^{X\vert M}$
λ_a^2	+	+	-	-
λ_u	+	0	+	+
$\lambda_a\lambda_u$	+	0	-	0

Tableau 3.1 – *Variations of transportation flows with respect to alternative farming share (λ_a) and urbanization (λ_u).*

λ_a	$\lambda_a^{\hat{x}\to CBD}$	$\lambda_a^{X\vert M}$	
T_a	+	+	+
$T_c^{x\to\hat{x}}$	$-$	$-$	$-$
$T_c^{\hat{x}\to CBD}$	+	$-$	$-$
T^{Trade}	$-$	$-$	+
E_T	$-$	$-$	+

Tableau 3.2 – *Variations of transportation flows with respect to alternative farming share (λ_a) for low-urbanized regions*

Appendix F : Endogenizing the regional grain elevator location

For simplicity, we have assumed that the grain elevator was located at the boundary between alternative and conventional areas $\hat{x}$. In this appendix, we release this assumption and we briefly discuss the implications on the equilibrium pattern.

Suppose that the transportation in the conventional farming is organized by a monopolistic logistics firm. This firm charges farmers for transporting goods from their farm to the grain elevator, and incurs a cost of ηt_c by unit of product and distance to ship the collected production from the elevator to the CBD. Hence, denoting by x^c the location of the grain elevator, the profit of this firm is given by :

$$\pi_L = t_c \int_{\hat{x}}^{\bar{x}} |x - x^c| dx - \eta t_c x^c \int_{\hat{x}}^{\bar{x}} q_c^{s^*}(x)|x - \hat{x}|dx \tag{3.46}$$

λ_a	$\lambda_a^{X\vert M}$	$\lambda_a^{\hat{x}\to CBD}$	
T_a	$+$	$+$	$+$
$T_c^{x\to\hat{x}}$	$-$	$-$	$-$
$T_c^{\hat{x}\to CBD}$	$+$	$+$	$-$
T^{Trade}	$-$	$+$	$+$
E_T	$-$	$+$	$+$

Tableau 3.3 – *Variations of transportation flows with respect to alternative farming share (λ_a) for high-urbanized regions*

The firm chooses the location of the elevator so as to maximize its profit (3.46). Substituting $\hat{x}$ and $\bar{x}$ by their respective expression and solving $\dfrac{\partial \pi_L}{\partial x^c} = 0$ for x^c yields :

$$x^c = \hat{x} - \left(\frac{p_c + \frac{2p_z}{\bar{q}^2\kappa^2\eta}}{2t_c} + \frac{(3\lambda_a - 1)\lambda_r + \frac{2\lambda_u}{\delta}}{8} \right) < \hat{x} \tag{3.47}$$

From (3.47), we show that endogenizing the location of the elevator leads to decrease the profits of conventional farmers, as the distance they have to cover to bring their production to the elevator is larger than $|x - \hat{x}|$.

Regarding the equilibrium farming pattern, this new location may have two major consequences. First, since profits in the conventional farming are lower for every location x in the region, we might expect a higher equilibrium share of alternative farming whatever the set of parameters' values. Second, as the cost of transportation in conventional farming now depends on the share of alternative farming λ_a, the profit differential between alternative and conventional farming is no longer linear. Indeed, carrying on the calculations for this new elevator' location, we can show that profits in conventional farming are now decreasing with the share of alternative farming while those of alternative farmers are concavely related with λ_a. Consequently, the profit differential is concave and there can be either one, two or no equilibrium. Moreover, in the "two equilibria" case, only the second one is stable.

Chapitre 4

Direct Selling Farming Under Varying Spatial Externalities

In this chapter, we develop a spatial economic model which takes into account the externality of urban pollution on agricultural yields. We study how the proximity to cities affects the decision of farmers to enter the direct selling market and therefore food diversity, as well as the quality of the agricultural goods supplied to consumers.
We highlight that direct selling farming is more likely to provide a wide range of varieties when located in a region hosting an intermediate-size city, the exposure to varying spatial externalities implying that, in highly urban crowded regions, only the most productive farmers can stay on direct selling market. Additionally, we find that the greater the variations of urban pollution over space, the smaller the opportunities for farmers to engage in direct selling, and the larger the quality differentiation between varieties. We finally show that the market equilibrium always leads to a number of direct selling farmers which is too low to fully satisfy urban households, but too much high from the farmers standpoint.

Keywords : Urban pollution, Peri-urban Farming, Land allocation

JEL Classification : F12 ; Q10 ; Q54 ; Q56 ; R12

4.1 Introduction

In the present context of rapid worldwide urbanization, feeding the cities in the ”Global North” is drawing a substantial public awareness [Morgan, 2014]. Evidence of this trend is found in the growing policy support for sustainable food supply chains, combining geographical proximity, reduced-reliance on synthetic inputs, and food quality and traceability. In the US as in several European countries, national programs for sustainable development now often address urban food supply, with a strong emphasis on building local alternatives (see notably USDA [2014] for the US, Kneafsey et al. [2013] for the EU, or DGAL [2011] for France). Initiatives of cities such as New York, Montreal, London, or Paris are among the many examples illustrating that urban agriculture is gradually gaining ground.

However, when considering the impact of pollution stemming from urban activities on agricultural yields, benefits local food production can be seriously questioned. As now shown by recent research, urban pollution adversely affect agriculture in many complex ways, causing reduced yield and quality in crops exposed to pollutants. Avnery et al. [2011] notably estimate that reductions of global yields due to ozone exposition could reach 2% for maize, 3.9 to 15% for wheat, and 8.5 to 14% for soybean. Still focusing on ozone pollution, Holland et al. [2006] show that the directly-induced economic consequences are far from being negligible, establishing the losses for Europe in 2000 to 6.7 billion Euros.

In addition, undesirable environmental impacts can be expected. From a transportation-related emissions standpoint first, yields losses are likely to create local significant imbalances between supply and demand and may, as a result, lead some regions to source food from remote locations. Second, if farmers located near the largest cities decide to use more synthetic inputs in order to compensate yields’ losses, additional negative impacts on environment and goods quality have to be considered.

In this chapter, we investigate whether direct selling farming can develop in the neighboring of highly-crowded cities. Even though the literature on periurban agriculture is quite extensive, covering diverse topics such as the impacts of sub-urbanization on agriculture [Berry, 1978], neighboring conflicts [Wu et al., 2011], or land value impacts of urbanization (Anderson and West [2006] ; Plantinga and Miller [2001]), there is to our knowledge no theoretical formalization of the issue we propose to handle. Besides, in the existing literature, neighborhood effects have mainly been analyzed from the environmental amenities standpoint, most of the works focusing on the impacts of agriculture on cities but rarely the reverse.

The objective of this chapter is twofold. First, we attempt to establish the required conditions under which direct selling farming can develop in the periphery of large-size cities. Second, we try to determine whether the market leads to less or more variety than the optimal outcome.

Formally, we explore these questions by developing a spatial economic model where farmers can choose between two types of agricultural goods : conventional goods and direct direct selling goods. The conventional products are assumed to be homogeneous. They are grown under perfect competition, the price of these goods being exogenously fixed and given by the equilibrium on the global market. The direct selling goods are both horizontally and vertically differentiated. Farmers engaged in this sector operate on a local market and face lower competition. They have the opportunity to set their price in an optimizing way. In order to account for these features, we suppose monopolistic competition for direct selling farming.

The framework used in this chapter is close from that of Melitz [2003] in the sense that farmers are heterogeneous in their productivity ; they face spatial externalities that depend on the size of the city and that induce different productivity levels according to their location within the region. As for the spatial aspect, the model follows the pioneering contribution of Alonso [1964]. We consider a monocentric city model in which urban pollution acts as a distance-dependent externality.

As in standard non-spatial model displaying monopolistic competition, we can show that the profit of farmers involved in direct selling rises as the size of the population increases. However, when accounting for the spatial externalities related to the city size, the relationship and therefore, the incentives for farmers to engage in direct selling farming, become more complex. Notably, we show that the exposure to varying spatial externalities induces that, in highly urban crowded regions, only the most productive farmers can stay on direct selling market. Additionally, we highlight that the greater the variations of urban pollution over space, the smaller the opportunities for farmers to engage in direct selling, and the larger the quality differentiation between varieties. As regards to the market outcome, we find that direct selling farming is more likely to provide a wide range of varieties when located in a region hosting an intermediate-size city. Lastly, from a welfare standpoint, we derive that the market always provides too few varieties, this result being all the more compelling for highly urban crowded regions.

The chapter proceeds as follows. Section 4.2 presents the model. In Section 4.3, we determine the short-run equilibrium and we deliver some findings on the way spatial externalities affect both the direct selling and the land markets. Section 4.4 presents the long-run equilibrium and provides some insights on the relationship between goods variety, goods quality, and the city size. We finally discuss the conditions ensuring that fostering direct selling development near cities leads to a welfare improvement from the urban consumers standpoint in Section 4.5.

4.2 The framework

Consider an economy formed by a total population exogenously split into urban and rural households, and two sectors : a perfectly competitive sector providing a homogeneous aggregate good, and an agricultural sector where farmers can choose between direct selling and conventional market. Agricultural goods are produced using labor, land, and fertilizer. Conventional farmers produce a homogeneous good under perfect competition while farmers engaged in direct selling operate under monopolistic competition and provide a quality-differentiated good through a short supply chain.

4.2.1 The spatial structure

The economy is formally described by a one-dimensional space made of an urban area including a CBD and urban households' lots, and a rural area where farmers live and produce agricultural goods. Natural amenities are homogeneously supplied within the region. Distances and locations are denoted by x and measured from the CBD located in the center of the region. Without loss of generality, we focus on the right-hand side of the region, the left-hand side being perfectly symmetrical.

The urban area is entirely used for residential purposes. Urban inhabitants are assumed to be uniformly distributed across the city. They inelastically consume a residential plot of fixed size $\frac{1}{\delta}$, δ capturing the urban density (with $\delta > 1$). Letting λ_u be the size of the urban population, we get the right endpoint of the city given by

$$\bar{x}_u = \frac{\lambda_u}{2\delta} \tag{4.1}$$

Farmers live and produce in rural areas located at the periphery of the city. Then, assuming that each farmer uses one unit of land to produce, the right endpoint of the region is given by :

$$\bar{x} = \bar{x}_u + \frac{\lambda_r^s + \lambda_r^c}{2}. \tag{4.2}$$

where λ_r^s and λ_r^c stand for the number of direct selling farmers and conventional farmers, respectively.

4.2.2 Preferences and demand

In order to capture both the consumer's taste for variety as in the Spence-Dixit-Stiglitz framework, and the consumers' relative valuation of goods' quality, we use the utility specification of Gaigne and Larue [2013]. Consumers share the same Cobb-Douglas preferences for two types of goods ; a homogeneous aggregate good M (*chosen* *as the numéraire*) and agricultural differentiated products indexed by v [1] :

$$U(Q, M) = Q^{\alpha} M^{1-\alpha} \tag{4.3}$$

with

$$Q = \left(\int_1^{\lambda_r^s} \theta(v)^{\beta} q(v)^{\frac{\sigma-1}{\sigma}} dv \right)^{\frac{\sigma}{\sigma-1}} \tag{4.4}$$

and where $q(v)$ and $\theta(v)$ stand respectively for the quantity and the quality of the variety v, and σ represents the elasticity of substitution between two varieties. Utility is increasing with respect to the range of varieties λ_r^s and the quality. Besides, we assume $0 < \beta < 1$ which implies that the marginal utility of improving the quality of agricultural good is decreasing.

Goods quality The goods supplied by direct selling farmers differ in quality $\theta(v)$. This quality, perceived by the consumers, is assumed to be directly linked to the quantity of inputs used in the production and can be described as follows :

$$\theta(v) = \frac{\bar{\theta}}{z(v)} \tag{4.5}$$

where $\bar{\theta}$ is the maximum quality level and $z(v)$ the amount of input used to produce the variety v.

Demand Consumers live in the urban area and work in the CBD. They bear urban costs, given by the sum of the commuting costs and the land rent. Letting t_u and R be the per-mile commuting cost and the land rent respectively, these costs are such that

$$UC(x) = t_u x + \frac{R(x)}{\delta} \tag{4.6}$$

Then, denoting by P the price index for the range of agricultural goods supplied in the region and w_u the urban wage, the budget constraint for any urban dweller is given

1. For simplicity, we assume that farmers consume a fraction of their own production and supply the remaining.

by :

$$PQ + M = w_u - UC(x) \tag{4.7}$$

The individual demand for the composite good and the aggregate demand for the agricultural goods are derived from the maximization of the utility (4.3) subject to the budget constraint (4.7) :

$$M^d = \frac{1-\alpha}{\alpha}\bar{w}_u(x) \tag{4.8}$$

$$Q^d = \frac{\bar{w}_u(x)}{P} \tag{4.9}$$

where $\bar{w}_u(x) \equiv \alpha(w_u - UC(x))$ is the share of the urban net income available for direct selling goods consumption. Finally, denoting by $p(v)$ the price of the variety v of agricultural goods and maximizing CES sub-utilities subject to the budget constraint $\bar{w}_u = \int_1^{\lambda_r^s} p(v)q(v)dv$ leads to the following demand function for the variety v :

$$q^d(v) = \theta(v)^{\sigma\beta}p(v)^{-\sigma}P^{\sigma-1}\lambda_u\bar{w}_u \tag{4.10}$$

with

$$P = \left(\int_1^{\lambda_r^s} \theta(v)^{\sigma\beta}p(v)^{1-\sigma}dv\right)^{\frac{1}{1-\sigma}} \tag{4.11}$$

4.2.3 The direct selling sector

Spatial externalities and production Farmers produce a unique variety v using labor, one unit of land and an amount $z(v)$ of input. They have to carry their production to the central market located in the CBD, incurring costs that are increasing with the distance. These costs – *referred to as opportunity cost of transportation $t(x)$ in the following*– can be seen as units of working-time required for shipping goods to the market and that cannot be allocated to the production. The net labor supply of any farmer is then obtained by subtracting transportation time from his total time available[2]. Transportation therefore affects the individual production level through a

2. Note that this specification where producers allocate their working time between goods production and another related activity is used by Lucas and Moll [2014]. In their model, firms allocate a fraction of time to production while the remaining part is used for innovative activities.

reduction of the time spent in growing agricultural goods : the farthest from the city center, the lower the time available to grow crops, and the fewer the production. It creates an incentive for farmers to locate close to the urban fringe and captures thus, the opportunity cost of remoteness from the city center.

Fields located in the land strip $]\bar{x}_u, \bar{x}]$ are exposed to urban pollution, causing losses in yields that are proportional to the level of pollution encountered in each location. The source of this pollution is located in the CBD. The pollution intensity $h(x, \lambda_u)$ is supposed to be increasing with the level of urban activities ($h_{\lambda_u} > 0$) but decreasing with respect to the distance from the CBD ($h(0, \lambda_u) > 0$ and $h_x < 0$). Moreover, we suppose that the level of pollution encountered in the region in the absence of urban population is zero ($h(x, 0) = 0$), and that the urban population size does not interact with the spatial diffusion of the pollution ($h_{x,\lambda_u} = 0$).

The technology The production function accounts for the effects of both the transportation and the pollution on the total output. Denoting by $\bar{q}$ the natural ability of soils to grow crops in the region, we define the individual production for the agricultural variety v as :

$$q^s(v, x, \lambda_u) = \bar{q}z(v) \times E(t(x), h(x, \lambda_u)) \tag{4.12}$$

where $0 < E(t(x), h(x, \lambda_u)) < 1$ stands for the agricultural productivity coefficient at x, which value is influenced by the total space-related effect of location on the production level. Formally, it encompasses the pollution externality cost and the opportunity cost of transportation, that operate in opposite directions as the distance from the city center increases. $E(t(x), h(x, \lambda_u))$ is decreasing with its two arguments $t(x)$ and $h(x, \lambda_u)$. Moreover, we posit $E(0, 0) = 1$ meaning that, without spatial externalities, the agricultural production is given by the combination of soil quality and input use. In order to keep the discussion as broad as possible, we dot not specify the shape of $E(t(x), h(x, \lambda_u))$. We only assume that the function is additively separable, which implies that there is no correlation between the yields losses stemming from the pollution and transportation time ($E_{t,h} = 0$).

The marginal productivity of the input is increasing with respect to the quality of the land and the agricultural productivity coefficient. Rewriting (4.12) so as to isolate z and setting $\bar{q} = 1$ without loss of generality, yields the quantity of inputs used by the farmer located at x and producing the variety v :

$$z(v, x, \lambda_u) = \frac{q^s(v)}{E(t(x), h(x, \lambda_u))} \qquad \text{with} \quad z > 0 \tag{4.13}$$

We easily verify from (4.13) that supplying a large quantity of any variety v always requires more inputs. Likewise, the use of the input is all the more intensive that the pollution externality and the opportunity cost of remoteness are high. This offsetting effect lies in the specification of the production function which allows farmers to compensate some of the yields losses due to the space-related factors by using more input.

Productivity, distance and city size. Differentiating $E(t(x), h(x, \lambda_u))$ with respect to the distance from the city center x yields :

$$\begin{aligned} E_x \equiv \frac{\partial E(t(x), h(x, \lambda_u))}{\partial x} &= \frac{\partial E(t(x), h(x, \lambda_u))}{\partial t(x)} \frac{\partial t(x)}{\partial x} + \frac{\partial E(t(x), h(x, \lambda_u))}{\partial h(x, \lambda_u)} \frac{\partial h(x, \lambda_u)}{\partial x} \\ &= E_t t'(x) + E_h h_x \end{aligned} \tag{4.14}$$

Eq.(4.14) displays the comparative effect of transportation and pollution. Locating near the city allows to keep a high productivity since the opportunity cost of transportation is lower but can, in the same time, diminish it because of the pollution externality. Hence, from a location to the direct neighboring one, productivity will decrease if the opportunity cost of remoteness (transportation effect $E_t t'(x)$) outweighs the losses in crop yields due to urban pollution (pollution effect $E_h h_x$), and increase otherwise.

The relationship between the spatial variation of productivity and the urban population size is given by :

$$E_{x,\lambda_u} \equiv \frac{\partial^2 E(t(x), h(x, \lambda_u))}{\partial x \partial \lambda_u} = E_{h,h} \times h_x \times h_{\lambda_u} \tag{4.15}$$

where $E_{h,h}$ is the second order impact of pollution on yields losses. It can be either positive or negative, depending on both the nature of the pollution and the type of crops considered.

The sign of (4.15) is given by the opposite sign of $E_{h,h}$: as the urban population size grows, the impact of externalities on productivity – *and therefore, the spatial heterogeneity in agricultural production* – tends to smooth over space if E is convex in h and to intensify for E concave.

For simplicity of notations, we further denote $E(t(x), h(x, \lambda_u))$ by $E(x, \lambda_u)$.

The market structure Direct selling farmers operates under monopolistic competition. They supply close substitutes and are free to enter and exit the market. They neglect their mutual strategic interdependence and act as if they were monopolists. Since each variety is produced by a single farmer, the number of differentiated goods is given by the number of farmers involved in direct selling and any variety v can therefore be identified by the location x where it is grown.

The profit of a farmer producing a direct selling variety at x is given by the receipts from his sales minus a total cost which consists of a fixed cost associated with the purchase of one unit of land, and a constant marginal cost of inputs. Hence, letting p_z and $R(x)$ be the unit cost of the input and the unit rent of land at x, we have :

$$\pi(x, \lambda_u) = \underbrace{p(x, \lambda_u) \times q(x, \lambda_u)}_{receipts} - \underbrace{[R(x) + p_z z(x, \lambda_u)]}_{\text{total cost}} \tag{4.16}$$

where $q(x, \lambda_u)$ is the Marshallian demand for the variety produced at x, obtained by plugging (4.13) into (4.5) and by substituting the resulting expression of $\theta(x, \lambda_u)$ into (4.10) :

$$q(x, \lambda_u) = \left[\bar{\theta} E(x, \lambda_u)\right]^{\frac{\sigma\beta}{1+\sigma\beta}} p(x, \lambda_u)^{-\frac{\sigma}{1+\sigma\beta}} (\lambda_u \bar{w}_u)^{\frac{1}{1+\sigma\beta}} P^{\frac{\sigma-1}{1+\sigma\beta}} \tag{4.17}$$

Each farmer sets his price so as to maximize his profit, considering that his decision has no impact on the other prices[3]. Taking the price index P as a constant and diffe-

3. The number of competitors is assumed to be large enough so that the effect of $p(x, \lambda_u)$ on P can

rentiating $\pi(x, \lambda_u)$ with respect to $p(x, \lambda_u)$, leads to the equilibrium price of the variety produced at x :

$$p(x, \lambda_u) = \frac{\sigma}{\sigma - 1 - \sigma\beta} \left(\frac{p_z}{E(x, \lambda_u)} \right) \tag{4.18}$$

where $\sigma > \frac{1}{1-\beta}$ must hold for $p(x, \lambda_u)$ to be positive.

The first element of (4.18) is the monopolistic mark-up. It includes the parameter β and increases with it, reflecting the fact that consumers value the quality of the agricultural goods. The term in parentheses represents the marginal cost of production for the variety grown at x. It increases with the unit cost of the input pz, but also with the urban pollution externatity cost and the opportunity cost of transportation, highlighting the fact that farmers partially pass on the charge of their own location costs to consumers through the productivity coefficient $E(x, \lambda_u)$.

$p(x, \lambda_u)$ and $E(x, \lambda_u)$ share similar properties regarding their variation in space. Denoting by x_a and x_b two neighboring locations such that $\bar{x}_u < x_a < x_b < \bar{x}_s$, we can consequently show that $p(x_a, \lambda_u) < p(x_b, \lambda_u)$ if and only if $E(x, \lambda_u)$ is decreasing from x_a to x_b. Hence, provided that the opportunity cost of remoteness from the city center outweighs the yields losses due to the pollution externality, the price of the variety grown at x_a will be lower than that produced at x_b.

Using Eqs (4.5) and (4.13)-(4.18) in (4.11), we obtain the price index of agricultural goods :

$$P = \left(\frac{\lambda_u \bar{w}_u}{\bar{\theta}} \right)^{\frac{\sigma\beta}{\sigma-1}} \left(\frac{\sigma p_z}{\sigma - 1 - \sigma\beta} \right)^{\frac{\sigma-1-\sigma\beta}{\sigma-1}} \left(2 \times \int_{\bar{x}_u}^{\bar{x}_s} E(x, \lambda_u)^{\epsilon} dx \right)^{-\frac{1}{\epsilon}} \tag{4.19}$$

where $\epsilon \equiv \frac{\sigma-1}{1+\sigma\beta}$ is the elasticity of the demand with respect to the direct selling price index. Observe that, in the case where spatial externalities would not be considered (i.e. $E(x, \lambda_u) = 1$ for all x) and where consumers would not value the quality of the agricultural goods ($\beta = 0$), we recover the standard Dixit–Stiglitz framework where $P = \frac{\sigma}{\sigma-1} p_z \lambda_r^{s\,\frac{1}{1-\sigma}}$.

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be disregarded.

Market share and competition   Multiplying (4.17) by (4.18), we can derive the receipts of the direct selling farmer located at x :

$$r^s(x, \lambda_u) = \frac{\lambda_u \bar{w}_u}{2\int_{\bar{x}_u}^{\bar{x}} E(x, \lambda_u)^\epsilon dx} \times E(x, \lambda_u)^\epsilon \tag{4.20}$$

where the first element is common to all the farmers involved in direct selling, while the second term is the relative location-dependent part of the receipts at x. We can then calculate the market share defined as :

$$s(x, \lambda_u) \equiv \frac{r^s(x, \lambda_u)}{2\int_{\bar{x}_u}^{\bar{x}_s} r^s(x, \lambda_u)dx} = \frac{E(x, \lambda_u)^\epsilon}{2\int_{\bar{x}_u}^{\bar{x}_s} E(x, \lambda_u)^\epsilon dx} \tag{4.21}$$

with $0 \leq s(x, \lambda_u) \leq 1$. It is readily shown that, without spatial externalities, direct selling farmers have a same market share given by $s = \frac{1}{\lambda_r^s}$. The market share varies with the distance from the city center, reflecting the fact that farmers are affected by spatial externalities at different extents :

$$s_x(x, \lambda_u) \equiv \frac{\partial s(x, \lambda_u)}{\partial x} = \frac{\epsilon E_x}{E(x, \lambda_u)} \times s(x, \lambda_u) \tag{4.22}$$

The spatial variation of the market share follows that of $E(x, \lambda_u)$; it is therefore decreasing with the distance from the CBD if the effect of the opportunity cost of transportation dominates that of the urban pollution externality, and increasing otherwise.

Since the nature of the competition on direct selling market depends on both the number of farmers involved on the market (supply-side) and the urban population size (demand-side), it is interesting to examine how the market share varies with λ_r^s and λ_u. For simplicity of notation, the market share of the farmers located at both edges of the direct selling area $s(\bar{x}_u, \lambda_u)$ and $s(\bar{x}_s, \lambda_u)$ will be denoted thereafter as $\bar{s}_u$ and $\bar{s}$, respectively.

Differentiating the (4.21) with respect to λ_r^s, we obtain the variation of the market shares value in each location with respect to the number of direct selling farmers :

$$s_{\lambda_r}(x, \lambda_u) = -s(x, \lambda_u)\bar{s} \tag{4.23}$$

We get from (4.23) that the market share is always decreasing with the number of competitors. Additionally, we can show that the larger the weight of the farmer located at x, the greater his loss in market share. This implies notably that the market concentration defined as $\bar{s}_u - \bar{s}_s$ is always decreasing with λ_r^s.

Note that this unequivocal relationship between the market concentration and the number of varieties holds because of the monopolistic competition ; the farmers set their price without taking into account the weight of their decision on the sector. Consequently, by neglecting the supply-side market size, their supply does not correctly responds to competition. With the entry of a new competitor, they adjust their production far less than optimally needed, leading the farmers with the highest market share to encounter a more significant decrease of their operating income than the other farmers. Notably, the farmer located at the urban fringe always faces a decrease in his market share larger than that located at the right-hand side boundary. Finally, as a result of this lower operating profit, the bid of the farmer located at the urban fringe on the land market decreases and causes the fall of the opportunity cost of urban land.

As regards to the urban population size, differentiating $s(x, \lambda_u)$ with respect to λ_u yields :

$$s_{\lambda_u}(x, \lambda_u) = s(x, \lambda_u) \times \left[\epsilon |E_h h_{\lambda_u}| \left(\frac{\int_{\bar{x}_u}^{\bar{x}_s} E(x, \lambda_u)^{\epsilon-1} dx}{\int_{\bar{x}_u}^{\bar{x}_s} E(x, \lambda_u)^{\epsilon} dx} - \frac{1}{E(x, \lambda_u)} \right) + \frac{\bar{s}_u}{2\delta} \right] \tag{4.24}$$

The first term in the square brackets captures the overall pollution intensity effect. Recalling that $0 < E(x, \lambda_u) < 1$ for all x, we can show that $\int_{\bar{x}_u}^{\bar{x}_s} E(x, \lambda_u)^{\epsilon-1} dx > \int_{\bar{x}_u}^{\bar{x}_s} E(x, \lambda_u)^{\epsilon} dx$ whatever E and ϵ, which implies that this effect at x is positive if and only if $E(x, \lambda_u) > \frac{\int_{\bar{x}_u}^{\bar{x}_s} E(x,\lambda_u)^{\epsilon} dx}{\int_{\bar{x}_u}^{\bar{x}_s} E(x,\lambda_u)^{\epsilon-1} dx}$ or equivalently, provided that the losses in aggregate receipts in direct selling due to a rise in pollution intensity outweigh the individual losses in x.

The second term accounts for the decrease in competition between direct selling farmers, stemming from the fact that, in a region hosting a larger city, some plots of land located at the urban fringe are under urban use while they would be dedicated to agricultural production in lowly-crowded regions. It is always positive but negatively correlated to the urban density.

We can state from (4.24) that the market share of a farmer located at x is positively linked to the urban population size provided that the productivity coefficient in x is sufficiently high :

$$E(x, \lambda_u) > \frac{\int_{\bar{x}_u}^{\bar{x}_s} E(x, \lambda_u)^{\epsilon} dx}{\int_{\bar{x}_u}^{\bar{x}_s} E(x, \lambda_u)^{\epsilon-1} dx + \frac{E(\bar{x}_u, \lambda_u)^{\epsilon}}{2\delta\epsilon |E_h h_{\lambda_u}|}} \tag{4.25}$$

Condition (4.25) is more likely to occur in regions hosting a low-density city (δ low) or, as regards to the features of the externality, when pollution causes low yields losses (E_h low) and/or is weakly correlated to the urban population size (h_{λ_u} low). Moreover, it is readily verified that if the market share of the farmer located at $\bar{x}_s$ is increasing with the urban population size, then the market share of every farmer involved in direct selling increases.

4.3 The short-run equilibrium.

We now turn to the short-run equilibrium. We determine first the spatial allocation of land between urban households and farmers (land market equilibrium) and then, the quantity and the quality of each variety of goods supplied in the region (direct selling market).

4.3.1 The land market

In the manner of Von Thunen, we suppose that each plot of land is allocated to the highest bidder. The short-run equilibrium land rent is thus given by the upper envelop of bid rents, that is :

$$R^{sr}(x) = \max\{\Phi_u(x), \Phi_r^s(x), \Phi_c^s(x)\} \tag{4.26}$$

$\Phi_u(x)$, $\Phi_r^s(x)$, and $\Phi_c^s(x)$ being the bid land rent of urban households, direct selling farmers, and conventional farmers, respectively. For simplicity, we further assume that the conventional bid land rent equals to the opportunity cost of land $\bar{R}$.

The urban bid rent Plugging (4.8) and (4.9) into (4.3) and rearranging gives the indirect utility of urban households :

$$V_u(x) = \left(\frac{\alpha}{P}\right)^{\alpha} (1-\alpha)^{1-\alpha} (w_u - UC) \tag{4.27}$$

At the residential equilibrium, the urban bid rent $\Phi_u(x)$ must solve $V_u'(x) = 0$ or equivalently :

$$\left(\frac{\alpha}{P}\right)^{\alpha} (1-\alpha)^{1-\alpha} \left(t_u + \frac{\Phi_u'(x)}{\delta}\right) = 0 \tag{4.28}$$

which solution is such that $\Phi_u(x) = \bar{r}_u - \delta t_u x$, $\bar{r}_u$ being a constant. Knowing that urban costs must be equal across households residing in the region and that urban and agricultural land rents equalize at the city boundary $\bar{x}_u$, we get $\bar{r}_u = \delta t_u \bar{x}_u + \Phi_r^s(\bar{x}_u)$. The urban bid rent and the share of the urban net income used for agricultural goods consumption are thus respectively given by :

$$\Phi_u(x) = \delta t_u (\bar{x}_u - x) + \Phi_r^s(\bar{x}_u) \tag{4.29}$$

$$\bar{w}_u(x) \equiv \bar{w}_u = \alpha \left(w_u - t_u \bar{x}_u - \frac{R(\bar{x}_u)}{\delta}\right) \tag{4.30}$$

Observe that, because of the fixed lot size assumption, the total value of non-spatial goods consumption at the residential equilibrium does not depend on locations ; the equilibrium value of urban costs – *and therefore, the share of the urban net income available for agricultural goods consumption* $\bar{w}_u$ – is the same across urban households.

The direct selling bid rent The farmers location choice is driven by two considerations. On the one hand, producing goods near the urban boundary allows reducing the opportunity cost of transportation. On the other hand, as urban activities generate pollution, locating away from the city center allows farmers to be less affected by this externality and, therefore, to reduce yields losses.

Plugging the price index (4.19) into the agricultural supply for variety v (4.17) and substituting $q(x)$ by the resulting expression in (4.16) yields the agricultural profit for a farmer located at x :

$$\pi(x, \lambda_u) = [\psi \lambda_u \bar{w}_u \times s(x, \lambda_u)] - R_r(x) \tag{4.31}$$

where $\psi \equiv \frac{1+\sigma\beta}{\sigma}$ is the monopolistic power index, common to all farmers regardless of their location, and capturing the constant non-spatial share of the growth in profit stemming from increasing market opportunities. It varies from 0 to 1 and plays as the Home Market Effect ; as the size of the urban population rises, the incentive to enter the direct selling market increases. The operating income, given by the term in brackets, depends on the two factors that allow to qualify the degree of competition on the direct selling market : the monopolistic power index that gives an overview of the power of producers relative to consumers, and the market share that accounts for the power of each producer relative to his competitors.

Differentiating $\pi(x, \lambda_u)$ with respect to x and equating to zero, we get that the direct selling bid rent must satisfy $\Phi_r^{s\prime}(x) = \psi \lambda_u \bar{w}_u \times s_x(x, \lambda_u)$ which solution is given by :

$$\Phi_r^s(x) = \bar{r}_r - \psi \lambda_u \bar{w}_u s(x, \lambda_u) \tag{4.32}$$

$\bar{r}_r$ being a constant.

Let denote by $\bar{x}_s$ the right-hand boundary of the direct selling area. Posing that the direct selling land rent must equalize the opportunity cost of land $\bar{R}$ at $\bar{x}_s$, we have $\bar{r}_r = \bar{R} - \psi \lambda_u \bar{w}_u \bar{s}_s$, which is increasing with λ_r^s. Hence, the entry of a new farmer on direct selling market increases the intercept of the bid land rent function but tends, in the same time, to flatten the function since its slope decreases with respect to λ_r^s. As a result, we can show that any rise in direct selling farmers can either lead to an increase or a decrease of the bid, depending on the location within the region.

The explanation of this result is to be found in the variation of the direct selling profit with respect to the number of varieties ; as previously mentioned, a new entrant always leads to a decrease in the market share of all the competitors already engaged in direct selling. Their operating profit is consequently lower, as a result of a loss in terms of location rent. However, in the same time, the new competitor enters the market with a smaller share, leading to lower the benchmark value to which the profit of all the farmers should equalize at the land market equilibrium $\pi(\bar{x}_s, \lambda_u)$. In the end, each farmer can either make a larger or a lower bid, depending on his own loss in operating profit relative to the overall decrease in direct selling profits.

Recalling that agricultural profits must equalize over the land strip $]\bar{x}_u, \bar{x}_s]$, and substituting $\bar{w}_u$ by its expression, yields the direct selling land rent :

$$\Phi_r^s(x) = \left(\delta w_u - t_u \frac{\lambda_u}{2} - \bar{R}\right) \times \frac{s(x, \lambda_u) - \bar{s}}{\bar{s}_u - \bar{s} + \frac{\delta}{\alpha\psi\lambda_u}} + \bar{R} \tag{4.33}$$

The direct selling bid rent follows the spatial variations of $E(x, \lambda_u)$; it is thus decreasing with the distance from the CBD if the effect of the opportunity cost of transportation dominates that of the urban pollution externality, and increasing otherwise.

Still from (4.33), we can show that the bid land rent is positively linked to the market size effect $\frac{\alpha\psi\lambda_u}{\delta}$, but negatively related to the market share gap $\bar{s}_u - \bar{s}_s$. The latter (*thereafter referred to as the land rent bill index*) reflects the power of direct selling farmers relative to urban households and conventional farmers on the land market ; the lower $\bar{s}_u - \bar{s}_s$, the flatter the direct selling bid land rent, and the smaller the part of the direct selling profit captured by the land rent.

Land use equilibrium Combining (4.29) and (4.33), the short-run equilibrium land rent is finally given by :

$$R^{sr}(x) = \begin{cases} \delta t_u \left(\bar{x}_u - x\right) + R_r(\bar{x}_u) & \text{if } 0 < x \leq \bar{x}_u \\ \left(\delta w_u - t_u \frac{\lambda_u}{2} - \bar{R}\right) \times \frac{s(x, \lambda_u) - \bar{s}_s}{\bar{s}_u - \bar{s}_s + \frac{\delta}{\alpha\psi\lambda_u}} + \bar{R} & \text{if } \bar{x}_u < x \leq \bar{x}_s \\ \bar{R} & \text{if } x > \bar{x}_s \end{cases} \tag{4.34}$$

Depending on the bid rent curves' ranking, several land use configurations can occur. For our study, we propose to concentrate on the configuration where the zone dedicated to direct selling farming is located at the periphery of the city and right-bordered by the conventional farming area (Fig. ??).

The occurence of this intra-regional land use pattern requires that two conditions be satisfied. First, the derivative of $s(x, \lambda_u)$ with respect to x at the right-hand direct selling boundary $\bar{x}_s$ must be negative to allow the direct selling bid land rent to be lower than the opportunity cost of land $\bar{R}$ for any distance x greater than $\bar{x}_s$. Second, as direct selling farming takes place immediately at the urban fringe, we have $\bar{s}_u > \bar{s}_s$. If this condition is not met, spatial patterns where urban and direct selling farming areas are separated by a zone dedicated to conventional farming can occur. Besides, since $s(x, \lambda_u)$ is positive over the full range $[\bar{x}_u; \bar{x}_s]$ and larger than $\bar{s}_s$, $R_r(x)$ is also ensured to be positive in all locations.

According to the shape of the agricultural productivity coefficient $E(x, \lambda_u)$, the direct selling bid rent can be either first increasing or always decreasing over space, implying that the regional land allocation can alternatively be depicted by the two following graphs.

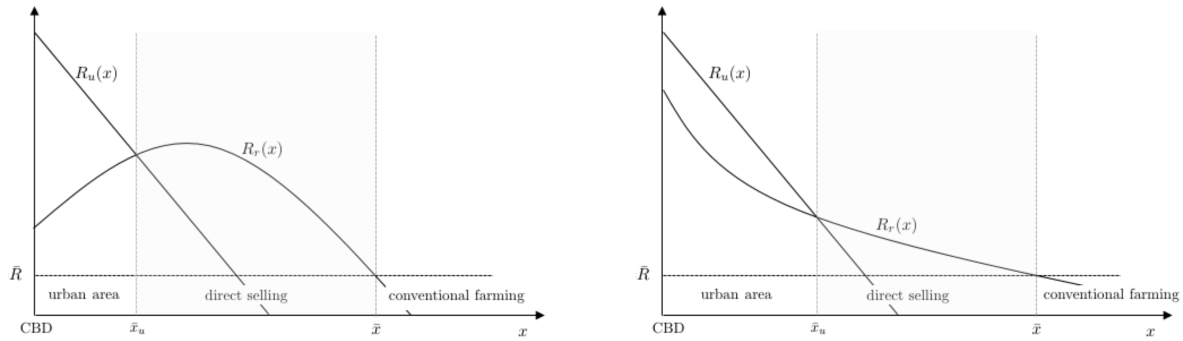

Figure 4.1 – *The regional land allocation*

Proposition 7 *At the short-run equilibrium, a spatial pattern where direct selling farming is located at the periphery of the city occurs provided that the agricultural productivity coefficient is greater at the urban fringe than at the right-hand boundary of the direct selling area, and tends to a very low value for the farthest plots of land from the CBD.*

From the spatial externality standpoint, this notably implies that, far from the city center, the opportunity cost of transportation always dominates the pollution cost.

4.3.2 Direct selling goods market

Plugging the equilibrium land rent (4.34) into (4.30) and using the resulting expression in (4.19) yields the short-run equilibrium value of the price index for direct selling goods :

$$P^{sr} = \left(\frac{\lambda_u \bar{w}_u^{sr}}{\bar{\theta}}\right)^{\frac{\sigma\beta}{\sigma-1}} \left(\frac{\sigma p_z}{\sigma - 1 - \sigma\beta}\right)^{\frac{\sigma-1-\sigma\beta}{\sigma-1}} \left(2 \times \int_{x=\bar{x}_u}^{\bar{x}_s} E(x, \lambda_u)^{\epsilon} dx\right)^{-\frac{1+\sigma\beta}{\sigma-1}} \tag{4.35}$$

with

$$\bar{w}_u^{sr} = \frac{\alpha\left(w_u - t_u\frac{\lambda_u}{2\delta} - \frac{\bar{R}}{\delta}\right)}{\frac{\alpha\psi\lambda_u}{\delta} \times (\bar{s}_u - \bar{s}_s) + 1} \tag{4.36}$$

and where the properties of $E(x, \lambda_u)$ ensure that the price index is always positive.

As shown from (4.35), the impact of the number of direct selling farmers on the price index is twofold. It has a positive income effect through $\bar{w}_u^{sr}$; the larger the number of varieties, the lower the market concentration, the higher the urban net income, and the greater the price index. It also has a negative effect due to the fiercer competition between farmers.

The total impact of λ_r^s on P^{sr} is given by the combination of these two effects. We can easily show from (4.35) that the competition effect always offsets the net income effect, implying that the price index is always decreasing with the number of direct selling farmers :

$$\frac{\partial P^{sr}}{\partial \lambda_r^s} \times \frac{1}{P^{sr}} = -\frac{\bar{s}_s}{\sigma - 1}\left(1 + \frac{1}{\frac{\alpha\psi\lambda_u}{\delta} \times (\bar{s}_u - \bar{s}_s) + 1}\right) \tag{4.37}$$

Competition, location and goods quality Using (4.35), we obtain the quantity and the quality of the variety produced at x at the short-run equilibrium, respectively given by :

$$q^{sr}(x, \lambda_u) = \frac{1}{p_z}\frac{\sigma - 1 - \sigma\beta}{1 + \sigma\beta}\frac{\delta w_u - t_u\frac{\lambda_u}{2} - \bar{R}}{\bar{s}_u - \bar{s}_s + \frac{\delta}{\alpha\psi\lambda_u}} \times s(x, \lambda_u)E(x, \lambda_u) \tag{4.38}$$

and

$$\theta^{sr}(x, \lambda_u) = \bar{\theta}p_z\frac{1 + \sigma\beta}{\sigma - 1 - \sigma\beta}\frac{\bar{s}_u - \bar{s}_s + \frac{\delta}{\alpha\psi\lambda_u}}{\delta w_u - t_u\frac{\lambda_u}{2} - \bar{R}} \times s(x, \lambda_u)^{-1} \tag{4.39}$$

$q^{sr}(x, \lambda_u)$ and $\theta^{sr}(x, \lambda_u)$ vary in opposite direction with respect to the distance from the city center ; letting x_a and x_b be two neighboring locations such that $\bar{x}_u < x_a < x_b < \bar{x}_s$, we can state that $q^{sr}(x_a, \lambda_u) > q^{sr}(x_b, \lambda_u)$ and $\theta^{sr}(x_a, \lambda_u) < \theta^{sr}(x_b, \lambda_u)$ provided that $s(x_a, \lambda_u) - s(x_b, \lambda_u) > 0$. More generally, we derive the following proposition :

Proposition 8 *At the short-run equilibrium, the supply of any direct selling variety decreases with the distance from the city center provided that the marginal impact of transportation is larger than that of the urban pollution externality. In this situation, the farther from the CBD, the lower the supply of a variety, but the higher its quality.*

The implication of Proposition (8) in terms of goods quality may be counter-intuitive ; since we have shown from (4.13) that the use of inputs z is decreasing with respect to $E(x, \lambda_u)$, we may have expected that the quality would be lower for the varieties grown at low-productivity locations ($E(x, \lambda_u)$ low). Instead, we find that the quality of high-productivity varieties is always lower than that produced at remote locations from the city center and displaying low-productivity levels. The explanation of this result lies in the relationship between productivity, market share, and goods supply. By definition, the highest market share farmers have to supply a larger quantity of goods, giving them an incentive to use more input so as to meet the demand (see Eq.(4.13)), and making the quality of their variety lower.

As regard to the features of the competition on direct selling market, we show that the quality of any variety is improving with the land rent bill index, but decreasing as the monopolistic power index rises. Additionally, by differentiating (4.38) and (4.39) with respect to λ_r^s, we can show that increasing the number of direct selling goods always leads to decrease the supply of each variety while improving its quality. Urban households have thus access to a wider range of better quality goods, but in lower quantity.

4.3.3 Direct selling profit and spatial externalities.

We finally assess the impact of spatial externalities on the direct selling market profitability. From (4.31), we can rewrite the direct selling profit at the short-run equilibrium as :

$$\pi^{sr}(\lambda_r^s, \lambda_u) = \frac{(\delta w_u - t_u \frac{\lambda_u}{2} - \bar{R}) \times \bar{s}_s}{\bar{s}_u - \bar{s}_s + \frac{\delta}{\alpha\psi\lambda_u}} - \bar{R} \tag{4.40}$$

Then, differentiating $\pi^{sr}(\lambda_r^s, \lambda_u)$ with respect to λ_r^s, we can show that the short-run equilibrium profit decreases as the number of farmers involved in direct selling increases. Given our framework, the latest entrant on the direct selling market always supplies a variety less expensive and in a lower quantity than his competitors. His operating income is consequently lower than that of the other farmers (see Eq.(4.31)). However, since profits must equalize over space at the short-run equilibrium, spatial externalities are captured by the equilibrium land rent which, once fed back into the profit, leads to smooth the direct selling net incomes and results in lower profits for every farmer.

From (4.40), we can capture the net effect of the spatial externalities. First, supposing that farmers produce in a non-spatial framework (i.e. $E(x, \lambda_u) = 1$ for all x), and denoting by hat the non-spatial value of any variable, we get :

$$\hat{\pi}^{sr}(\lambda_r, \lambda_u) = \frac{\delta w_u - t_u \frac{\lambda_u}{2} - \bar{R}}{\hat{\lambda}_r^s \times \frac{\delta}{\alpha\psi\lambda_u}} - \bar{R} \tag{4.41}$$

As highlighted by (4.41), when farmers are neither affected by urban pollution nor transportation, the operating income is given by the total market size in value –*that is, the total urban net income available for direct selling goods consumption, weighted by the monopolistic power index* – divided by the number of direct selling farmers. Then, comparing (4.40) to (4.41), we can calculate the relative rate of change of the operating income due to spatial externalities :

$$\frac{\hat{\pi}^{sr} - \pi^{sr}}{\hat{\pi}^{sr}} = 1 - \hat{\lambda}_r^s \times \frac{\bar{s}_s}{(\bar{s}_u - \bar{s}_s) \times \frac{\alpha\psi\lambda_u}{\delta} + 1} \tag{4.42}$$

This rate can be either positive or negative, depending on the value of the spatial-adjusted coefficient given by the last term of (4.42). More precisely, if the value of the market share in the non-spatial configuration is higher than the spatial-adjusted coefficient, then spatial externalities always lead to decrease profitability in direct selling market.

4.4 The long run equilibrium.

Farmers enter the direct selling market as long as the profit they can earn is higher than the (exogenous) equilibrium profit prevailing in conventional farming π^c. In the long run, the number of direct selling farmers adjusts to ensure that they all earn a profit equal to π^c.

4.4.1 The equilibrium number of direct selling varieties.

As the agricultural profit is decreasing with the number of farmers involved in direct selling, the long-run equilibrium is ensured to be a unique stable interior solution. Posing $\pi^c \equiv \bar{\pi} - \bar{R}$ and equating it to π^{sr}, we get that the number of direct selling varieties at the equilibrium λ_r^{s*} must verify :

$$\alpha\psi\lambda_u = \frac{\delta}{\phi\bar{s}_s - \bar{s}_u} \tag{4.43}$$

where $\phi \equiv \frac{\delta w_u - t_u \frac{\lambda_u}{2} - \bar{R} + \bar{\pi}}{\bar{\pi}}$ can be likened to a standard-of-living index.

The LHS of (4.43) stands for the market size effect. It is increasing with the urban population size and the monopolistic power index. The RHS captures the supply-side competition effect (or monopolistic competition effect) and is increasing with the number of direct selling farmers. Eq.(4.43) can alternatively be written as $\bar{s}_s = \frac{\bar{s}_u + \frac{\delta}{\alpha\psi\lambda_u}}{\phi}$, meaning that farmers keep entering the market until the market share of the latest entrant reaches a floor value. Graphically, λ_r^{s*} is given by the abscissa of the intersection point between the market size effect and the supply-side competition effect.

Observe finally that without spatial externalities, the equilibrium would be simply given by $\hat{\lambda}_r^{s*} = \frac{\alpha\psi\lambda_u}{\delta} \times (\phi - 1)$, which corresponds to the market size effect adjusted by the standard-of-living index.

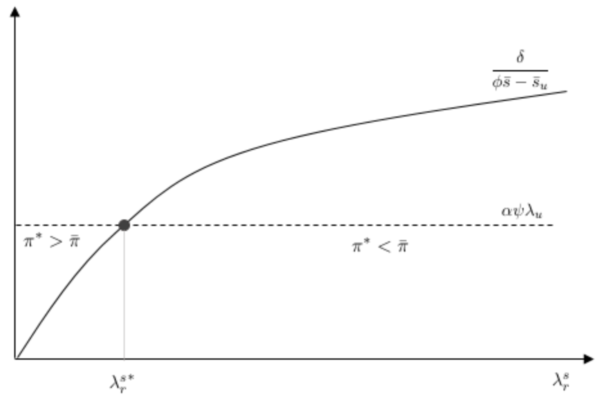

Figure 4.2 – *The long-run equilibrium*

4.4.2 Direct selling varieties and the city size.

The relation between the urban population size and the number of direct selling varieties is not trivial as it jointly affects the supply and the demand sides. On the one hand, a highly crowded city creates an incentive for farmers to enter the direct selling market since they would benefit from a large demand. On the other hand, the city size influences the level of the spatial externalities, playing on both the pollution intensity and the opportunity cost of transportation, and inducing changes in the relative productivity gap between farmers. These externalities, captured by the land rent, modify the level of competition on the land market, implying income changes for both urban and rural households.

Table 4.1 summarizes the elements to be considered when studying the relationship between the urban population size and the number of direct selling varieties. It notably highlights that urbanization may favor diversity in direct selling farming provided that the home market effect offsets the disincentives occurring on the land market.

This result can be analytically derived by studying the variations of the direct selling profit with respect to the urban population size at the equilibrium. Recalling that $\pi^{sr}(\lambda_u, \lambda_r^{s*})$ does not vary in the long-run and using the total differential, we can draw the relationship between the urban population size and the number of direct selling

Direct Selling Market	**Land Market**		
		remoteness cost ($E_t t'(x)$)	pollution cost ($E_h h_{\lambda_u}$)
Market size effect ($\alpha\psi\lambda_u \uparrow$ with λ_u)	*Standard-of-living index* ($\phi \downarrow$ with λ_u)	*Land rent bill index* ($\bar{s}_u - \bar{s}_s \downarrow$ or $\uparrow$ with λ_u)	
$\lambda_r^s \uparrow$	$\lambda_r^s \downarrow$	$\lambda_r^s \downarrow$ if $(\bar{s}_u - \bar{s}_s) \uparrow$ $\lambda_r^s \uparrow$ if $(\bar{s}_u - \bar{s}_s) \downarrow$	

Tableau 4.1 – *Factors influencing the number of direct selling varieties*

varieties, given by :

$$\frac{\partial \lambda_r^{s*}}{\partial \lambda_u} = \frac{\partial \pi^{sr}(\lambda_u, \lambda_r^{s*})}{\partial \lambda_u} \times \left| \frac{\partial \pi^{sr}(\lambda_u, \lambda_r^{s*})}{\partial \lambda_r^s} \right|^{-1} \tag{4.44}$$

λ_r^{s*} will be then positively (resp. negatively) correlated to λ_u provided that $\pi^{sr}(\lambda_u, \lambda_r^{s*})$ is increasing (resp. decreasing) with λ_u. Differentiating (4.40) with respect to λ_u and rearranging, we get :

$$\frac{\partial \pi^{sr}(\lambda_u, \lambda_r^{s*})}{\partial \lambda_u} = \frac{\bar{\pi}}{(\phi - 1)\bar{s}_s} \times \left[\frac{\phi \bar{s}_s - \bar{s}_u}{\lambda_u} - \frac{t_u \times \bar{s}_s}{2\bar{\pi}} + \phi s_{\lambda_u}(\bar{x}, \lambda_u) - s_{\lambda_u}(\bar{x}_u, \lambda_u) \right] \tag{4.45}$$

where the terms in brackets stand respectively for the market size effect, the standard-of-living effect, and the land rent bill effect.

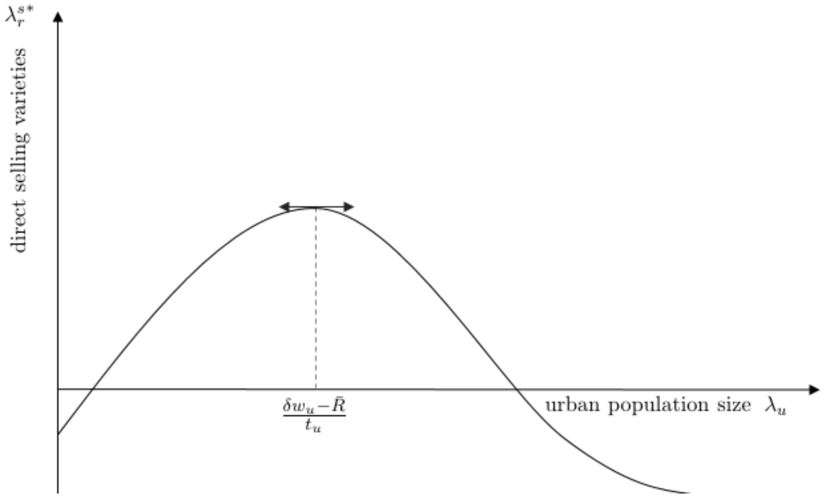

Figure 4.3 – *Direct selling varieties and urbanization (without spatial externalities)*

Urban population size and direct selling farming without externalities Consider first that spatial externalities do not affect the agricultural productivity, so that there is no heterogeneity between farmers. In this case, $s(x, \lambda_u) = \frac{1}{\lambda_r^s}$ for all x and (4.45) describes a concave relationship which expression is given by $\frac{\bar{\pi}}{\lambda_u} - \frac{t_u}{2(\phi-1)}$. It only displays two standard competing effects in urban economics : (i) a market size effect that plays positively, leading farmers to enter the direct selling market so as to benefit from the additional outlets, but loses strength as the urban population grows, and (ii) a net income effect which restricts the urban households spending at an increasing rate. The interplay of these two effects gives rise to a bell-shaped relationship between the urban population size and the direct selling varieties ; the latter rises as long as the market size effect outweighs the net income effect and reaches a threshold value $\hat{\lambda}_r^{s*}$ beyond which, any further urban population growth would lead to a decline in goods variety. As a result, we derive that direct selling farming provides wider ranges of varieties in regions hosting an intermediate size city.

How do spatial externalities change the bell-shaped outcome ? Accounting for the spatial externalities induces two major changes. Regarding the market size effect first, it is readily shown from (4.45) that spatial externalities lessen its impact from a coefficient $\frac{\phi\bar{s}_s - \bar{s}_u}{(\phi-1)\bar{s}_s} < 1$. The incentive to enter direct selling market in presence of externalities is consequently lower, implying less varieties for a same city size, all things being equal.

Second, spatial externalities introduce a new effect stemming from the fact that, because of the heterogeneity in productivity over space, increasing the urban population size applies with different weight among locations, and captured by :

$$\begin{aligned}\phi s_{\lambda_u}(\bar{x}_s, \lambda_u) - s_{\lambda_u}(\bar{x}_u, \lambda_u) = (\phi\bar{s}_s - \bar{s}_u) \times \left(\epsilon|E_h h_{\lambda_u}| \frac{\int_{\bar{x}_u}^{\bar{x}_s} E(x,\lambda_u)^{\epsilon-1}dx}{\int_{\bar{x}_u}^{\bar{x}_s} E(x,\lambda_u)^{\epsilon}dx} + \frac{\bar{s}_u}{\delta}\right) \\ - \epsilon|E_h h_{\lambda_u}| \times \frac{\phi\bar{E}_s^{\epsilon-1} - \bar{E}_u^{\epsilon-1}}{\int_{\bar{x}_u}^{\bar{x}_s} E(x,\lambda_u)^{\epsilon}dx}\end{aligned} \tag{4.46}$$

The first line refers to the overall variation of the aggregate receipts in direct selling due to the rise in both pollution intensity and city size. It is always positive. The second line represents the comparative individual pollution effect between the two boundaries of the direct selling area. It can be either positive or negative depending on the sign of $\phi \bar{E}_s^{\epsilon-1} - \bar{E}_u^{\epsilon-1}$.

In order to better understand the trade-off at play, it may be convenient at this stage to structure the discussion according to the effect of urban pollution on agricultural yields.

(i) Suppose first that the pollution intensity is weakly influenced by the urban population size ($E_h h_{\lambda_u} \to 0$). In this case, only the competition effect matters so that (4.46) becomes :

$$\phi s_{\lambda_u}(\bar{x}_s, \lambda_u) - s_{\lambda_u}(\bar{x}_u, \lambda_u) = \frac{(\phi \bar{s}_s - \bar{s}_u) \times \bar{s}_u}{\delta} \tag{4.47}$$

which is always positive. Returning to (4.45), we can calculate the change in the magnitude of the market size effect. The non-spatial market size effect $\frac{\bar{\pi}}{\lambda_u}$ is now multiplied by a coefficient $\frac{\phi \bar{s}_s - \bar{s}_u}{(\phi-1)\bar{s}_s}\left(1 + \frac{\bar{s}_u \lambda_u}{\delta}\right)$ that can be either smaller or larger than 1.

Since the above coefficient depends on the urban population size, further calculations can lead to the following statement : provided that $\frac{\phi \bar{s}_s - \bar{s}_u}{(\phi-1)\bar{s}_s}\left(1 + \frac{\bar{s}_u \lambda_u}{\delta}\right)$ is increasing with λ_u, accounting for the spatial heterogeneity tends to decrease diversity in direct selling for farming located near the smallest cities, but to increase diversity near the largest cities. In this situation, the market size effect increases as the urban population size grows, strengthening the incentive to convert to direct selling in highly-crowded regions. It is however worth noting that these changes only applies on the magnitude of the market size effect, so that the general bell shape of the relationship between urbanization and direct selling varieties is preserved [4]. Still in this respect, we can note that the higher the urban density, the weaker the additive effect from spatial externalities, and the closer from the benchmark equilibrium number of varieties $\hat{\lambda}_r^{s*}$ [5].

4. More precisely, it is readily shown that accounting for the spatial externalities does neither cancel nor modify the nature of the net income effect.

5. $\frac{\phi \bar{s}_s - \bar{s}_u}{(\phi-1)\bar{s}_s}$ is increasing with δ.

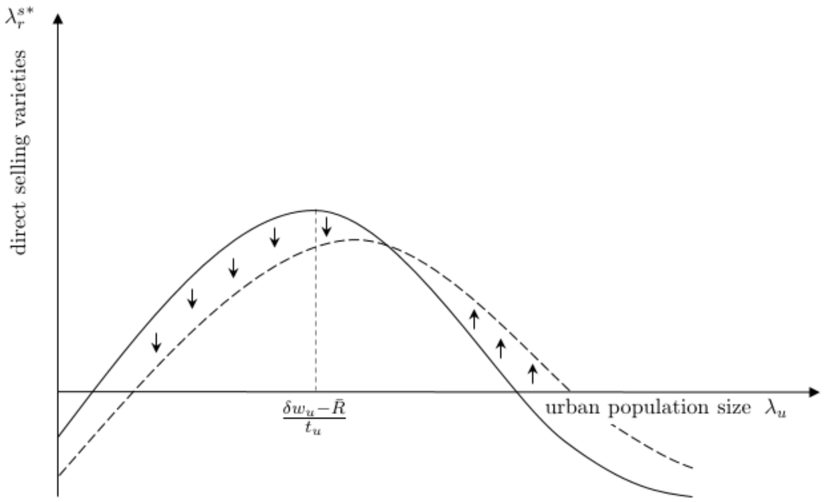

Figure 4.4 – *Direct selling varieties and urbanization (with low pollution effect)*

(ii) The pollution intensity is strongly influenced by the urban population size. When accounting for the pollution effect, two elements have to be added in the discussion that are namely, the aggregate level effect of pollution, and the comparative individual level effect. The aggregate level effect is positive, meaning that it always concurs in direct selling development. As for the comparative individual level effect, its impact lies on the sign of $\phi \bar{E}^{\epsilon-1} - \bar{E}_u^{\epsilon-1}$.

From (4.46), we can show that the overall effect of pollution intensity on direct selling farming is positive provided that :

$$\frac{\int_{\bar{x}_u}^{\bar{x}_s} E(x, \lambda_u)^{\epsilon-1} dx}{\int_{\bar{x}_u}^{\bar{x}_s} E(x, \lambda_u)^{\epsilon} dx} > \frac{\phi \bar{E}^{\epsilon-1} - \bar{E}_u^{\epsilon-1}}{\phi \bar{E}^{\epsilon} - \bar{E}_u^{\epsilon}} \tag{4.48}$$

If this condition is not verified, the overall effect is negative, meaning that pollution always restrict direct selling development. Finally, combining the different steps of the above analysis, we can derive the following proposition :

Proposition 9 *Direct selling farming is likely to provide a wider range of varieties in regions hosting an intermediate-size city, whatever the shape of the spatial externalities.*

Besides, we can add that urbanization may favor agricultural goods diversity provided that the market concentration in direct selling is low enough. This is notably the case for regions where the spatial variations of the urban externalities are low, so that farmers tend to be equally affected by pollution and remoteness ($\bar{E}_u \to \bar{E}$). By contrast, when urban externalities greatly differ over space, the heterogeneity between farmers due to the location-specific impact on productivity is wide. The aggregate profit is then significantly absorbed by the land rent – *as a result of individual profit smoothing* –, lowering the incentive to enter direct selling and leading, in turns, to limit the number of varieties. In this case, the larger the size of the urban population, the lower the direct selling profit and therefore, the lower the range of varieties.

Lastly, observe that, provided that the additive effects of spatial externalities are highly significant, taking them into account may, in some specific cases, either induce a strong joint development between the urban population size and direct selling farming (i.e. λ_r^s always increases with λ_u), or fully prevent its development near cities ($\lambda_r^s \to 0$ even for the least-crowded cities.). In this respect, urban density plays a significant role as it allows to modify the weight of the distance effect relative to the level effect.

4.5 Direct selling farming and regional welfare.

We finally evaluate the welfare implications of direct selling farming. To do so, we assess the indirect utility of urban households at the long-run equilibrium and we examine whether increasing the number of varieties leads to a utility improvement. In a second step, we enlarge the analysis to include the considerations of farmers.

4.5.1 Urban households utility

Direct selling farming interacts with urban households utility at two levels : it has a direct impact on consumption through the available range of varieties, the quality and the price level, and a net income spillover effect through the land market.

Diversity, quantity and quality Using (4.43), we can calculate the long-run equilibrium value of the quantity and the quality of the variety produced at x :

$$q(x, \lambda_u)^* = \frac{\bar{\pi}}{p_z} \frac{\sigma - 1 - \sigma\beta}{1 + \sigma\beta} \times \frac{E(x, \lambda_u)^{\epsilon+1}}{E(\bar{x}_s^*, \lambda_u)^{\epsilon}} \tag{4.49}$$

$$\theta(x,\lambda_u)^* = \frac{\bar{\theta}p_z}{\bar{\pi}}\frac{1+\sigma\beta}{\sigma-1-\sigma\beta} \times \frac{E(\bar{x}_s^*,\lambda_u)^\epsilon}{E(x,\lambda_u)^\epsilon} \tag{4.50}$$

First, remark that in order to better highlight the role of spatial externalities, (4.49) and (4.50) can be rewritten as $q(x,\lambda_u)^* = \hat{q}^* \times \frac{E(x,\lambda_u)^{\epsilon+1}}{E(\bar{x}_s^*,\lambda_u)^\epsilon}$ and $\theta(x,\lambda_u)^* = \hat{\theta}^* \times \frac{E(\bar{x}_s^*,\lambda_u)^\epsilon}{E(x,\lambda_u)^\epsilon}$, respectively. Hence, comparatively to a non-spatial framework, the quantity of good supplied in presence of urban externalities is higher for the varieties grown on locations experiencing a productivity coefficient larger than $E(\bar{x}_s^*,\lambda_u)^{\frac{\epsilon}{\epsilon+1}}$, and lower otherwise. Regarding the quality however, we get that externalities always lead to a quality loss for each variety except that produced at $\bar{x}_s$. For a given variety x, this loss will be even greater that the location benefits from a large productivity coefficient compared to the right-hand side boundary of the direct selling area.

Second, we can assess the impact of an increase in goods variety. Differentiating $q(x,\lambda_u)^{sr}$ and $\theta(x,\lambda_u)^{sr}$ with respect to λ_r^s and evaluating them at the equilibrium value yields :

$$\frac{\partial q^{sr}}{\partial \lambda_r^s}_{|\lambda_r^s=\lambda_r^{s*}} = -\frac{\phi\bar{s}_s - \bar{s}_u}{\phi-1}q(x,\lambda_u)^* < 0 \tag{4.51}$$

$$\frac{\partial \theta^{sr}}{\partial \lambda_r^s}_{|\lambda_r^s=\lambda_r^{s*}} = \frac{\phi\bar{s}_s - \bar{s}_u}{\phi-1}\theta(x,\lambda_u)^* > 0 \tag{4.52}$$

The combination of (4.51) and (4.52) illustrates the trade-off between quantity and quality. Urban households will be willing to accept lower levels of consumption in each variety provided that they gain in both diversity and quality.

Urban net income Increasing the number of varieties affects the urban net income both through the total expenditures in direct selling goods and the opportunity cost of land. The consumers expenditures in direct selling goods can be obtained by multiplying (4.18) by (4.49) and integrating over x which, after rearrangement, yields :

$$I^{sr} = \frac{(\phi-1)\bar{\pi}}{\bar{s}_u - \bar{s}_s + \frac{\delta}{\alpha\psi\lambda_u}} \times \frac{1}{\psi} \tag{4.53}$$

Expenditures are rising with the number of direct selling varieties, meaning that, although the quantity supplied of each good decreases with the number of direct selling varieties, the extra cost spent on the new variety always offsets the savings on the previous range available.

Regarding the opportunity cost of land, we derive from (4.34) :

$$R^{sr}(\bar{x_u}) - \bar{R} = \frac{(\phi - 1)\bar{\pi}}{\bar{s}_u - \bar{s}_s + \frac{\delta}{\alpha\psi\lambda_u}} \times (\bar{s}_u - \bar{s}_s) \tag{4.54}$$

Equilibrium vs urban households optimum Plugging (4.35) and (4.36) into (4.27), the indirect utility at the short-run equilibrium becomes :

$$V_u^{sr} = \Omega \left(2 \int_{\bar{x}_u}^{\bar{x}_s} E(x, \lambda_u)^{\epsilon} dx \right)^{\frac{\alpha}{\epsilon}} \times \left(\frac{\alpha\psi\lambda_u}{\delta} (\bar{s}_u - \bar{s}) + 1 \right)^{\alpha\frac{\sigma\beta}{\sigma-1} - 1} \tag{4.55}$$

where $\Omega \equiv \left(\frac{\bar{\theta}}{\lambda_u}\right)^{\frac{\alpha\sigma\beta}{\sigma-1}} \left(\frac{\sigma-1-\sigma\beta}{\sigma p_z}\right)^{\alpha\frac{\sigma-1-\sigma\beta}{\sigma-1}} \left(\frac{1-\alpha}{\alpha}\right)^{1-\alpha} \left(\frac{\alpha(\phi-1)\bar{\pi}}{\delta}\right)^{1-\alpha\frac{\sigma\beta}{\sigma-1}}$ is a constant.

First, we can easily show that without externalities, the market outcome always leads to a smaller set of varieties than the optimum ; posing $E(x, \lambda_u) = 1$ for all x, we get $V_u^{sr} = \Omega \times (\lambda_r^s)^{\frac{\alpha}{\epsilon}}$ for all x, which is increasing with λ_r^s. In this case, increasing the number of varieties leads to a rise in the aggregate agricultural productivity, inducing a stronger competition between farmers and leading, as a result, to lower prices. Moreover, as in this case the productivity is the same for all the farmers, the direct selling bid rent is flat and new entries in the sector do not affect the urban households net income.

Assuming then that cities creates externalities but that they do not vary in space (i.e. $E(x, \lambda_u) = e(\lambda_u)$, with $0 < e(\lambda_u) < 1$), we have $V_u^{sr} = \Omega \times [\lambda_r^s e(\lambda_u)]^{\frac{\alpha}{\epsilon}}$ which is still increasing with the number of direct selling varieties but at a lower rate. Any rise in varieties is thus beneficial to consumers but entails changes in the market share distribution ; the productivity gap increases which implies lower net income because of spillover effects on land market.

Lastly, when accounting for the spatial varying externalities, we can show that the result whereby the equilibrium always leads to a smaller range of available varieties than the optimum holds. Indeed, differentiating V_u^{sr} with respect to λ_r^s and evaluating it at the long-run equilibrium gives :

$$\frac{\partial V_u^{sr}}{\partial \lambda_r^s} = V_u^{sr} \bar{s}_s \times \left(\frac{2\alpha}{\epsilon} + \left| \frac{\alpha\sigma\beta - \sigma + 1}{\sigma - 1} \right| \frac{\bar{s}_u - \bar{s}_s}{(\phi - 1)\bar{s}_u} \right) \tag{4.56}$$

which is always positive. Then, knowing that the indirect utility describes a concave parabola in λ_r^s, we directly derive from (4.56) that direct selling provides less varieties at the equilibrium than optimally wished ; given our framework, a rise in goods diversity will always increase the satisfaction of urban households, as they will get more varieties of higher quality.

Observe anew that the non ambiguous relationship between the urban households utility and the number of varieties holds because of the monopolistic pricing on direct selling market which, combined with the bidding process on land market, implies that strengthening the competition on direct selling market always leads to a lower cost of land at the urban fringe and therefore, to a positive urban net income effect [6].

4.5.2 Regional welfare

We finally add the farmers considerations to the analysis. From the previous subsection, we derive that the urban households utility is increasing with the number of varieties. However, since direct selling profits are decreasing with the number of competitors, there is a conflict between urban and rural wishes, meaning that the welfare-maximizing number of varieties is necessarily lower than the optimal outcome for urban households.

Let the farmers utility be defined as the sum of the rural households profits :

$$V_r^{sr}(\lambda_r^s, \lambda_u) = \lambda_r^s \pi^{sr}(\lambda_r^s, \lambda_u) + (\lambda_r - \lambda_r^s)\bar{\pi} \tag{4.57}$$

$V_r^{sr}(\lambda_r^s, \lambda_u)$ describes a concave parabola in λ_r^s passing through $(0, \bar{\pi})$ and $(\lambda_r^{s*}, \bar{\pi})$. At $\lambda_r^s = 0$, all the farmers earn a same profit $\bar{\pi}$. The entry on direct selling market

6. Another way to figure out this result is to remark from Eq.(4.27) that V_u is decreasing with the price index but increasing with the urban net income. Decomposing the total effect of the number of direct selling farmers on V_u, we get $\frac{\partial V_u}{\partial \lambda_r^s} = \frac{\partial V_u}{\partial P}\frac{\partial P}{\partial \lambda_r^s} + \frac{\partial V_u}{\partial \bar{w}_u}\frac{\partial \bar{w}_u}{\partial \lambda_r^s}$ which is always positive because of the properties of the CES that gives $\frac{\partial P}{\partial \lambda_r^s} < 0$.

allows some farmers to benefit from the monopolistic competition and, consequently, to get a higher profit $\pi^{sr} > \bar{\pi}$. The utility of farmers is therefore first increasing with the number of competitors, until reaching a threshold from which the gains from imperfect competition vanish. From this value, any new entry would entail a decrease in direct selling profit.

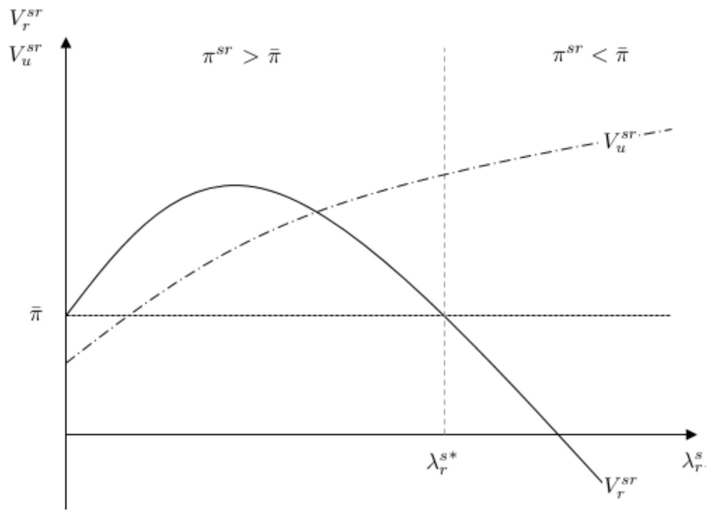

Figure 4.5 – *Direct selling farming and welfare components.*

Therefore, as illustrated by the Fig.(4.5), the market equilibrium always leads to a number of direct selling varieties too much high compared to that which would maximize the farmers utility.

The welfare function can finally be defined as the sum of the urban and the farmers indirect utilities :

$$W^{sr}(\lambda_r^s, \lambda_u) = \lambda_u V_u^{sr}(\lambda_r^s, \lambda_u) + \lambda_r V_r^{sr}(\lambda_r^s, \lambda_u) \tag{4.58}$$

Because of the non linearity of (4.58), searching for an analytic solution of the welfare-maximizing problem is intricate. Some general findings can however be drawn ; using the two previous subsections, we can easily show that the optimal number of direct selling farmers is necessarily lower than that allowing to maximize the urban households welfare, but larger than the farmers' optimum. Yet, as indirect utilities are weighed by the population type, this result can be refined if jointly appreciated with the relative size of the urban population. More precisely, it is readily verified from (4.58) that the optimal outcome would be all the more close to the urban household optimum that the region hosts a highly crowded city.

4.6 Conclusion

In this chapter, we have investigated the conditions for which direct selling farming could emerge under free-market. We have derived that, at the short-run equilibrium, the supply of any direct selling variety would decrease with the distance from the city center provided that the marginal impact of transportation is larger than that of the urban pollution externality. In this situation, we have shown that the farther from the CBD, the lower the supply of a variety, but the higher its quality since quantity and quality vary in opposite direction with respect to the distance from the city center.

As regards to the relationship between the urban population size and direct selling farming, we have succeeded in proving that regions hosting an intermediate-size city are more likely to provide a wider range of varieties. Besides, even if accounting for the spatial heterogeneity between farmers does not cancel this result, it nonetheless modifies the value of the variety range achieved at each level of urbanization. In this respect, we have found that, even when urban pollution affects agricultural yields, cities may benefit from a large set of varieties provided that the productivity coefficient varies weakly over space.

Finally, we have shown that the market equilibrium always leads to a number of direct selling farmers which is too low to fully satisfy urban households, but too much high from the farmers standpoint. In this respect, it is worth noting that this general finding on welfare lays some ground for further research on the public policy aspects. Notably, we can logically think that implementing a subsidy to reward farmers who engage in direct selling may be welfare improving as long as the cost of this measure does not exceed the gains in urban households utility.

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A : The shape of the space-related productivity $E(t(x), h(x, \lambda_u))$

The second derivative of $E(t(x), h(x, \lambda_u))$ with respect to the distance from the city center x is given by :

$$\begin{aligned} E_{x,x}(x, \lambda_u) &= [E_{t,t} t'(x) + E_{h,h} h_x(x, \lambda_u)] \times [t'(x) + h_x(x, \lambda_u)] \\ &+ E_{t,h} \times [t'(x) + h_x(x, \lambda_u)]^2 + E_t t^{''}(x) + E_h h_{x,x}(x, \lambda_u) \end{aligned} \tag{4.59}$$

Then, assuming for simplicity that the marginal effects of transportation and pollution on productivity are constant (i.e. $E_{t,t} = 0$ and $E_{h,h} = 0$), and that there is no cross-interactions between transportation and pollution (i.e. $E_{t,h} = 0$) yields :

$$E_{x,x}(x, \lambda_u) = E_t t^{''}(x) + E_h h_{x,x}(x, \lambda_u) \tag{4.60}$$

Then, recalling that $E_t < 0$ and $E_h < 0$, the second derivative of E is negative provided that :

(i) $t(x)$ and $h(x, \lambda_u)$ are convex or

(ii) $t(x)$ (resp. $h(x, \lambda_u)$) is convex and $h(x, \lambda_u)$ (resp. $t(x)$) is slightly concave.

Chapitre 5

Conclusion

L'agriculture fait plus que jamais l'objet de fortes attentes de la société en termes d'alimentation et de qualité des produits. Dans un contexte d'urbanisation croissante de notre économie, il se dessine aujourd'hui les contours d'une nouvelle problématique autour de la durabilité du système d'approvisionnement alimentaire des villes ; s'il s'agit toujours de fournir une production agricole suffisante pour répondre à une demande nette croissante, il est désormais de nouvelles contraintes à intégrer. Ces dernières peuvent se regrouper en trois grandes catégories, portant sur les préférences des consommateurs, les impacts environnementaux, ainsi que sur les tensions en matière d'allocation des ressources humaines et foncières entre usages urbain et rural.

L'émergence de systèmes d'approvisionnement alimentaire alternatifs dédiés à l'approvisionnement de certains grands pôles urbains, constitue une première tentative de réponse à la problématique. Bien que de natures multiples, ces initiatives sont toutes le symbole d'efforts consentis à la re-spacialisation et la re-socialisation conjointes des chaines d'approvisionnement alimentaire. Cependant, en l'absence de recul suffisant sur ces expériences, la capacité de ces solutions à apporter une réponse viable et correctement adaptée aux enjeux soulevés par la nouvelle problématique alimentaire reste incertaine.

A travers cette thèse, nous avons tenté de fournir un éclairage théorique à cette problématique de durabilité alimentaire en milieu urbain. En abordant tout d'abord la question de localisation à une échelle multirégionale, nous avons pu montrer que *la promotion d'un système où l'ensemble des villes dépendraient d'un approvisionnement exclusivement local ne saurait être inttrinsèquemet optimale* ; en présence d'un ensemble géographique caractérisé par une forte hétérogénéité dans la taille des villes notamment, contraindre l'intégralité des villes à l'autosuffisance alimentaire contribuerait à dégrader le bilan écologique, les émissions additionnelles induites par l'allongement des distances intra régionales étant moins que compensées par les économies d'émissions réalisées sur le commerce inter-régional. Dans un tel cas de figure cependant, nos résultats n'excluent pas la possibilité pour certaines régions de dépendre d'un approvisionnement exclusivement local ; le schéma optimal correspondrait alors à une configuration où les villes de tailles intermédiaires seraient autosuffisantes en denrées alimentaires tandis que les régions à faible population urbaine exporteraient leurs excédents agricoles vers les villes de grande à très grande taille.

En se focalisant dans un second temps sur la nature de l'agriculture, nous avons pu mettre en évidence qu'en l'absence d'intervention publique, une agriculture de type alternative proposant une gamme variée de produits est plus susceptible de se développer durablement dans la périphérie des villes de taille intermédiaire. Par ailleurs, bien que n'aboutissant pas de manière systématique à un meilleur bilan environnemental, nous avons montré cependant que promouvoir l'implantation d'une agriculture alternative à proximité des villes peut conduire à une amélioration du bien-être, à condition que le coût d'opportunité marginal des terrains urbains reste suffisamment faible. Enfin, en prenant en compte les effets négatifs de la pollution urbaine sur les rendements agricoles, nous sommes parvenu à démontrer qu'en présence de fortes disparités spatiales dans l'impact de l'externalité, une agriculture de proximité dispose de peu d'opportunité pour se développer et proposera, le cas échéant, des biens particulièrement hétérogènes en terme de qualité.

De manière générale, les travaux de cette thèse font apparaître l'élément majeur suivant : du fait de la forte et inextricable interconnexion entre milieux urbain et rural, l'évaluation environnementale, sociale et économique d'un système alimentaire ne peut se faire qu'en connaissance des caractéristiques démographiques (taille de la population) et physique (indicateur de densité, pollution) de la ville concernée. Bien que pouvant apparaitre comme trivial, ce résultat constitue tout de même une invitation à engager des recherches adéquates en amont afin de bien saisir et prévoir les potentiels effets pervers associés à la promotion d'une solution alternative.

En proposant un traitement théorique de la question, nous espérons que cette thèse contribue à faire avancer le débat de façon constructive. Si nous gardons à l'esprit que ces travaux n'offrent qu'une vue parcellaire de la problématique et peuvent, par conséquent, n'aboutir qu'à des recommandations "sous condition", nous pensons toutefois qu'ils constituent un point de départ intéressant pour jeter les bases d'une réflexion théorique rigoureuse sur la question de l'approvisionnement alimentaire dans les économies à dominance urbaine. Ce travail ouvre ainsi la voie à de futures extensions, invitant à poursuivre les efforts de modélisation dans le but d'affiner les mécanismes qui sous-tendent aux dynamiques spatiales de relocalisation des agents. Notons à ce sujet que deux voies méritent notamment d'être davantage explorées :

- la question de l'endogénéisation de l'ensemble des dynamiques de migrations, le raisonnement à localisation de la population urbaine non fixée permettant notamment de basculer dans une logique de long terme (horizon temporel d'autant plus légitimes pour aborder les questions de durabilité).
- l'introduction d'une dynamique temporelle afin d'appréhender la nouvelle problématique alimentaire comme un processus d'adaptation et de convergence vers un état stationnaire. Primordiale pour la construction de politiques publiques, ce passage d'une analyse statique à une analyse dynamique permettrait de gagner en réalisme en introduisant des phénomènes de rigidité et d'irréversibilité.

Résumé

Au cours des soixante dernières années, la population mondiale a connu un sursaut spectaculaire, passant de 2,5 milliards d'habitants à la fin de la Seconde Guerre mondiale à 7 milliards en 2011. Cette croissance démographique se distingue des précédents épisodes tant par son importance que par l'apparition conjointe d'une tendance nouvelle et soutenue à la concentration des populations au sein des villes. Appelée à se renforcer partout dans le monde, cette tendance au grossissement des villes lance un véritable défi à la communauté internationale en matière de durabilité de notre système économique en général et alimentaire en particulier.

Cette thèse propose un traitement théorique de la question de la durabilité des systèmes d'approvisionnement alimentaires en milieu urbain. A la frontière entre économie publique et économie géographique, elle poursuit comme objectif principal de permettre la conduite d'une analyse formalisée des arbitrages environnementaux et sociaux dans un cadre spatial explicite. En outre, l'idée selon laquelle aucune réponse ne saurait être satisfaisante sans qu'une attention spécifique soit portée aux interactions spatiales, économiques et écologiques entre espaces urbains et agriculture constitue l'un des positionnements clés défendus dans ce travail.

De manière générale, les travaux de cette thèse font apparaître l'élément majeur suivant : du fait de la forte et inextricable interconnexion entre milieux urbain et rural, l'évaluation environnementale, sociale et économique d'un système alimentaire ne peut se faire qu'en connaissance des caractéristiques démographiques *(taille de la population)* et physique (indicateur de densité, intensité de la pollution urbaine) de la ville concernée.