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Développement urbain et services écosystémiques : une analyse du marché foncier

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Avertissement

Les chapitres de cette thèse sont issus d'articles de recherche indépendants. Ceci explique la présence des termes « paper » ou « article », ainsi que l'éventuelle répétition de certaines informations. Le chapitre 2 est co-écrit avec Cécile Détang-Dessendre, Mohamed Hilal, Sophie Legras et Gengyang Tu . Le chapitre 4 est co-écrit avec Sophie Legras et publié dans la revue *Environmental and Resource Economics*.

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Résumé

Depuis la fin de la révolution industrielle, la sphère scientifique aussi bien que la sphère politique se sont interrogées sur la forme optimale des villes. D'abord marqué par un courant majoritaire prônant le désentassement urbain et la ville "aérée", le paradigme s'est retourné au fil du temps et notamment après la forte montée de nouveaux enjeux environnementaux. Le débat public s'oriente aujourd'hui vers la nécessité d'une densification de la croissance urbaine, et d'une lutte contre l'étalement urbain. Se pose dès lors la question de la validité de telles mesures, et plus largement de conception de stratégie d'intervention publique sur la marché foncier assurant un développement urbain compatible avec la préservation de l'environnement.

Cette thèse propose donc de contribuer au débat sur les formes optimales de villes durables, en répondant à la question suivante : est-il possible de concilier développement urbain et préservation de l'environnement ? Plus précisément, la ville compacte est-elle une forme de ville durable ? Si oui, est-elle la seule ? La fournitures des services écosystémiques est-elle conditionnée par la structure urbaine considérée et si oui quels services et comment ?

A travers une analyse micro-économique du marché foncier, et en utilisant la notion de services écosystémiques, nous proposons de répondre à ces questions.

De manière générale les travaux de cette thèse font apparaître l'élément majeur

suivant : en raison de la complexité du lien entre les différents services écosystémiques et des interconnexions entre ceux-ci et le développement qui revêtent des facettes multiples, les conclusions sur les formes de ville durable ne peuvent se faire qu'en des termes conditionnels. Ce résultat constitue 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 unique forme de ville durable.

Abstract

Since the end of the industrial revolution, scientists as well as politicians have been interesting in the questions related to the optimal shape of cities. Initially, a majority branch advocates for a « garden city », with open space and low density. However, the paradigm has turned over time and especially after the rise of new environmental stakes. The public debate is now focused on the need to intensify urban growth and to combat urban sprawl. This raises the question of the validity of such measures and, more broadly, of the design of a public intervention strategy on the land market ensuring urban development compatible with the preservation of the environment.

This thesis proposes to contribute to the debate on the optimal forms of sustainable cities by answering the following question : is it possible to reconcile urban development and environmental preservation ? More specifically, is the compact city a form of sustainable city ? If so, is it the only one ? Is the provision of ecosystem services conditioned by the urban structure and, if so, what services and how ?

Through a micro-economic analysis of the land market, and using the concept of ecosystem services, we propose to answer these questions.

In general way, this thesis reveals the following major element : due to the complexity of the link between the different ecosystem services and the interconnections between them and urban development, the conclusions on sustainable city structure

can only be done in conditional terms. This result is an invitation to undertake adequate researchs upstream in order to better grasp and foresee the potential perverse effects associated with the promotion of a single form of sustainable city, as is currently the case with the paradigm of the compact city.

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Introduction

1.1 Quelle forme urbaine pour une ville durable ?

1.1.1 Ville dense VS ville étalée : un débat ancien

Les récents évènements liés aux pics de pollution dans les grandes villes françaises poussent à s'interroger sur la durabilité des modes de vie urbains. En plus de la remise en cause de l'utilisation intensive de l'automobile, ce sont tous les questionnements autour de la structure urbaine qui reviennent sur le devant de la scène. L'interrogation autour de la possibilité de maintenir des formes de villes étalées, dans lesquelles les ménages se localisent toujours plus loin des centres, est notamment mise en exergue. Ces questionnements et ces débats ne sont pourtant pas récents, les penseurs aussi bien que les hommes politiques se sont emparé des réflexions sur les formes urbaines dès la construction des villes modernes au moment de la révolution industrielle du XIX^{eme} siècle.

La révolution industrielle transforme en effet les paysages urbains, et entraîne la croissance très forte des densités de population dans les centre villes. Les densités urbaines ont ainsi connu une augmentation considérable dans la première moitié du

XIX^{eme} siècle, passant par exemple du simple au double dans les parties centrales de Londres et de Paris (Guerois, 2003). Cette explosion urbaine provoque des réactions, et c'est d'abord le courant du « désentassement » qui prime, s'opposant à l'augmentation démesurée des densités urbaines et promouvant une ville « aérée », dans laquelle circulent l'air et la lumière (Beaucire, 2000). Ce courant repose avant tout sur des arguments hygiénistes, la forte agglomération des hommes étant à l'époque perçue comme une des causes principales de la surmortalité qui caractérise les villes jusqu'à la fin du XIX^{me} siècle (Pinol, 1991).

Dès le début du XX^{me} siècle, le paradigme commence cependant à s'inverser. L'idée selon laquelle le développement urbain doit être contrôlé prend toute son ampleur dans la seconde moitié du siècle : l'expansion urbaine est très vigoureuse sous l'effet de la révolution de la mobilité individuelle, induite par la démocratisation de l'automobile, qui ouvre le marché foncier dans les périphéries urbaines. Rapidement s'amorce la dénonciation du mitage des campagnes et la valorisation d'un modèle de ville compacte et dense, en opposition à la ville « aérée ».

C'est à cette période qu'apparaît la notion, devenue idiomatique, d'*urban sprawl*. Elle apparaît d'abord aux Etats-unis et est traduite par « étalement urbain » en français (Nédélec, 2016). Les débats autour de la forme urbaine, qui opposent la ville dense à la ville étalée, vont dès lors se cristalliser autour de cette notion. Elle est aujourd'hui encore employée abondamment et désigne, dans son acception contemporaine issue du langage courant, une dynamique d'extension des surfaces bâties et d'éloignement spatial par rapport aux centres urbains historiques. Plus précisément, l'Agence Européenne pour l'Environnement considère que « l'étalement urbain représente le phénomène d'expansion géographique des aires urbaines par l'implantation en périphérie, au détriment de larges zones principalement agricoles, de types d'habitat peu denses (banlieues pavillonnaires, maisons individuelles) ». Cette dilatation de l'espace urbain se traduit par une diminution de la densité des zones urbanisées du fait d'une extension géographique plus rapide que la croissance démographique (Commission Européenne, 2006).

Dans la littérature scientifique, la notion d'étalement urbain est profusément utilisée, mais plusieurs définitions y sont attachées. Comme Galster et al. (2001) le démontrent, le terme d'étalement urbain est employé indifféremment pour définir le processus d'expansion des régions urbaines, des modèles d'occupation du sol, les causes d'un usage particulier du sol ou bien la conséquence de cet usage. En se concentrant sur la littérature économique récente, l'étalement urbain est quantifié au travers de fortes mesures empiriques. Ces mesures sont fondées sur une ou plusieurs des caractéristiques de développement urbain suivantes : densité résidentielle ou densité d'emplois, continuité ou fragmentation du développement, centralité de la population autour des centres d'emplois, proximité des transports, etc. (Grout et al., 2016).

La notion d'étalement urbain a dès son apparition une connotation péjorative dans les débats publics : il s'agit de dénoncer un développement urbain incontrôlé et néfaste, et de promouvoir une croissance urbaine plus rationnelle, la « Smart Growth » aux Etats-Unis. Le premier ouvrage de référence qui fustige l'étalement urbain et valorise la ville compacte est publié dans les années 1970 (Dantzig and Saaty, 1973), suite à la crise urbaine des Etats-Unis qui s'est traduite par le déclin de la population dans les centres et par l'abandon de quartiers entiers aux populations les plus défavorisées. Ce livre fait l'hypothèse que le déclin des métropoles est en partie lié à leur desserrement. Les arguments en faveur d'une ville compacte sont donc d'abord liés à la volonté de « ré-urbanisation » au profit du renouvellement des centres-villes. A la fin des années 1980 et dans les années 1990, ces arguments entrent en résonance avec l'émergence des préoccupations environnementales, et c'est à cette époque que la question de la gestion de l'étalement urbain et de sa maîtrise revient avec force sur le devant de la scène politique et scientifique.

1.1.2 Les termes du débat actuel : concilier environnement et développement urbain

Dans les années 1980, de nombreux scientifiques commencent à tirer la sonnette d'alarme à propos des dégradations environnementales provoquées par les activités humaines. La Conférence des Nations Unies sur l'Environnement humain de Stockholm, en 1972, fait émerger la notion d'éco-développement ; mais c'est en 1987 que le concept de développement durable est défini comme « un développement qui permet de répondre aux besoins des générations présentes sans compromettre la capacité des générations futures à répondre à leurs propres besoins » (Brundtland, 1987), et devient dès lors un objectif à atteindre.

La priorité accordée aux préoccupations environnementales enrichit d'une dimension supplémentaire la notion de ville compacte qui avait émergé dans les années 1970 avec les politiques de renouveau urbain. La ville compacte devient alors le modèle de référence, et l'orientation vers des formes urbaines denses est perçue comme une des conditions nécessaires à l'existence de « villes durables ». Le Livre vert sur l'environnement urbain (Commission Européenne, 1990), dans lequel la Commission Européenne dénonce les conséquences néfastes de l'étalement urbain et se prononce en faveur d'un modèle de ville compacte, a marqué profondément la littérature et a accéléré la diffusion de ce modèle.

La littérature sur l'étalement urbain se focalise aujourd'hui encore sur son impact sur l'environnement, comme le démontre un second rapport de la Commission Européenne intitulé « Urban Sprawl : the ignored challenge » (Commission Européenne, 2006). Dans la même veine que le précédent, ce rapport dénonce l'étalement urbain comme responsable de nombreuses dégradations environnementales et promeut donc un mode de ville compacte et dense. On observe également récemment un glissement progressif du modèle idéal vers une structure urbaine de type polycentrique. C'est cette référence qui, de plus en plus, est associée aux formes spatiales les plus durables, avec un centre dense au périmètre délimité, et des centres secondaires en périphérie (Guerois, 2003).

Dans le débat public ainsi que dans la littérature scientifique traitant des enjeux environnementaux, la notion très large de développement durable a été étayée par la notion de services écosystémiques pour rendre compte du lien entre l'Homme et les écosystèmes qui l'entourent. Bien qu'il s'agisse d'un concept légèrement différent de celui du développement durable, la notion de services écosystémiques est venue préciser les formes de relations homme-nature, en proposant une nomenclature détaillée des différentes formes de services rendus à l'Homme par la nature. Elle permet de mettre en lumière les liens existant entre forme urbaine et environnement : l'urbanisation peut avoir des effets néfastes mais également bénéfiques en fonction du type de services écosystémiques étudié.

La notion de services écosystémiques est relativement nouvelle dans le débat scientifique, mais elle a montré une croissance exponentielle cette dernière décennie (Fisher et al., 2009). Son émergence est souvent associée aux études de Daily (1997) et Costanza et al. (1997). Le concept apparaît pour souligner la force du lien existant entre les écosystèmes naturels et le bien-être des individus. En effet, comme Daily (1997) le décrit avec des exemples marquants, les écosystèmes naturels maintiennent et satisfont la vie humaine. Elle affirme avec force que l'humanité n'est rien sans des écosystèmes durables et de qualité :

« Les êtres humains dépendent totalement de la continuité des cycles naturels pour leur propre existence. Si les cycles de vie des espèces prédatrices qui contrôlent naturellement la plupart des espèces de ravageurs venaient à être interrompus, il est peu probable que les pesticides puissent prendre leur place de façon satisfaisante. Si le cycle de la pollinisation des plantes cessait, la société ferait face à de graves conséquences économiques et sociales. Si le cycle du carbone était gravement perturbé, le changement climatique rapide pourrait menacer l'existence même de la civilisation. De façon générale, les être humains n'ont ni la connaissance ni les capacités pour remplacer entièrement les fonctions exercées par ces cycles naturels. (Daily, 1997, p.5) »

Ici, Daily fournit implicitement la définition de ce que l'on entend par la notion de services écosystémiques : comme définis par le Millennium Ecosystem Assesment (2005), les services écosystémiques sont les bénéfices que les individus tirent des écosystèmes.

En suivant la typologie fournie par le Millennium Ecosystem Assesment (2005), nous pouvons classer les services écosystémiques en quatre principales catégories. La première regroupe les services d'approvisionnement, faisant référence aux produits directement obtenus grâce aux écosystèmes, comme par exemple la nourriture, le bois, les ressources génétiques, ou encore l'eau fraîche.

La deuxième catégorie inclut les services régulateurs, qui sont les avantages obtenus grâce à la régulation des processus des écosystèmes, par exemple, l'entretien de la qualité de l'air, le contrôle de l'érosion, la purification des eaux, le contrôle des maladies, ou la pollinisation.

La troisième catégorie englobe les services culturels, définis comme les avantages non-matériels que les hommes tirent des écosystèmes à travers l'enrichissement spirituel et le développement cognitif, comme la diversité culturelle, les valeurs éducatives, les valeurs esthétiques, ou les activités récréatives. Les services culturels peuvent aussi être qualifiés d'aménités naturelles.

Enfin, la dernière catégorie des services des écosystèmes recouvre ceux nécessaires à la production de tous les autres services écosystémiques, sous la dénomination de services de soutien. Ces services peuvent avoir un impact indirect ou fournir des avantages sur le très long terme. Des exemples de services de soutien sont la production d'oxygène dans l'atmosphère, la formation et la rétention du sol, les cycles bio-géo-chimiques, ou l'offre d'habitat naturel.

La biodiversité n'apparaît pas explicitement comme un service dans la typologie précédente ; cependant, la biodiversité qualifie les écosystèmes et donc est à la base d'une partie des services rendus. Elle joue un rôle clef dans la distribution des services écosystémiques (Hooper et al., 2005). Suivant les recommandations du Millennium Ecosystem Assesment (2005), l'Institut Français de l'Environnement (IFEN) développe des indicateurs basés sur la biodiversité pour évaluer le niveau de différents services écosystémiques. Par exemple, pour mesurer le niveau des services culturels, les indicateurs recommandés peuvent être la variation du nombre total d'espèces ou la variation de l'importance des espèces emblématiques (Conférence Française pour la Biodiversité, 2010).

Dans la littérature scientifique, les articles reliant les notions de services écosystémiques et d'urbanisation sont de plus en plus nombreux. Une recherche rapide sur Science Direct l'illustre bien : en 2000, seulement 9 articles ont été publiés comprenant dans leur titre les termes « ecosystem services » et « urban », alors que plus de 200 articles sont référencés pour la seule année 2016. Le résultat est similaire avec les termes « ecosystem services » et « cities ».

La littérature économique reliant l'étalement urbain et l'environnement n'inclut pas explicitement les impacts en terme de « services écosystémiques ». Dans la littérature examinée dans ce chapitre et dans les suivants, les économistes utilisent le plus souvent le terme « aménité », mais offrent rarement une définition précise de ce qu'ils entendent par ce mot. Dans la plupart des cas, la notion d'aménité semble être utilisée comme un synonyme de services culturels (Dendrinos, 2000), et certaines études ne se concentrent que sur les espaces ouverts (Turner, 2005; Wu and Plantinga, 2003). Néanmoins, dans d'autres articles, la notion d'aménité peut inclure plusieurs autres services écosystémiques : Cavailhès et al. (2004) emploient le terme d'aménité pour décrire les services fournis par les plaines agricoles, et peuvent donc inclure des services d'approvisionnement en plus des services culturels. Wu and Irwin (2008), quant à eux, utilisent le terme d'aménités environnementales pour décrire à la fois les services culturels et les services régulateurs de l'écosystème d'un lac.

Cette thèse a pour objectif d'alimenter les réflexions sur le lien existant entre développement urbain et environnement, à travers l'utilisation de la notion de services écosystémiques. Notre objectif est de mettre en lumière la relation complexe existant entre ces deux concepts, afin de déterminer quelle forme de ville peut permettre de concilier urbanisation et préservation de l'environnement : La ville compacte est-elle une forme de ville durable ? Si oui, est-elle la seule ? La notion de services écosystémiques nous permet de repositionner les questionnements en ces termes : en quoi les services écosystémiques influencent-ils la forme urbaine d'équilibre ? La fourniture de ces services est-elle conditionnée par la structure urbaine d'équilibre, et si oui, quels services et comment ? Nous proposons avant tout de démontrer que la réponse à ces questions ne peut être univoque.

Dans la partie suivante de cette introduction, nous reprenons la littérature existante sur le sujet afin de faire un état des lieux des réponses déjà établies et des manques qu'il reste à combler.

1.2 Un lien complexe entre développement urbain et environnement

1.2.1 L'étalement urbain peut en partie être expliqué par la recherche de certains services écosystémiques

Après avoir revu les arguments fournis par l'économie urbaine classique dans l'explication du phénomène d'étalement urbain, nous nous concentrons sur le rôle joué par l'environnement dans les choix de localisation des individus. Nous expliquons comment les services écosystémiques peuvent avoir un impact sur le développement résidentiel en bordure des villes.

Au cours des dernières décennies, la notion d'étalement urbain a engendré une grande littérature en économie. En analysant les villes des Etats-Unis, Glaeser and Kahn (2004) montrent qu'en moyenne, seulement 63% de la population des villes vit dans un rayon de 10 miles autour du centre, tandis que 10% des villes ont presque 60% de leurs résidents à l'extérieur de ce cercle. Brueckner (2000, 2001) essaie d'expliquer ce comportement expansif. Il rappelle que l'étalement urbain est un processus économique : les développeurs immobiliers doivent enchérir pour obtenir la terre et rivaliser avec ceux qui en font un usage agricole. S'ils sont capables de mener l'enchère, la terre vaut plus en usage urbain qu'en usage agricole, et engendre de ce fait une contribution économique plus importante dans son état développé.

Suivant l'analyse faite par Mieszkowski and Mills (1993), Brueckner (2000) argumente que l'utilisation urbaine des terres donnera les meilleurs résultats économiques à cause de trois forces sous-jacentes : la croissance de la population, l'augmentation des revenus des ménages, et l'amélioration des transports. En effet les mécanismes suivants sont à l'oeuvre : à mesure que la population augmente, les villes doivent s'étendre spatialement pour pouvoir accueillir plus d'individus. La croissance des revenus permet aux ménages de demander plus d'espace habitable. Ils trouvent des espaces peu chers en périphérie de la ville centre, où ils peuvent s'installer grâce aux améliorations des systèmes de transports, qui réduisent le coût des trajets. Le modèle fondateur d'Alonso (1964), repris par Brueckner (1987), qui décrit la ville monocentrique, permet de démontrer que la combinaison de ces trois effets stimule la croissance spatiale des villes.

Glaeser and Kahn (2004) soulignent eux aussi aussi le rôle essentiel de l'automobile dans le processus d'étalement urbain. Ils insistent sur le fait que l'automobile a deux effets sur la déconcentration de la population. Premièrement, comme dans l'analyse de Brueckner (2000), la réduction des coûts des transports accroît la distance possible entre le lieu de résidence et le lieu de travail. Deuxièmement, l'automobile élimine les économies d'échelle à l'oeuvre dans d'anciennes technologies des transports. En effet, les ports et les gares sont des infrastructures importantes qui ne peuvent être dupliquées facilement à travers la zone métropolitaine. En conséquence, les villes traditionnelles sont regroupées autour d'un port ou d'un noeud ferroviaire. Au fur et à mesure que la voiture et les camions ont remplacé les bateaux et les trains, ces économies d'échelle ont disparu, permettant la déconcentration de l'emploi à travers les zones métropolitaines et à travers le pays. Cet effet renforce, à son tour, l'effet précédent.

La hausse des revenus et la dominance de la technologie automobile sont deux biais par lesquels l'étalement urbain est rendu possible. Cependant, ces deux phénomènes ne permettent pas d'expliquer complètement pourquoi les ménages choisissent de s'implanter dans les banlieues et au delà, loin du centre-ville.

Dans les années 1970, le phénomène de périurbanisation des classes moyennes aux États-Unis a également été expliqué par un effet de rejet des centres villes dit « effet push » : les ménages choisissent de s'éloigner de zones centrales car elles concentrent des désaménités urbaines telles que la criminalité ou encore la congestion (Nechyba and Walsh, 2004).

Au cours des dernières années, c'est un effet d'attraction, dit « effet pull », qui a été étudié : l'étalement urbain est en partie motivé par les préférences des ménages pour le cadre de vie propre aux zones périurbaines, qui leur permet de « vivre dans un cadre naturel loin de l'agitation des villes, dans des maisons spacieuses et pourvues de jardins, tout en conservant la source de rémunération qu'est l'emploi en ville » (LeJeannic, 1997). Les services écosystémiques, présents à la périphérie des villes, jouent un rôle dans cet effet « pull ».

Les modèles économiques urbains standards considèrent la ville comme une plaine homogène et sans aspérités, ce qui ne constitue pas un cadre adéquat pour étudier le rôle de l'environnement et des services écosystémiques. Cependant, des modèles plus récents intègrent l'hétérogénéité de l'espace à travers la présence de certains types de services écosystémiques. Wu (2001) fut le premier à concevoir un modèle où les localisations résidentielles sont différenciées par leur niveau d'aménités environnementales. Le niveau d'aménités offert à une localisation particulière dépend de sa distance à un point de repère majeur du paysage, comme par exemple le littoral. Plus les ménages s'installent près du littoral, plus ils bénéficient d'aménités environnementales.

Dans un cadre légèrement différent, Cavailhès et al. (2004) ou plus récemment Coisnon et al. (2014a) proposent un modèle dans lequel les terres agricoles fournissent des services à la périphérie de la ville. Ils introduisent des préférences pour les aménités rurales directement dans la fonction d'utilité des ménages. Le modèle de Cavailhès et al. (2004) fournit une explication à l'existence d'une ceinture périurbaine dans les villes françaises, où la terre est partagée entre les ménages et les agriculteurs. Les auteurs mettent en avant un effet de substitution possible entre la taille des parcelles résidentielles et le niveau d'aménités rurales. Les ménages veulent s'installer dans des parcelles de grande taille à proximité directe de la ville, mais ils sont prêts à habiter dans des parcelles plus petites si celles-ci sont accolées directement à des terres agricoles. Ces choix reflètent les préférences des ménages pour les espaces ouverts, qui fournissent des services écosystémiques.

Wu and Plantinga (2003) examinent la structure urbaine quand les ménages ont une préférence pour les espaces ouverts, qui dans ce modèle sont localisés de manière exogène, comme les parcs. Ils démontrent que l'existence d'espaces ouverts exogènes peut être responsable d'un développement urbain du type « saut-de-mouton », où des parcelles développées sont juxtaposées à des parcelles non-développées, conduisant à un étalement de la ville.

Utilisant un modèle dynamique de théorie des jeux, Turner (2005) montre également que quand les ménages tirent de l'utilité des espaces ouverts à proximité de chez eux, l'équilibre sur le marché foncier est atteint avec une structure urbaine mixte, où des zones bâties se mélangent à des zones naturelles, et dans laquelle des zones reculées peuvent être développées avant des zones plus centrales.

Tous les résultats théoriques cités précédemment révèlent que les préférences des ménages pour des services écosystémiques présents à la périphérie des villes encouragent le phénomène d'étalement urbain. Ce résultat est confirmé par la littérature empirique.

En reprenant l'analyse faite par Pouyanne (2008), nous pouvons mettre en avant deux courants de la littérature empirique qui traitent de ces questions. Le premier s'intéresse de façon détournée à la question des services écosystémiques : il s'agit de la littérature sur les migrations résidentielles. Dans la continuité des travaux fondateurs de Graves and Linneman (1979), de Palma et al. (2007) analysent les inégalités de distribution des aménités environnementales dans la région parisienne. Ils démontrent que les ménages tendent à se localiser près des parcs et des jardins. Cet effet est significatif seulement à l'échelle spatiale la plus fine, et non à l'échelle communale, ce qui signifie que c'est la proximité directe aux espaces ouverts qui est valorisée : soit la vue immédiate, soit l'accessibilité à pied. Détang-Dessendre et al. (2004) analysent les comportements de migrations résidentielles en fonction de la position dans le cycle de vie. Elles révèlent que les habitants d'Ile de France âgés de 45 à 64 ans sont davantage susceptibles d'immigrer dans une commune rurale. Ce résultat proviendrait « du désir de profiter d'aménités rurales après avoir vécu dans une ville encombrée » (p.22).

Le second courant de la littérature empirique étudie de façon plus directe l'impact de certains services écosystémiques sur la forme urbaine : il s'agit de la littérature consacrée aux « externalités d'usage du sol », au sens où l'on cherche à mesurer les effets externes liés à différent types d'usage du sol dans l'espace urbain. Cette littérature va permettre de vérifier et de préciser l'hypothèse de préférence des ménages pour des services écosystémiques. Elle repose sur les méthodes habituelles d'évaluation des biens publics en économie de l'environnement : la méthode des préférences révélées et la méthode des préférences déclarées. La plupart des études montrent la présence d'effets externes positifs associés aux services écosystémiques en milieu urbain.

Dans la plupart des études, des prix positifs sont rapportés pour les arbres, (Kestens et al., 2004; Cavailhès et al., 2009), les forêts périurbaines (Tyrväinen and Miettinen, 2000) aussi bien que pour les parcs et les ceintures vertes (Shultz and King, 2001) [1]. Irwin and Bockstael (2002, 2004) utilisent des données parcellaires pour étudier les externalités liées à l'usage du sol dans le Maryland, Etats-Unis. Elles montrent que les caractéristiques du paysage et la présence plus ou moins importante de voisins expliquent l'évolution vers un développement urbain s'étalant à la frange rurale-urbaine. Dans la même veine, Carrion-Flores and Irwin (2004) constatent que les préférences

1. McConnell and Walls (2005) proposent une revue complète de la littérature sur la valorisation non marchande des espaces ouverts

des ménages pour des zones à basse densité influencent la structure du développement urbain : les nouvelles zones bâties se situent près de terres non-développées, à la périphérie urbaine. Burchfield et al. (2006) étudient également les facteurs déterminants de l'étalement urbain ; ils insistent sur l'importance des aménités environnementales, comme un climat tempéré ou l'état de l'aquifère.

Le rôle des services écosystémiques dans les choix de localisation des ménages, entrainant le phénomène d'étalement urbain, est donc largement accepté de manière à la fois théorique et empirique. Les services écosystémiques existant à la périphérie urbaine améliorent de manière directe la qualité de vie dans les zones périphériques qui, à leur tour, attirent les ménages (Blomquist et al., 1988). Cependant, le développement de nouvelles terres et la conversion d'anciennes terres agricoles vers des usages urbains peuvent conduire à la dégradation des services rendus par l'écosystème. La prochaine sous-section examine comment l'urbanisation affecte la fournitures des services écosystémiques.

1.2.2 Les services écosystémiques peuvent être dégradés ou stimulés par l'étalement urbain

Dans cette section, nous voulons comprendre comment le processus d'étalement urbain vient modifier la production des services écosystémiques. En effet, il affecte la nature de deux manières : premièrement, il a un impact sur les consommations énergétiques, ce qui affecte le climat à l'échelle locale et régionale ; deuxièmement, il peut modifier l'écosystème et la disponibilité en ressources naturelles.

1.2.2.1 Etalement urbain et consommation d'énergie

L'étalement urbain entraîne l'éloignement des zones résidentielles du centre de la ville. Les ménages, en vivant plus loin, doivent donc parcourir quotidiennement une plus grande distance pour accéder à leur lieu de travail, en utilisant le plus souvent l'automobile, ce qui augmente la consommation d'énergie globale. L'augmentation de la consommation énergétique est responsable d'une hausse des emissions de gaz à effet de serre et d'autres polluants. En venant modifier les écosystèmes existants, l'augmentation des émissions polluantes perturbe la capacité de ceux-ci à réguler les températures et le régimes des précipitations, et affecte donc les services écosystémiques du maintien de la qualité de l'air et de la régulation du climat.

La relation entre étalement urbain et consommation énergétique a été étudiée depuis les travaux de Newman and Kenworthy (1989) qui relient de façon inverse la densité résidentielle et la consommation d'énergie par tête (voir figure 1.1). Les deux auteurs obtiennent cette relation à partir d'une comparaison de 32 grandes villes dans le monde. Ils opposent notamment le modèle américain/australien, faiblement dense, dont le développement est fondé sur l'usage de l'automobile et le modèle européen/asiatique, aux densités élevées, qui procurent un environnement plus favorable aux transports en communs et aux modes « doux ».

La courbe de Newman and Kenworthy (1989) a été confirmée par plusieurs études ultérieures. Naess (1996) étudie 22 grandes villes nordiques et conclut que les variables décrivant les formes urbaines, notamment la densité de population, exercent une forte influence sur la consommation d'énergie dans les transports (déplacements quotidiens). En France, Fouchier (1997) teste plusieurs critères de densité sur l'ensemble des communes d'Ile de France et établit une relation inverse entre la densité humaine (somme des densités résidentielle et d'emploi) et la distance de déplacement par jour ainsi qu'avec les consommations énergétiques et les émissions de polluants pour les déplacements.

L'ensemble des résultats de ces travaux portant sur le lien entre l'étalement urbain et la mobilité viennent corroborer le fait que l'étalement urbain a un impact négatif sur

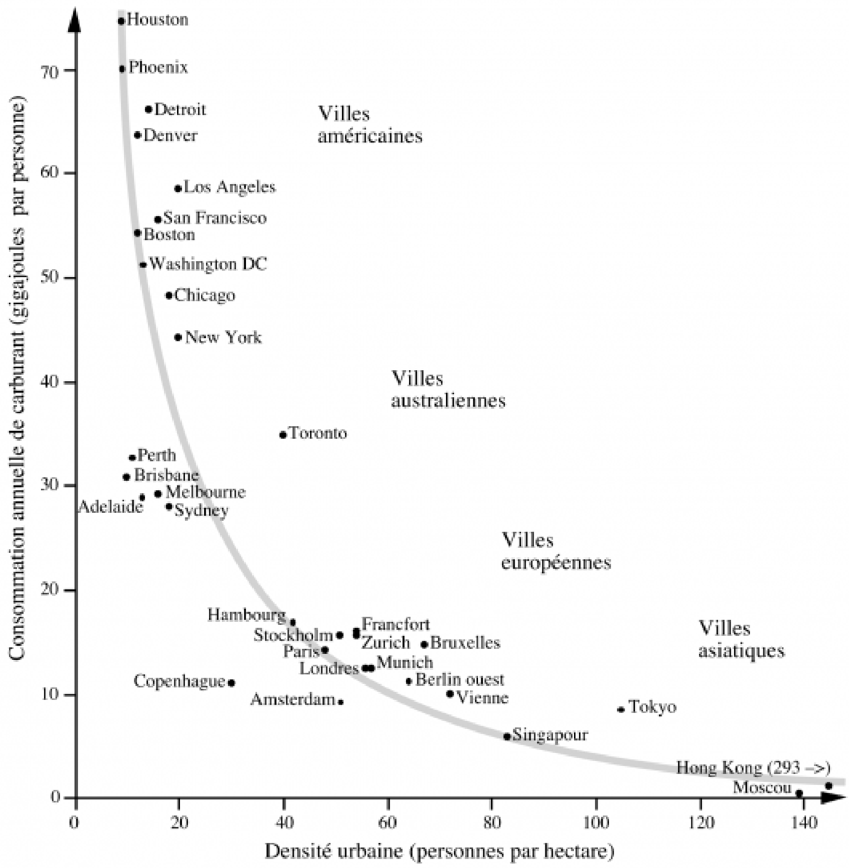

FIGURE 1.1 – La relation inverse entre densité et consommation de carburant. Source : Newman et Kenworthy (1989).

le changement climatique et la qualité de l'air, aussi bien au niveau local qu'au niveau global. Certaines études le démontrent de façon explicite : Bart (2010) montre que l'augmentation des émissions de GHG liées au transport sont expliquées, en partie, par l'augmentation des surfaces bâties ; en allant se localiser en bordure des villes, les ménages américains contribuent à une augmentation des émissions de CO2, ayant des implications globales sur le changement climatique. Stone (2008) étudie d'autres types de polluants et démontre que l'étalement urbain a aussi un impact négatif sur la qualité de l'air local.

Ces résultats ont toutefois été controversés. Kahn and Schwartz (2008) soulignent le rôle des progrès technologiques : en dépit de la plus grande distance parcourue, les consommations de carburant ont peu évolué toutes choses égales par ailleurs, et la qualité de l'air n'a pas diminué dans les villes en expansion, car les voitures sont de moins en moins polluantes.

D'autre part, l'impact des déplacements sur la qualité de l'air n'est pas uniquement lié à la distance ; d'autres facteurs affectent directement la qualité de l'air comme la congestion ou le régime moteur des véhicules. Pouyanne (2004) met en effet en avant le fait que la densification implique un fort risque d'accroissement de la congestion, ce qui constitue un gaspillage d'énergie avéré. En se basant sur la loi dite « de Zahavi » (Zahavi and Ryan, 1980), qui stipule que le gain de vitesse permis par l'usage croissant de l'automobile a alimenté l'étalement de préférence à un gain de temps, il fait le raisonnement inverse, et avance que pour maintenir les temps de trajet stables, la réductions des distances moyennes permises par la densification se traduirait par une baisse des vitesses, et donc de la congestion.

La relation entre forme urbaine, consommation d'énergie et qualité de l'air est donc encore en questionnement.

1.2.2.2 Etalement urbain et ressources naturelles

Le processus d'étalement urbain est aussi responsable de la disparition d'une partie des ressources naturelles disponibles. En Europe, 1,3% du stock total des terres a subi un changement de couverture du sol entre 2000 et 2006 et ce sont les surfaces artificielles qui ont le plus augmenté (European Environment Agency, 2010). Aux Etats-Unis, presque 25 millions d'hectares de terres ont été convertis en terres développées entre 1982 et 1997, la moitié de ces terres étant à l'origine des terres agricoles, et plus d'un tiers des terres forestières (Natural Resources Conservation Service, 1999). La disparition de la forêt et des terres agricoles au profit du développement urbain affecte une grande partie des services écosystémiques.

Tout d'abord, le développement urbain provoque la diminution de la quantité et de la qualité des réserves d'eau. L'urbanisation croissante engendre une augmentation de la taille et du nombre des surfaces imperméables, menant à la dégradation des systèmes de cours d'eau. L'absorption des précipitations et leur retour aux nappes phréatiques aquifères se fait dès lors moins efficacement. Le volume plus important des ruissellements augmente la sévérité des inondations, tandis que les infiltrations moins efficaces ont pour conséquence la baisse de la quantité de l'eau emmagasinée dans les nappes phréatiques. Comme le soulignent Arnold and Gibbons (1996), cela menace les réserves d'eau potable, et réduit la contribution de la décharge d'eau souterraine au débit des cours d'eau. Dans le même temps, à la fois la sédimentation et la pollution transportée par les eaux pluviales augmentent, ce qui réduit la qualité de l'eau (Bannerman et al., 1993; Brabec et al., 2002).

L'urbanisation est également responsable de la transformation rapide de l'habitat naturel de la faune et de la flore : elle réduit la quantité d'habitats disponibles, la taille des parcelles d'habitat restantes, et le degré de connectivité entre ces parcelles, et elle est souvent mise en cause dans la perte de biodiversité (Czech et al., 2000).

Cependant la littérature n'est pas unanime sur le sujet, et certains auteurs ont montré que la biodiversité pouvait être préservée avec une urbanisation peu dense. Dans une revue de la littérature reprenant 105 études écologiques sur l'impact de l'urbanisation sur la richesses des espèces non-aviaires, McKinney (2008) montre que la nature variée du tissu urbain a une influence complexe sur la biodiversité locale. Il note que près de 65% des études sur les plantes mettent en avant une augmentation de la richesse des espèces dans les zones où l'urbanisation est modérée, ainsi que 30% des études sur les invertébrés et presque 15% des études sur les petits mammifères.

Dans la même veine, des études introduisant le débat sur le *land-sharing/land-*

sparing dans un contexte urbain se sont interrogées directement sur le rôle de la forme urbaine dans le maintien possible de la biodiversité. Le *land sparing* minimise la superficie des zones urbanisées, de sorte que ces zones soient les plus denses possibles, afin de maintenir de larges espaces ouverts à proximité. A contrario, le *land sharing* propose un développement plus étendu mais moins intense, ce qui rend les espaces ouverts plus fragmentés mais entremêlés aux habitations (Brenda and Fuller, 2013; Stott et al., 2015). Soga et al. (2014) montrent notamment qu'à un taux d'urbanisation élevé (c'est-à-dire avec un nombre d'immeubles important pour une surface donnée), le *land sparing* est la structure qui permet de conserver une population plus importante pour la majorité des espèces, alors qu'à un taux d'urbanisation plus faible, le *land sharing* permet de mieux préserver certaines espèces comme les papillons. L'impact du développement urbain et de la forme urbaine sur la biodiversité est donc complexe et reste flou.

Bien que la biodiversité ne soit pas considérée en elle-même comme un service écosystémique, elle influence de manière significative le fonctionnement des écosystèmes et a dès lors des impacts sur les bénéfices que peuvent tirer les hommes de ces écosystèmes.

Ainsi, cette section nous permet de souligner la double relation existant entre le développement urbain et l'environnement : certains services écosystémiques, notamment les services culturels fournis par les espaces ouverts, attirent les ménages vers la périphérie des villes, ce qui contribue à amplifier le phénomène d'étalement urbain. Ce faisant, les ménages viennent perturber les écosystèmes, et sont dès lors eux-mêmes responsables de la modification de la fourniture des services écosystémiques dans ces zones. Certains services écosystémiques se retrouvent dégradés, alors que d'autres peuvent potentiellement être maintenus, voire augmentés. Toutes ces interactions s'expriment sur le marché foncier, à travers les comportements individuels de localisation. Il apparaît important de saisir quel est l'impact des mesures prises sur ce marché, qui viennent complexifier les interconnexions existantes entre développement urbain et environnement.

1.3 Le rôle d'une intervention publique sur le marché foncier

Les études citées précédemment ont amélioré notre compréhension des implications possibles de la relation entre développement urbain et état des écosystèmes. Se basant sur les résultats qui mettent en avant la dégradation de l'environnement par l'étalement urbain, les institutions mettent en place des politiques publiques visant à promouvoir une forme de ville compacte. En France, c'est le cas de la loi relative à la « Solidarité et au Renouvellement Urbain » (dite loi SRU) de 2000, qui comprend notamment un volet ayant pour but l'incitation à réduire la consommation des espaces non urbanisés et ceux à la frange urbaine, en favorisant la densification des espaces déjà urbanisés. En 2014, la loi ALUR (Accès au Logement et un Urbanisme Renové) vient encore renforcer les incitations à la densification. On retrouve l'équivalent aux Etats-Unis avec les politiques de « Smart Growth », en vigueur depuis le milieu des années 1990.

La question se pose de savoir comment ces politiques publiques affectent la fourniture de services écosystémiques. Quels en sont les effets directs, et indirects ? Viennent-elles renforcer la complexité du lien entre forme urbaine et environnement ? Pour répondre à ces questions, cette section propose de rapidement passer en revue les différentes études qui traitent des politiques de maîtrise de l'occupation du sol. Nous faisons la distinction entre d'une part les études qui traitent des politiques visant à contrôler directement l'étalement urbain à travers la maitrise de l'occupation du sol pour un usage résidentiel, et d'autre part les études qui passent par une maîtrise d'occupation du sol pour des usages environnementaux et qui peuvent avoir des effets inattendus.

1.3.1 Les politiques de maîtrise de l'occupation du sol pour un usage résidentiel : quelle efficacité ?

Les types politiques ayant pour but de maîtriser l'occupation du sol à travers l'usage résidentiel qu'en font les ménages peuvent être fondés soit sur des outils réglementaires, soit sur le marché.

Les outils basés sur le marché prennent majoritairement la forme de taxes sur la propriété ou sur le développement. Les taxes sur la propriété concernent des parcelles déjà urbanisées, tandis que les taxes sur le développement sont payées pour la création de nouvelles parcelles urbanisées.

Les outils réglementaires font quant à eux partie des mesures les plus répandues pour gérer l'étalement urbain, en France et en Europe comme aux Etats-Unis. Ils peuvent être séparés en trois catégories. La première regroupe les politiques de zonage. De tels outils sont, par exemple, les zonages d'exclusion qui définissent une utilisation des terres restreinte, ou les régulations et normes concernant les nouvelles constructions. Nous pouvons citer comme exemple les proportions définissant la surface maximale constructible dans une parcelle, comme le coefficient d'occupation du sol (COS) qui ont été mis en place dans les plans locaux d'urbanisme (PLU) en France. Le COS impose une surface minimum de terrain non bâtis et a été utilisé pour contrôler la densification, il a été supprimé suite à la loi ALUR, afin de favoriser la densification.

Les restrictions quantitatives, comme les plafonds de croissance ou les plafonds de population forment la deuxième catégorie d'outils réglementaires. Ces restrictions limitent directement le nombre de permis de construire accordés chaque année.

Enfin, dans la dernière catégorie de ces outils, nous retrouvons les frontières géographiques, telles que les ceintures vertes ou les frontières urbaines. Les ceintures vertes et les frontières urbaines ferment les zones urbanisées au niveau de l'agglomération : elles définissent des délimitations géographiques que l'urbanisation ne doit en aucun cas dépasser. Tous les outils mentionnés précédemment ont le même objectif initial : contrôler l'étalement urbain en agissant directement sur la maîtrise de l'occupation du sol pour un usage résidentiel, afin de gérer les effets négatifs, en particulier ceux liés à la dégradation de l'environnement. Les études économiques qui analysent les effets de telles politiques foncières sont détaillées ci-dessous.

Brueckner (2000, 2001) propose un cadre conceptuel permettant d'évaluer l'efficience des politiques de lutte contre l'étalement urbain mises en place pour gérer la défaillance du marché liée à la non-prise en compte des bénéfices fournis par les espaces ouverts. Il met en avant que la taille de la ville à l'équilibre du marché est trop grande car les bénéfices procurés par les espaces ouverts ne sont pas pris en compte dans le calcul économique des agents, et qu'une taxe sur le développement est donc un outil idéal pour matérialiser le coût de la perte de ces bénéfices, afin d'obtenir une structure de ville optimale. Cependant, il insiste sur la difficulté de mettre en place une telle politique de façon efficace car elle requière de connaître et d'assigner une valeur monétaire aux bénéfices fournies par un hectare de terre naturelles.

Bento et al. (2006) étendent cette analyse en comparant différents types de politiques de contrôle de l'étalement urbain, telles qu'une taxe sur le développement, une taxe sur la propriété, une frontière urbaine, et une taxe sur le carburant pour limiter l'usage de l'automobile. Ils développent un modèle théorique d'économie urbaine qui compare ces politiques à travers leur efficacité et leur effets redistributifs. L'efficacité des politiques est mesurée par la variation de la valeur totale de la terre dans la ville, alors que les effets redistributifs sont calculés en séparant les propriétaires fonciers en trois catégories : ceux qui attribuent leurs terres à l'usage résidentiel avant et après la politique, ceux qui modifient leur comportement en réponse à la politique en ne développant pas les terres en usage résidentiel, et ceux qui attribuent leurs terres à un usage agricole avant et après la politique. Les auteurs démontrent que dans une perspective d'efficacité, une taxe sur le développement ainsi qu'une frontière urbaine sont les deux outils les plus appropriés. Néanmoins, ils démontrent par l'analyse des effets redistributifs que l'utilisation de ces outils ne sera pas forcément bénéfique pour tous les propriétaires fonciers.

Langpap and Wu (2008) proposent d'étudier les fondements empiriques du lien existant entre les politiques foncières et l'environnement. Ils démontrent que les politiques de zonages et de frontières urbaines, qui sont des politiques où la terre est acquise directement, sont les plus efficaces pour modifier la couverture du sol, et ce sont celles qui ont l'effet positif le plus important sur l'abondance des espèces naturelles. A contrario, les politiques publiques incitatives, qui essayent de baisser la rente du développement relativement aux autres usages de la terre, comme la mise en place d'une taxe sur le développement, n'ont pas d'effets significatifs sur la fourniture d'habitat et la biodiversité.

1.3.2 Les politiques de maîtrise de l'occupation du sol pour des usages environnementaux : des effets inattendus

Les études citées précédemment analysent les politiques ayant pour but de limiter l'étalement urbain à travers la maîtrise de l'usage résidentiel du sol. Nous détaillons maintenant les études économiques qui analysent les politiques publiques implémentées directement pour améliorer la qualité de l'environnement à travers la valorisation de l'occupation du sol pour des usages environnementaux. Nous montrons que ces politiques ont parfois des effets parfois inattendus sur le marché foncier et donc sur l'étalement urbain.

La détérioration de l'environnement a lieu le plus souvent à l'échelle locale, ceci en fait un problème spatialisé, qui nécessite de mettre en place des politiques publiques également spatialisées (Tietenberg, 1974). Dans la pratique, de telles politiques peuvent prendre différentes formes, et il existe à nouveau une distinction entre les outils réglementaires et les outils incitatifs basés sur le marché. La seconde catégorie d'outils est notamment utilisée dans le secteur agricole, où les exploitants agricoles sont incités à limiter leurs émissions de pollution afin d'améliorer la qualité environnementale dans un secteur donné. Ce sont ce que l'on appelle des politiques agro-environnementales. Les instruments réglementaires sont quant à eux utilisés sous la forme de zonages environnementaux. Certaines zones spécifiques sont définies comme revêtant une importance particulière dans la préservation des écosystèmes et dans la fourniture de services écosystémiques, et les activités humaines à l'intérieur de ces zones sont dès lors sujettes à des conditions spéciales. En France, de telles réserves écologiques sont par exemple implémentées à travers l'appellation « zones Natura 2000 ». Aux Etats-Unis, des politiques similaires ont également été utilisées, à travers par exemple la mise en place du « Endangered Species Act » qui a pour but de protéger les écosystèmes affaiblis par les activités humaines en sauvegardant des lieux répertoriés comme habitats naturels critiques.

Les économistes se sont intéressés aux conséquences de l'utilisation de ces politiques environnementales sur le marché foncier. Par exemple, Irwin and Bockstael (2004) montrent que plusieurs politiques américaines de « smart growth » ou croissance raisonnée ont eu une influence significative et parfois inattendue sur la conversion des terres. Les politiques de croissance raisonnée incluent des zonages environnementaux, et sont promues comme étant des instruments efficaces de contrôle de la croissance permettant de préserver les espaces ouverts et les habitats naturels. Cependant, ces politiques modifient également la croissance des zones se situant aux alentours directs des zones protégées : elles ont pour effet d'augmenter l'urbanisation des zones alentours. Ces résultats sont confirmés par l'étude de Vyn (2012), qui étudient les conséquences inattendues des politiques de zonage agricole strict mises en place en Ontario. Il observe un effet d'urbanisation en « saute-moutons » autour des zonages agricoles, car la demande de terres pour un usage urbain a augmenté dans les zones accolées aux zones protégées. Ce résultat a également été démontré dans un cadre théorique : Coisnon et al. (2014b,c) mettent en lumière l'importance des politiques agricoles dans le processus de développement urbain. Les politiques agro-environnementales instituées pour préserver les paysages traditionnels et la qualité environnementale des zones agricoles ont pour conséquence d'attirer les ménages qui trouvent leur bien-être augmenté par la présence de telles aménités. En utilisant un modèle théorique de ville monocentrique, Coisnon et al. (2014b) démontrent que la mise en place de politiques agro-environnementales territorialisées est directement responsable d'une hausse de l'urbanisation, ce qui est contradictoire avec l'objectif initial de ces politiques. Egalement dans un cadre théorique, Quigley and Swoboda (2007) étudient les effets de l'Endangered Species Act américain sur le marché foncier. Ils simulent un modèle d'équilibre général et démontrent que cette régulation n'affecte pas seulement les terres des zones protégées, mais également la région dans son ensemble : la rente foncière et la densité de population des zones non-ciblées augmentent, ce qui entraine une augmentation de la quantité totale de terres développées dans la région.

Ces études démontrent donc que la mise en place de politiques environnementales peut avoir des effets inattendus sur le développement urbain à travers des mécanismes à l'oeuvre sur le marché foncier. Il apparaît donc important de comprendre et d'analyser ces mécanismes, afin d'appréhender de façon globale la relation existante entre l'urbanisation et l'environnement.

1.4 Apports et canevas de la thèse

1.4.1 Les apports de cette thèse

La question principale à laquelle répond cette thèse est la suivante : est-il possible de concilier développement urbain et préservation de l'environnement ? Plus précisément, nous revisitons le débat sur les formes de villes durables en répondant aux questions suivantes : la ville compacte est-elle une forme de ville durable ? Si oui, est-elle la seule ? La provision des services écosystémiques est-elle conditionnée par la structure urbaine considérée et si oui quels services et comment ?

A travers une analyse microéconomique du marché foncier, nous proposons de répondre à ces questions.

Cette thèse contribue d'abord à la littérature par son apport méthodologique. En effet, afin d'analyser les questions ayant trait à la fois à la structure urbaine et à l'environnement, nous sommes amenés à mobiliser et à combiner deux cadres d'analyse théorique : l'économie de l'environnement et l'économie spatiale. Le cadre méthodologique de l'économie spatiale nous est indispensable afin de pouvoir mener une analyse à l'échelle de la ville. Le cadre méthodologique de l'économie de l'environnement nous permet quant à lui de mobiliser les notions d'externalité et de bien-être.

L'introduction des préoccupations écologiques dans les modèles d'économie spatiale peut prendre des formes diverses, et les études sur le sujet se scindent en deux catégories suivant le cadre analytique retenu : les modèles reposant sur la Nouvelle Economie Géographique (NEG), et les modèles d'allocations des sols d'économie urbaine. Les premiers, dans la lignée des travaux de Krugman (1991), rendent compte des mutations spatiales à une échelle inter-régionale, tandis que les seconds, inspirés par les travaux de Von Thünen (1827) ont une dimension micro-spatiale. Les modèles développés en économie urbaine 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 proportionnels à leur distance au centre. Leur disponibilité individuelle à payer pour une localisation en chaque emplacement de l'espace détermine leur fonction d'enchère foncière. 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 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 une base de modélisation intéressante pour répondre à notre problématique où la répartition des sols entre différents usages avec des impacts variés sur l'environnement est un aspect essentiel. En introduisant la problématique environnementale à travers la notion de services écosystémiques et en menant une analyse en terme de bien-être, cette thèse contribue à enrichir la littérature mêlant les cadres de l'économie urbaine et de l'économie de l'environnement.

Dans cette thèse, nous adoptons en effet un point de vue microéconomique et nous nous intéressons au fait que l'étalement urbain est le résultat des comportements résidentiels individuels sur le marché foncier. En conséquence du comportement des agents économiques, l'étalement urbain est caractérisé simultanément par une baisse de la demande pour le développement des terres du centre ville ainsi qu'une hausse de la demande pour les zones périphériques. Ce phénomène augmente la compétition entre les différents usages du sol à l'orée des villes, et mène à la conversion des terres agricole vers un usage urbain [2]. L'analyse économique du marché foncier à l'échelle micro-spatiale nous permet d'éclairer le débat sur les formes de villes durables en l'enrichissant d'une dimension sociale : au lieu de se concentrer uniquement sur les conséquences écologiques du développement urbain, nous analysons également les conséquences en terme de comportements des agents. Cela nous permet de mettre en avant la façon dont les préférences des ménages viennent complexifier les questionnements autour de la ville durable.

De plus, nous analysons différents types de services écosystémiques. Ce faisant, nous mettons en avant les arbitrages et les synergies qui peuvent exister entre ces différents services : l'expansion urbaine peut avoir lieu aux dépens de certains types de services, tout en en favorisant certains autres. Nous analysons à la fois la préservation de différents types de services au sein d'un même modèle (chapitre 2 et chapitre 3), mais aussi deux types de services différents dans des modèles complémentaires (chapitre 3 et chapitre 4). Le premier type d'analyse nous permet de voir comment il est possible de préserver un bouquet de services écosystémiques, tandis que la deuxième analyse nous permet de tester la robustesse des conclusions sur la forme de ville durable lorsque différents services sont à l'étude. La combinaison de ces deux analyses nous permet de saisir toute la complexité du lien entre urbanisation et environnement, et d'éclairer le débat d'un regard neuf.

Le corps de la thèse est constitué de trois chapitres, que nous présentons ici rapidement pour en faciliter la lecture.

2. C'est pourquoi les termes étalement urbain, expansion urbaine, développement urbain et urbanisation seront utilisés comme synonymes pour le reste de cette thèse.

1.4.2 Plan de la thèse

Chapitre 2

Le deuxième chapitre de cette thèse est une étude empirique qui compare la valeur esthétique des paysages urbains à leur valeur écologique. Dans ce chapitre, notre but est d'étudier les types de relation existants entre les préférences des ménages et la préservation de l'environnement. Dans un premier temps, nous testons le postulat selon lequel les ménages valorisent les paysages et l'environnement qui les entoure car ils leur procurent des services écosystémiques culturels, notamment parce-qu'ils sont vecteurs de valeurs esthétiques.

Il s'agit de déterminer comment les ménages valorisent l'environnement urbain qui les entourent. Pour ce faire, nous conduisons une étude de choix expérimentaux appliqués au choix résidentiel, réalisée sur un échantillon de 854 habitants de la région Dijonnaise. Nous étudions en particulier deux attributs relatifs à l'environnement urbain : la présence de vert dans le paysage à proximité de la résidence, et la densité de bâti dans le voisinage de la résidence. Nous démontrons que les ménages préfèrent les environnement verts et peu denses.

Dans un second temps, il s'agit de comparer les préférences des ménages avec une valeur écologique des différents environnements urbains. En effet, la présence d'arbres, de pelouses, d'arbustes, etc et d'un bâti plus ou moins dense peut avoir un impact sur la fourniture d'autres services écosystémiques, et notamment la fourniture d'habitat naturel, faisant partie de la catégorie des service de régulation.

En comparant la valeur esthétique accordée par les ménages aux différents types d'environnement urbains et leur valeur écologique, nous démontrons que les préférences des ménages ne sont pas nécessairement contradictoires avec la préservation de l'environnement. Il serait possible de concilier les deux dans des types d'habitat peu denses et entourés de verdures. Comprendre si les attentes des ménages, consommateurs de foncier résidentiel, vis-à-vis des attributs paysagers sont en accord avec la valeur écologique de ces attributs est crucial pour distinguer les contextes où politiques d'aménagement, agricoles et environnementales peuvent bénéficier de synergies de ceux où la recherche de compromis est nécessaire.

Cette étude nous permet donc de valider empiriquement le fait que (i) les ménages valorisent certains formes de paysages urbains plus que d'autres, et que (ii) ces paysages ont des valeurs écologiques différentes. La validation de ces hypothèses dans une étape préalable nous sert de base à notre analyse théorique du chapitre suivant.

Chapitre 3

Se basant sur les résultats empiriques démontrés dans le chapitre précédent, le troisième chapitre de cette thèse analyse de manière théorique les formes optimales de structure urbaine lorsque le planificateur social a un objectif de préservation des habitats naturels et de la biodiversité. La question sous-jacente est la suivante : est-il préférable d'avoir des formes urbaines étalées avec de la nature en ville (land sharing) ou à l'inverse des villes compactes mais qui préservent les écosystèmes alentours (land sparing) ? Nous proposons dans ce chapitre d'introduire le débat sur le « land-sharing vs land-sparing » dans un contexte urbain et en utilisant des outils d'analyse microéconomique. Nous testons ici encore la combinaison possible entre la valorisation de services écosystémiques culturels, et de services de régulation tels que la provision d'habitat par les espaces ouverts. Nous démontrons que l'optimum social peut être atteint avec des formes urbaines différentes, allant d'une ville très compacte à une ville très étalée, selon la capacité de différents types d'espaces ouverts à produire des habitats naturels. Nous montrons ici encore sous quelles conditions les préférences des ménages peuvent être conciliables avec les objectifs de préservation de l'environnement.

Chapitre 4

Enfin, le quatrième chapitre de cette thèse, nous nous intéressons à un service écosytémique de régulation, qui est le maintien de la qualité de l'air. Ce chapitre est néanmoins directement relié aux deux premiers car il interroge sur la capacité de différentes formes urbaines à soutenir au mieux ce service. En se basant sur le modèle de ville monocentrique établi par Ogawa and Fujita (1982), nous démontrons que la prise en compte de la pollution industrielle dans le comportement de localisation des ménages amène à un équilibre du marché où la ville est plus spatialisée : les zones industrielles d'un coté, et les zones résidentielles de l'autre. La conséquence directe est dès lors l'augmentation de la distance parcourue par les ménages pour les trajets domicile-travail, provoquant une augmentation de la pollution atmosphérique émise par les voitures. Nous étudions ensuite dans ce chapitre quelles doivent être les politiques publiques mises en place pour préserver la qualité de l'air, sachant que deux types de pollution sont en cause : l'une provenant des industries, et l'autre des ménages par leur utilisation de la voiture. Nous démontrons l'impact indirect que peuvent avoir certaines politiques publiques, comme une taxe sur le carburant, sur le marché foncier et le bien-être. Il s'agit ici encore d'étudier comment les choix individuels de localisation affectent la structure urbaine générale et la préservation de l'environnement. Dans ce cas, les préférences des ménages et leurs comportements résidentiels entrent en contradiction avec la préservation de la qualité de l'air. Cela remet en cause l'utilisation des politiques publiques partielles dans un contexte où les externalités environnementales proviennent de sources multiples.

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Chapitre 2

Comparing aesthetic and ecological values of urban landscape

2.1 Introduction

Slightly lower than 30% in 1950, the share of the world population living in urban areas reached the 50% milestone in 2007. In the mean time, more than 360 000 km^2 of land were converted to urban use (Klein Goldewijk and Van Drecht, 2006). The combination of these two phenomena, namely the increase in urban population and in soil artificialization, points out the fast urban expansion in recent years. This phenomenon is responsible for numerous changes in the structure of urban areas. In particular, we note the apparition of periurbanisation, which is a diffuse urbanization at the periphery of cities, often explained by households' preferences for a green environment. The role of landscape in people's preference has received a lot of attention for the past half century in multiple disciplines, such as economics, geography and psychology. In psychology studies, Kaplan (1997) Staats et al. (2003) and Hartig and Staats (2006) demonstrate that natural environments, particularly green spaces, recorded consistently higher preference ratings than environment with little or no nature at all. In economics, a large empirical literature explores this question, mostly with the use of hedonic methods. In almost all these studies, positive hedonic prices are reported for trees (Kestens et al., 2004; Cavailhès et al., 2009), nearby recreational woods (Tyrväinen and Miettinen, 2000) as well as for parklands and greenbelts (Shultz and King, 2001) [1]. Whitehead et al. (2013) also found that individuals have higher levels of well-being when living in urban areas with more green spaces and Abrey et al. (2014) reports a positive relationship between the percentage of public green spaces in a resident's local area and their self-reported life satisfaction.

Urbanization is associated with fragmentation and loss of habitat which both affect landscape connectivity, defined as the degree to which the landscape facilitates the movement of species and other ecological flows (Taylor et al., 1993). Maintaining and restoring landscape connectivity, is critical for the preservation of biodiversity (Crooks and Sanjayan, 2006) and is of increasing concern for policy-makers.

Taxa have been shown to respond differently to urban environment : there has been a decrease in specialist species, but metropolitan areas and especially periuban areas have appeared favorable supports for generalist species (birds, butterflies, plants and other animal species) (Clergeau et al., 2006; Ramírez Restrepo and Halffter, 2013; McKinney, 2006, 2008). Green spaces such as public and domestic gardens or wastelands have appeared increasingly important to maintain connectivity in urban landscapes.

Hence, urban green landscapes are potential providers of both cultural and support ecosystem services. To what extent is the provision of one service compatible with the potential of the other ? In other words, are ecologically-rich green urban landscapes those that are also highly valued by households for their cultural or asthetic value ?

Several studies indeed indicate that population favor landscapes with strong ecolo-

1. See McConnell and Walls (2005) for a complete review of non market valuation studies applied to green space

gical performances (Tyrväinen et al., 2003; Klein, 2013). On the contrary, some others show that visually preferred landscapes are not those that are the richest from an ecological point of view (Hands and Brown, 2002; Williams and Cary, 2002). Context elements such as the type of landscape under study or the study's localization influence the results of these works (Gobster et al., 2007).

This study contributes to this literature by assessing the possible coexistence between cultural amenities and biodiversity in urban environment (see Ives and Kelly (2015) for an multidisciplinary review). The interest of this question is to evaluate the consistency between household's preferences and the supply of ecosystem services in order to highlight trade-off and synergies between different ecosystem services. Understanding if households' demand are consistent with ecological issues is important to distinguish between contexts were public policies could benefit from synergies from those where trade-off is required. This study aims to contribute to the debate by analyzing if households' preferences for landscape amenity are consistent with the contribution of landscape to habitat connectivity. The paper is organized as follow : in section 2, we evaluate households' preferences for urban landscape features with a choice experiment method based on their residential choice. In section 3, we compute the ecological performance of urban landscapes through the use of connectivity metrics. Finally, we compare both measures and discuss the results in section 4, and we conclude in section 5.

2.2 Choice experiment and residential location

2.2.1 Insight from the literature

The choice experiment (CE) method is based on the Lancasterian consumer theory (Lancaster, 1966) combined with the random utility theory. The CE method states that the value of a particular good is best explained in terms of the characteristics, or attributes, of that good. Using observations of people choice data through the construction of a hypothetical market using a survey design, this method allows to infer (i) which attributes significantly influence their choice, (ii) assuming price is included as one attribute, what they are willing to pay for an increase in any other attribute (Hanley and Barbier, 2009).

In the present study, we construct a hypothetical market for residential choice.

The extensive empirical literature allows to identify four broad categories of factors explaining residential location choice : dwelling unit characteristics (size, parking, garden, etc.), location characteristics (safety, air pollution, noise, etc.), accessibility characteristics (working places, leisure opportunities,etc.) and finally individuals socio-demographics characteristics (income, age, etc.) (Hunt, 2010; Prashker et al., 2008).

Applying choice experiment methodology, Kim et al. (2005) and Liao et al. (2015) investigate accessibility and location attributes. Kim et al. (2005) show that individuals prefer residential locations with a combination of shorter commuting time, lower transport costs, lower density and higher quality of school. Along with these results, Liao et al. (2015) demonstrate that respondents prefer walkable and transit-friendly neighborhoods.

Some other studies focus on attributes related to the environment around the place of residence. Earnhart (2002) shows that households are more likely to select houses located adjacent to water-based (river of lakes) or land-based features (forest or open fields) than houses lacking natural features. Phaneuf et al. (2013) also show that households prefer to live closer to a river, and even more when the river is clean of pollution.

Tu et al. (2016) analyse households' preference relative to their access to green space. They found that periurban forests have a significant recreation value for the local population, and that living near a park is also preferred by people in general.

To the best of our knowledge, there is a lack of choice experiment (CE) investigating the preference for the environment in urban location, such as urban density. As seen in the introduction, this question is extensively treated with revealed preferences methods. Despite the fact that CE is not based on actual choices of residents, this approach has a number of advantages over revealed preferences methods. In particular, CE offers better trade-off between variables that exist in the real world, allowing to avoid omitted variable issue : when respondents make their choice, they are asked to consider only the attributes specified in the experiment while considering that all other attributes are the same as in their current place of residence. Unobservable characteristics that matter to households are supposed to be the same for every alternatives in each choice. Thus, there is no bias due to the omission of a variable correlated with the amenity of interest. CE studies also avoid collinearity among attributes. Indeed, the attributes level presented to the respondent are chosen using principles from the design of fractional factorial experiment, and are considered to be orthogonal (Earnhart, 2002; Adamowicz et al., 1994).

In this way, CE appears to be an appropriate methodology to estimate the benefit that people gain from living in certain type of urban environment. In particular, we are interested in the preferences of respondents for a green view close to their house, and the intensity of the building density in their neighborhood. As the main goal of our study is to investigate the relationships between biodiversity and household's preferences for urban greenness, we choose to focus on these two attributes because they are at the same type drivers of residential choice and they have an impact on urban biodiversity.

2.2.2 Experimental design and data collection

2.2.2.1 Experimental design

The first step in experimental design is to choose relevant attributes and their levels to describe a particular good. In our study, we develop potential residential location alternatives that the respondents are ask to choose between. In order to focus on trade-offs between private housing characteristics and location characteristics related to urban environment, we identify six attributes affecting residential choice.

Table 2.1 lists the selected attributes and their levels. We select 3 attributes related to private dwelling characteristics : the presence of a private garden, the size of the living area, and a monetary attribute given by price of the house for owners and monthly rent for renters. The size of the living area and the price levels are expressed as percentage differences from the current situation. Although the pivoted percentage can introduce a potential bias because of different absolute level variations, it also guarantees reality of scenarios and comparability between responses, which is an important element in our case as respondents include both renters and owners.

We also select an attribute related to accessibility, measured by the distance in kilometers to the city center (the reference mark is the city hall) , which is in Dijon the place of most of urban amenities (cinema, restaurants, shops, etc). Finally, we choose to focus on two attributes related to the urban environment surrounding the residence. The first one is the presence of green in the street of the residence. The view on a green landscape is valued by households in periurban area. Tyrväinen and Miettinen (2000) found that dwellings with a forest view were on average 4.9% more expensive than dwellings with otherwise similar characteristics in Salo, Finland. Cavailhès et al. (2009) found that the housing price will be increased by $1.5\% - 2\%$ for a view of trees and fields in Dijon, France. We want to test if this relation exists also in central urban areas. The second attribute related to the urban environment is the density of buildings footprints in the vicinity of the residence (Caruso et al., 2017). This indicator is based on a geographical approach that combines graph theory and local spatial autocorrelation analysis to differentiate two main urban forms (high or low density of buildings footprints).

Attribute	Level
Compactness of the neighborhood	compact dispersed
Presence of green in the street of the housing	high low
Distance to the city center	3km 6km 9km
Private garden associated to the housing	yes no
Size of the living space (m^2)	−10% current +10%
Price/rent of the housing	−20% −10% current +10% +20%

Table 2.1 – Housing attributes and their levels in the CE

Respondents may not exactly understand what is meant by compacity, and they may not have the same representations of what is a high (or low) percentage of green in an urban landscape. Miscomprehension of attributes definition and their levels may produce responses which are, from the perspective of standard economic theory, anomalous and unsuited for incorporation within decision-making (Bateman et al., 2009). There is a growing consensus in the literature and amongst best-practice guides that the most effective method for promoting a good comprehension is the use of visual stimuli(Krupnick and Adamowicz, 2006; Mathews et al., 2006). Following this recommendations, we choose to use pictures to describe these two attributes. Moreover, the use of pictures taken in real spot in Dijon allows us to compute biodiversity score in order to compare households preferences with ecological performance (see section 3).

Compacity, as it is defined at the neighborhood scale (250m*250m) is described with aerial pictures of a compact and of a dispersed neighborhood. The presence of green is described with four pictures, even though there are only two attribute's levels. Indeed, we needed to identity a place with a low percentage of green and another with a high one in a compact neighborhood, as well as a place with a low percentage of green and another with a high one in a dispersed neighborhood. We chose carefully the pictures to be almost similar in the compact and in the dispersed neighborhood, and we carefully described the attribute's levels to the respondents, in that way they easily understood that there was only two levels of percentage of green in the landscape. Table 2.2 summarize the pictures used.

	High percentage of green	Low percentage of green
Compact neighborhood 		
Dispersed neighborhood 		

TABLE 2.2 – Pictures describing attributes levels

Once the attributes and their levels are chosen, the next step is to choose which options (i.e. combinations of attributes' levels) to include in the questionnaire. The full factorial range of combinations associated to our experimental design was too wide to collect the respondents' opinion on all of them. We selected a statistically efficient sub-set combinations using a Bayesian D-efficient design, applying Ngene software (ChoiceMetrics, 2014). The efficient design yields more information than an orthogonal design for a given number of choice sets, but requires a priori values (priors) on the population's preferences. Thus, as a first step, we implemented a pilot study on a sample of people based on an orthogonal design.

The pilot study was administrated to 76 respondents in June 2016. This allowed us to obtain priors in order to formulate a D-efficient design on a representative sample of the population. We obtained an D-efficient design resulting in 12 choice sets. Each choice set is composed of three alternatives scenarios. We do not include a status quo option nor a no-choice alternative. According to Hensher et al. (2005), including the no-choice is relevant only if the objective is to estimate the demand for various alternatives within a market. In our case however, the main objective is to study the impact of the relationships different attribute levels have upon choice. Thus, any non-choice alternative is likely to be pointless. The only information obtained from a non-choice alternative is that the decision maker would prefer not to choose any of the available alternatives. By forcing respondents to make a choice, we oblige them to trade off the attribute levels of the available alternatives and thus obtain information on the relationships that exist between the varying attribute levels and choice.

The form of our choice situation is described in figure 2.1 (in French). The question asked is : « Imagine that you should move from your current residence and you have the choice between the three following alternatives. Assuming that all the characteristics stay the same except these six attributes, which residence would you choose among the three options ? »

2.2.2.2 Survey and Data description

Our study area is the city of Dijon and its agglomeration, which had 254 387 inhabitants in 2013, with 153 003 of them living in the city of Dijon. The survey was administrated online in October 2016 by a survey institute, yielding 860 answers from a sample of respondents living in the agglomeration of Dijon. The questionnaire was designed to last less than 20 minutes. After a short introduction on the topic of the survey, a section was devoted to obtain information about the respondent's actual residence. The most substantial section followed, composed of a choice experiment as described above. Socio-demographic information on the respondents such as income level, age, gender or households composition were collected at the end of the survey.

Some completed questionnaires appeared to have anomalies and were removed from the sample ; for example respondents who had chosen the same options in all the choice sets exhibited inconsistent choices. The final sample used in the estimation comprised 854 respondents.

Table 2.3 presents and compares the main demographic and socioeconomic characteristics of the effective sample used to estimate choice with the total population in Dijon and surrounding area.

The percentage of women is higher in our sample. Nonetheless, considering that respondents answer the questionnaire based on the behavior of their family and not on their own situation, this difference in gender distribution is expected to be harmless. The proportion of homeowners in the sample is very close to the actual one. People between 30 and 44 years are over-represented while the distribution rates of younger and older people are smaller. The age has been tested as a control variable affecting people's choice and appears to have insignificant effect (these results are not detailed in the paper but are available on request). Finally, our sample exhibits a slight under-representation of retired and others people without professional activities, as is usual

	Sample	Dijon and its surrounding area (Source : INSEE)
Gender distribution (% women)	65,3	51,8
Homeowners (in %)	60,2	58,7
Socio-professional categories (in %)		
Upper	29,9	25,4
Lower	42,2	32,7
Retired	16,4	25,7
Others	11,6	16,3
Age distribution (in %)		
18-29	19,2	21,3
30-44	35,5	19,1
45-59	24,4	19,3
60+	16,4	23,2

TABLE 2.3 – Comparison between our sample and the population of Dijon and surrounding area

in Internet and mail surveys. Table 2.4 describes the variable used in the analysis.

Variable	Definition	Mean	St. Dev
Highincome	1 if household income > 5500 euros/month and 0 otherwise	0.05	0.21
Retired	1 if retired and 0 otherwise	0.16	0.37
Children	1 if at least 2 children and 0 otherwise	0.20	0.40
Center	1 if lives $< 2km$ from the city hall of Dijon and 0 otherwise	0.33	0.47

TABLE 2.4 – Socio-demographics variables of the sample (N=854)

2.2.3 Empirical specification

2.2.3.1 Econometric models of choice

The discrete choice experiment technique is an application of the characteristics theory value (Lancaster, 1966), combined with random utility theory (Mcfadden, 1974). In a given sample with N respondents, each respondent n faces S choice situations. Every choice situation has a choice set of J alternatives. For each respondent n, the utility function of the alternative j in a choice set s is :

$$U_{njs} = \beta_i X_{njs} + \epsilon_{njs}, \quad n = 1, ...N, \quad j = 1, ..., J, \quad s = 1, ..., S \tag{2.2.1}$$

where X_{njs} is the observed attribute vector and β_n is a vector of individual-specific taste coefficients with a density function $f(\beta_n|\theta)$ where θ are the parameters of the distribution.

Conditional on β_n, the probability that respondent i chooses alternative j is the standard logit formula :

$$P_n(i|\beta_n) = \frac{e^{\beta_n X_{ni}}}{\sum_j e^{\beta_n X_{nj}}} \tag{2.2.2}$$

In the case of multiple choices for each respondent, the logit probability refers to the probability that the individual n will make the sequence of S choices specified as $s = (1, ..., S)$. Knowing that the probability of each choice is presented by (2.2.2), the logit probability of observed sequence of choices conditional on knowing β_n is given by :

$$P_n(j_{n1}, ..., j_{nS_n}|\beta_n) = \prod_{s=1}^{S} P_n(j_{ns})|\beta_n) \tag{2.2.3}$$

where j_{ns} represents the alternative chosen by individual n in choice situation s. In the standard logit model, the taste coefficients β are fixed, assuming the same preferences structures across individuals. However, this model had been oversteped by the mixed logit (ML) model, in which the taste parameters β are allowed to be random. In the ML model, the unconditional logit probability that individual n makes the observed sequence of choice j is integrated over the distribution of β_n :

$$L_n(\theta) = \int P_n(j_n 1, ..., j_{nS_n}|\beta_n) f(\beta_n|\theta) d\beta \tag{2.2.4}$$

In the mixed logit model, the distribution parameters θ of vector β can be specified with a continuous distribution such as normal, log-normal or triangular.

In our analysis, we estimate two types of model : the Conditional logit (CL) model, and the Mixed logit (ML) model. The CL model is a fixed effect logit model in which data are grouped by individual to take into account their repeated choice. Thus the CL model assumes that preferences are homogeneous. Moreover, it relies on the assumption of independence of irrelevant alternatives. This assumptions states that the odd of the probability of any two alternatives to be chosen by the respondent are independent of the presence of any other alternative in the choice set (Hensher et al., 2005). CL models are appropriate when the choice among alternatives is modeled as a function of the characteristics of the alternatives rather than (or in addition to) the characteristics of the individuals making the choice (Hoffman and Duncan, 1988).

The ML model is more flexible and has several advantages : it assumes that the alternatives are not independent, and it takes into account unobserved heterogeneity as well as random taste variation among individuals (Train, 2009). In the present sudy, we estimated the CL model with the use of clogit procedure in STATA 14, and the ML model with the « mixlogit » package (Hole, 2007).

2.2.3.2 Willingness-to-pay (WTP) approach

With the common two-step practice, which is also referred to as a model in preference space (Train and Weeks, 2005), the marginal WTP for an attribute is calculated by the ratio of the attribute's coefficient to the price coefficient, which are obtained from econometric models such as CL and ML models. In the case of the ML model, the ratio of two randomly distributed parameters will cause a skewed distribution of WTP. Some approaches such as fixing the price's coefficient (i.e., imposing no heterogeneity in cost sensitivity) or specifying the price coefficient as log-normally distributed have been applied so that WTP values will not 'explode' (Meijer and Rouwendal, 2006).

Train and Weeks (2005) suggested estimating the ML model in WTP space. Applying this approach, the WTP is directly estimated by reformulating the model in such a way that the WTP of attribute coefficients are directly obtained from the regression. Scarpa and Rose (2008) and Hole and Kolstad (2012) reported that the specification in WTP space had a better fit than the model in preference space in their empirical studies.

Based on (2.2.1), we separate the price attribute from the vector of attributes, i.e., assume $\beta_n X_n js = \alpha_n p_{njs} + b_n X'_{njs}$, where p_{njs} denotes the price attribute and X'_{njs} denotes a vector of other non-monetary attributes. The α_n is the random parameter for price and β_b are individual random parameters of other non-monetary attributes. The utility for respondent n of choosing alternative j in situation s is :

$$U_{njs} = \alpha_n p_{njs} + b_n X'_{njs} + \epsilon_{njs}, \quad n = 1, ...N, \quad j = 1, ..., J, \quad s = 1, ..., S \qquad (2.2.5)$$

ϵ_{njs} is a random term that is Gumbel-distributed and whose variance is $Var(\epsilon_{njs}) = k_n^2(\pi^2/6)$, where k_n is the scale parameter for the n^{th} individual. The WTP for attributes in preference space will be $-b_n/\alpha_n$. If we use the ML model to fit our data, then both the price parameter α_n and the attribute parameter b_n are random. As a result, the distribution of WTP, which is a ratio of two random variables, will be skewed. Train and Weeks (2005) presented the estimation of WTP by applying random parameter models in WTP space. They showed that dividing (2.2.5) by k_n does not change the household's behavior and gives us a new error term ϵ_{njs} , which is IID extreme value-distributed. The variance of the new error term is $\pi^2/6$:

$$U_{njs} = \lambda_n p_{njs} + c_n X_{njs} + \epsilon_{njs} \qquad (2.2.6)$$

where $\lambda_n = \alpha_n/k_n$, $c_n = b_n/k_n$ and $\epsilon_{njs} = \epsilon_{njs}/k_n$. Using the fact that the WTP for a given attribute is obtained through the ratio $WTP_n = c_n/\lambda_n = b_n/\alpha_n$, (2.2.6) can be rewritten as :

$$U_{njs} = \lambda_n[p_{njs} + \gamma_n X_{njs}] + \epsilon_{njs} \qquad (2.2.7)$$

This specification is referred to as a utility in willingness-to-pay space. Equations (2.2.6) and (2.2.7) describe the behaviors of individuals in the same way. This model can be estimated using hierarchical Bayesian estimation or maximum simulated likelihood estimation (Train, 2009). In this study, we applied the maximum simulated likelihood estimation using the « mixlogitwtp » package written by Arne Risa Hole in STATA 14.

2.2.3.3 Model specification

The vector X_{njs} in our model contains two groups of variables. The first group of variables includes random parameters variables. In order to account for preference heterogeneity, we defined all the attributes used in the CE as random parameters variables. Thus, the parameters associated to the variables « presence of green » (GREEN), « compactness of the neighborhood » (COMP), « presence of a private garden » (GARD), « distance to the city center » (DISTC), « surface of living area » (SURF) and « price » (PRICE) are assumed to be random. We choose to measure the variation of the attribute PRICE in percentage, like other residential choice studies (Liao et al., 2015; Phaneuf et al., 2013; Tu et al., 2016). As a result, the WTP estimated in this study is measured as a percentage of the respondent's current housing expenses.

The second group of variables is estimated as fixed parameters variables. The variables GREEN*COMP, GREEN*GARD and SURF*GARD are used to capture the effects of two-way interactions among attributes. Interactions occur when the combined effect of two attributes on the utility of respondents is different from the sum of their two main effects.

The role of household's characteristics on preference is analyzed by including interactions terms between households characteristics and attributes variables. This allows us to investigate the so-called deterministic heterogeneity around the means of the estimated parameters.

The interaction terms between « children » and « presence of green » (CHILD*GREEN) and « retired » and « presence of green » (RET*GREEN) are used to test if respondents who have children or those who are retired will have a higher WTP for living in a green environment. We also used the interaction between « center » and « distance to the city center » (CENTER*DISTC) to test whether people that already lived in the city center are willing to pay more to avoid an increase in distance from the center.

Finally, the interaction between « high income family » and « price » (INCOME*PRICE) is used to test the hypothesis that households with high income care less about the price attribute when they make their choices.

2.2.4 Results and interpretation

The estimation results of the two econometric models are shown in Table 2.5.

Since our sample contains both owners and renters, we needed to test whether their behavior regarding residential choice differs. The result of the Hausman test suggests that there is no significant difference between owners sample data and renters sample data (Prob > Chi^2=0.4841).

In the CL model and in the ML model, all parameters associated to simple variables are significant and have the expected sign. The results show that all respondents prefer residences that are larger, less expensive, with a garden in a green street and dispersed neighborhood and closer to the city center.

Looking at interactions variable, we see that only CENTER*DISTC is not significant in the ML model, meaning that people who already live in the city center do not act differently from the others regarding the distance attribute.

	CL	ML
Random parameters		
GREEN	0.612***	0.462***
	(0.064)	(0.078)
COMP	-0.192***	-0.285***
	(0.048)	(0.062)
GARD	1.281***	1.366***
	(0.043)	(0.077)
DISTC	-0.159***	-0.231***
	(0.005)	(0.013)
SURF	3.637***	3.843***
	(0.369)	(0.475)
PRICE	-1.648***	-2.293***
	(0.076)	(0.126)
Fixed parameters		
GREEN*COMP	-0.342***	-0.418***
	(0.085)	(0.100)
GREEN*GARD	-0.405***	-0.244***
	(0.060)	(0.073)
SURF*GARD	-2.746***	-2.831***
	(0.446)	(0.551)
HINCOME*PRICE	-0.656**	-0.958*
	(0.304)	(0.523)
CHILD*GREEN	0.101**	0.142*
	(0.051)	(0.082)
RET*GREEN	0.097*	0.167*
	(0.055)	(0.089)
CENTER*DISTC	0.014*	0.018
	(0.008)	(0.021)
Std Dev. of random parameters (ML model)		
GREEN		0.535***
		(0.048)
COMP		-0.561***
		(0.044)
GARD		1.776***
		(0.059)
DISTC		0.273***
		(0.010)
SURF		3.326***
		(0.240)
PRICE		2.302***
		(0.150)
Log L	-10029.17	-8606.43
N	854	854
N*S	10248	10248

Standard errors are in parentheses.
Significance level : *1%, **5%, ***10%

TABLE 2.5 – Estimation results

The variable HINCOME*PRICE is significant at the 10% level, meaning that households with high income care less about the price attribute when they make their residential choice. The variable CHIL*GREEN and RET*GREEN are also significant at the 10% level, showing that people who have children and retired people do have a stronger preferences for living in a green environment than the rest of the sample.

Another interesting result is the existence of interactions between the attributes : the variables GREEN*COMP is significant at the 1% level and negative, meaning that the preference for green decreases when the surrounding neighborhood is compact. This result, coupled with the estimates of GREEN and COMPACT, entails that people prefer to live in a green and dispersed neighborhood, and that their utility increase more than proportionally if both conditions are satisfied at the same time.

The variables GREEN*GARD is significant at the 1% level and negative. It means that the preference for living in a green street decreases when the residence has a garden. This result demonstrates the existence of substitutability between public green space (the trees in the street) and private green space (a garden).

Finally, there are interactions between the attributes surface and garden, as the variable SURF*GARD is significant at the 1% level. The negative sign entails that people care less about surface when the residence has a garden, which proves the substituability existing between the indoor space (surface of living space) and the outdoor space (existence of a garden) in people's choice.

The standard deviations of random parameters are all significant, which also proves the existence of unconditional unobserved preference heterogeneity in the sample. This indicates that the ML model provides a significantly better representation of the choices than a CL, which assumes that coefficients are the same for all respondents. Moreover, applications of the ML model have shown its superiority with respect to the CL model in terms of overall fits and welfare estimates (Lusk et al., 2003). For all these reasons, we compute WTP estimates based on the results of the ML model.

Table 2.6 presents the results of WTP estimates in preference space and in WTP space.

	WTP space		Preference space	
Variables	Estimates	Std. Err.	Estimates	Std. Err.
Random parameters				
GREEN	0.207***	0.033	0.210***	0.078
COMP	-0.121***	0.026	-0.124***	0.062
GARD	0.646***	0.038	0.595***	0.077
DISTC	-0.101***	0.006	-0.100***	0.013
SURF	1.690***	0.193	1.675***	0.475
Fixed parameters				
GREEN*COMP	-0.173***	0.043	-0.185***	0.100
GREEN*GARD	-0.086***	0.031	-0.106***	0.073
SURF*GARD	-1.185***	0.226	-1.123***	0.551
CHILD*GREEN	0.062*	0.034	0.061*	0.082
RET*GREEN	0.098***	0.038	0.073*	0.089
CENTER*DISTC	0.006	0.009	0.007	0.021

N = 854
Number of choice observations = 10248
Log likelihood at convergence = -8646,46
Significance level : *1%, **5%, ***10%

Table 2.6 – WTP estimates with ML in WTP space and preference space.

Comparing the results of the two approachs, we see that all estimates have the same sign, and their absolute values are not very different. Nonetheless, if we look at the « standard error » columns, we find that that the standard errors of the mean WTP of attributes estimated in preference space are higher than the ones estimated in WTP space. With a lower standard error, the uncertainty is smaller, and thus the results are better. We conclude that here the measures in WTP space are more efficient. This result is consistent with those of Hensher (2006) and Hole and Kolstad (2012). We thus prefer to interpret the results of the ML model in WTP space.

All the WTP estimates obtained for the attributes variables are highly significant. In our sample, an average-size home is 114m^2, while the average price is 180 320 euros for owners. According to these informations, we compute the WTP of people for each attributes, as there is no difference between the behavior of owners and renters, we compute WTP only for owners in order to keep readable results.

The WTP of living in a green street is equal to (0.00207*housing price), so in average people are ready to pay €373,3 to live in a green street. If we divide by the size of the residence, we obtain the WTP of housing price per square meters, which is equal to €3,27/m^2. We note that WTP parameters of GREEN*COMP and GREEN*GARD are significantly different from zero at the 1% level, and the negative sign implies that people are willing to pay less for living in a green street if they are in a compact neighborhood or if they have a garden. Precisely, the WTP for living in a green street decreases from €3,27/m^2 to €0,54/m^2 if the residence is in a compact neighborhood, and to €1,91/m^2 if the residence has a private garden.

The WTP parameters of CHILD*GREEN and RET*GREEN are also significant. The positive sign entails that having children or being retired increase the WTP for living in a green street. People who have children are willing to pay €4,25/m^2 to live in a green street, and people who are retired are willing to pay €4,82/m^2.

The WTP of living in a compact environment is negative, meaning that people do not prefer to live in a compact neighborhood, but they prefer the opposite situation : living in a dispersed neighborhood. In average, owners are willing to pay €1,92/m^2 to avoid living in a compact neighborhood.

The WTP of living in a residence with a private garden is positive and equals €10,21/m^2. The sign of the WTP parameters of the attribute « distance to the city center » is negative, meaning that people do not prefer living far away from the city center. They are ready to pay €0,53/m^2 to avoid an increase in distance of 1km from the city center.

Finally, the WTP for an increase in 1% of surface is equal to 1.690% of the price. Here, we interpret the WTP parameters in absolute value because both surface and price attributes are already described in percentage in our study. Thus, the WTP to increase surface by 1m^2 is equal to €2530. The negative sign of the parameters SURF*GARD, which is highly significant, entails that WTP for increasing the surface decreases if the residence has a private garden. Precisely, if the residence has a garden, people are willing to pay €656 for an increase of 1m^2 of indoor surface.

In our study, the WTP to live in a green street and the WTP to live in a dispersed neighborhood are found to be significative, but very small, as they are less than 1% of the housing price. Comparing to other studies in the field, we see that our WTP estimates are small. Indeed, using the hedonic pricing method, Tyrväinen and Miettinen (2000) found for example that dwellings with a forest view were on average 4.9% more expensive than dwellings with otherwise similar characteristics in Salo, Finland. Cavailhès et al. (2009) found that the housing price will be increased by $1.5 - 2\%$ for a view of trees and fields in Dijon, France. Using CE method, Tu et al. (2016) show that households are willing to pay around 1% of housing price to benefit from a scenic view in the agglomeration of Nancy, France.

The difference with our WTP estimates may be explained be the fact that we do not evaluate the same thing. Indeed, here, we do not evaluate the direct view from the residence, but we evaluate neighborhood characteristics : the presence of green in the street (but not necessarily directly visible from the windows of the house) and the compactness of the neighborhood. The price difference between house located in a street with trees (or in a dispersed neighborhood) and a house located in a street without trees (or in a compact neighborhood) is less important than the price difference between houses with a view on a scenic landscape (forest of fiels) than house without view.

Our results indicates that the presence of green in the street and the compactness of the neighborhood do not have an important impact on housing price, but they even though affect households choice : these two characteristics play a « tilting » role. If a household is confronted with a choice between two houses that have almost the same characteristics, the presence of green in the street or the compactness of the neighborhood will tip the scales in favor of one of the two houses.

As the main goal of this study is to elicit preference of people for the environment surrounding their residence in order to compare them to an ecological indicator, what is of prime important to us, more than absolute values, is the order of the WTP.

Here, we see clearly that people prefer to live in a green and dispersed environment, while the non-green and compact environment is ranked last. As people are willing to pay more to live in a green street than to avoid living in compact neighborhood, we can say that the environment mixing green street and compact neighborhood is ranked second, and the environment mixing non-green street and dispersed neighborhood is ranked third. Finally, the interactions terms between the greenness of the street and the compactness of the neighborhood reveals that the gap between the configuration ranked first and the second is bigger than the gap between the configuration ranked third and the last one.

In the last section, we derive the biodiversity score of each configuration in order to see if households' preferences are in line or contradict ecological values of urban environment.

2.3 Connectivity metrics and biodiversity

Among the numerous methods that have been proposed to quantify connectivity (Calabrese and Fagan, 2004; Kool et al., 2013), we apply graph-based landscape modelling. Under a graph perspective, a landscape is viewed as a set of habitat patches - the nodes - and connecting elements, the links - an actual physical corridor or a land cover patch that is not a potential habitat but allows movement between patches. Habitat patches are characterized by their surface. A link is the probability of dispersal between two patches ; in its simplest form it is the Euclidian distance. To account for the fact that not all land covers favor movement, a link may also incorporate a measure of resistance to dispersal specific to each land cover. Following (Urban and Keitt, 2001), this methodology has been widely applied to quantify landscape connectivity in a variety of contexts (see for instance (Minor and Urban, 2008; Galpern et al., 2011; Foltête et al., 2014; Serret et al., 131).

We defined squares of length 2.4 km centered on each of the observation point from which the pictures used in the choice experiment were taken : ID1 in the compact, high green area ; ID2 in the dispersed, high green area ; ID3 in the compact, low green area and ID4 in the dispersed, low green area. The land-use (raster layer at 5 m resolution) arises from a related research in progress (Joly et al., 2017). It was built by using three sources : the French national topographic database (BD TOPO, IGN [2]), Corine Land Cover (CLC, EAE [3]) and the Land Parcel Identification System (LPIS, IACS [4]) database. Land-uses were grouped into 6 classes : (1) built-up areas, (2) grassy plots (meadows, gardens and fields), (3) bushes and shrubs, (4) trees/forests, (5) water and (6) artificial surfaces.

Figure 2.2 presents the repartition of land cover in a small buffer (0-150 m) around the 4 observation points. Compact points are characterized by a higher proportion of built-up areas and artificial surfaces (especially for the low green one), while dispersed areas show higher shares of all types of green landscapes – grassy plots, bushes and trees.

The graphs construction and the connectivity metrics calculation were performed

2. Institut Géographique National, the French national institute of geographic and forest information
3. European Environment Agency
4. Integrated Administration and Control System

using Graphab 2.0.1 software (Foltête et al., 2012). We focused on the land-use class « grassy plots » to define the potential habitat patches. Links between patches were generated as least-cost paths, i.e. those that incur the least resistance from one patch to the other. This is motivated by the fact that land uses are not homogeneous in their ability to allow the dispersal of different species. We used arbitrary resistance values, following previous studies (See for instance Zeller et al. (2012) or Serret et al. (131) : the habitat land-use was assigned the lower resistance value (=1) ; bushes and shrubs, trees/forests and waterbodies were assigned a resistance value of 10 ; artificial surfaces (parking lots, etc.) were given a value of 100 while built-up areas reached the maximum value of 1000, denoting increasingly unfavorable conditions for the movement of butterflies and plant species sensitive to urbanization, as analyzed in the literature (see (Penone et al., 2012; Bergerot et al., 2010, 2013)). Given these sets of patches and links, various graphs were computed to account for different dispersal abilities of those species, by specifying a maximum distance above which patches are not considered linked. We followed previous literature (Serret et al., 131) and considered 3 different thresholds : d=200m, d=500m and d=1000m.

Table 2.7 presents the characteristics of the graphs obtained around each observation point ID1-to-4.

Compact landscapes count more patches of smaller size and links of higher length than dispersed ones, notwithstanding their high/low green nature. By the same token, low green landscapes count more patches of smaller size and links of higher length than high green ones, within the same compact/dispersed category. We computed connectivity metrics at the 2.4x2.4 km square scale having its center each observation point, in order to avoid any selection bias due to the choice of location of the observation points . Following recent literature, we focused on weighted metrics that take into account characteristics of both patches and links. This captures the idea

	Max dispersal distance (m)	Nb patches	Nb links	Mean patch capacity (m^2)	Max distance between patches (m)
$ID1 - C_{HG}$	1000	3363	8675	101 197,06	4459,57
	500	3363	8549	66 167,31	3541,63
	200	3363	7877	26 065,91	2874,28
$ID2 - D_{HG}$	1000	2510	6195	229 115,00	2370,55
	500	2510	6131	152 743,33	2106,84
	200	2510	5881	69 428,79	1703,71
$ID3 - C_{LG}$	1000	4755	11816	7287,30	10 848,23
	500	4755	11230	3106,86	9891,98
	200	4755	9794	3106,86	2713,26
$ID4 - D_{LG}$	1000	2844	7167	217 910,00	2466,26
	500	2844	7097	145 273,33	2303,37
	200	2844	6740	50 676,74	2378,19

TABLE 2.7 – Characteristics of patches and links of graphs constructed with maximum dispersal distance of 1000, 500 and 200 m.

that habitat should be both abundant and well connected to provide a satisfactory level of support (Saura and Pascual-Hortal, 2007).

The probability of connectivity index (PC) is defined as the probability that two individuals, randomly sited within the landscape, fall into connected habitat patches (Saura and Pascual-Hortal, 2007). Noting A the total landscape area, a_i and a_j the surface of two distinct patches, d_{ij} the least cost distance between patches i and j, α and β positive constants, it is calculated as follows and takes values between 0 and 1 :

$$PC = \frac{1}{A^2} \sum_i \sum_j a_i^\beta a_j^\beta e^{-\alpha d_{ij}} \tag{2.3.1}$$

Flux (F) measures the sum of potential dispersals between all patches in the landscape (Urban and Keitt, 2001) ; it is calculated as follows :

$$F = \sum_i \sum_j a_i^\beta e^{-\alpha d_{ij}} \tag{2.3.2}$$

Increasing values of PC and F denote an increasing connectivity potential of the landscape.

Table 2.8 presents the values of PC and F obtained for the 3 different graphs computed around each observation point.

	Max dispersal distance (m)	PC	F
$ID1 - C_{HG}$	1000	0,023439	1 170 415 082
	500	0,023437	1 170 055 989
	200	0,022912	1 121 510 488
$ID2 - D_{HG}$	1000	0,079058	1 976 203 149
	500	0,079056	1 975 799 729
	200	0,078946	1 959 827 213
$ID3 - C_{LG}$	1000	012613	877 170 356
	500	0,012608	876 301 667
	200	0,011723	797 278 195
$ID4 - D_{LG}$	1000	0,064327	1 902 707 859
	500	0,064326	1 902 306 127
	200	0,064096	1 878 442 399

Table 2.8 – Weighted connectivity metrics computed at the 2.4x2.4 km square scale

A first observation is that, for a given observation point, both weighted metrics increase with the maximum dispersal distance. Furthermore, whatever the maximum dispersal distance, the ranking of landscapes around our 4 observation points is always as follows : $D_{HG} > D_{LG} > C_{HG} > C_{LG}$.

This result means that a green and dispersed configuration provides the highest biodiversity potential, while the low green and compact configuration is the worst, which is in line with households' landscape preferences : the landscape configuration that has the highest biodiversity potential is also the one that in valued the most by households when they make their choice of localisation.

2.4 Discussion and conclusion

How people value the landscape at their place of residence is important to understand households' residential location choice and the environmental impact of this choice. In this chapter, we investigated the potential synergies and trade-offs between the provision of two ecosystem services from green urban landscapes, a cultural one directly valued by the households and one related to the support of habitats, hence biodiversity.

This study focuses on the preferences of the residents of the agglomeration of Dijon in particular in terms of the urban landscape around their residence : the share of green landscape in their immediate vicinity and the compactness, or density of building footprints, of the neighborhood. We used a CE approach to assess how residents value those two characteristics, a contribution to the scare literature on the application of CE to residential choice modeling to value of green spaces. Our results indicate that people in general tend to prefer to live in an area with a higher share of green urban landscape, all the more so when they do not have a private garden or maybe more surprisingly when they live in a dispersed neighborhood. They also show a higher preference for living in a dispersed neighborhood. The WTP for these attributes are significant, but very low : the presence of green urban landscape or the location in a dispersed neighborhood may not affect the purchasing price, but they appear to play a tilting role in the residential choice. When faced with a choice between two houses with the same other characteristics, the presence of green urban landscape, or a more dispersed neighborhood, will tip the scales in favor of the associated house. Consequently, households in the agglomeration of Dijon exhibit a preference for some cultural ecosystem service associated with green urban landscapes.

In a second step, we investigate the contribution of these green urban landscapes to the provision of another ecosystem service, of habitat provision hence biodiversity support. Applying recent developments in landscape graph theory and landscape connectivity analysis, we provide a first assessment of the contribution of green urban landscape patches to landscape connectivity. Our results suggest that on average, habitat patches in dispersed neighborhood provide a higher level of support ecosystem service that those located in compact neighborhoods, which is in line with residents' preferences for the cultural ecosystem service provided by those patches. Our results also show that patches in high green areas do not necessarily have higher connectivity scores that those located in low green areas ; indeed the level of compactness of the neighborhood matters. In this respect, we put in perspective a consistency between cultural and support ecosystem services, since households value more the green urban landscapes that tend to have the higher level of support service provision.

Our results have implications for land use planning and policies in urban areas. If households' preferences and ecological targets are indeed aligned, then public intervention is facilitated to achieve the objective of maximizing both households' utilities and biodiversity support.

These preliminary results, set in the context of green urban landscape, should however be considered with caution. First, the analysis of the support service is still in a preliminary stage, based on global connectivity metrics rather than local ones. Extensions are under way to specify the level of heterogeneity in connectivity potential within each area type along the compactness and greenness gradients. Second, most urbanization pressure happens at the urban fringe, which is not covered by our study, focused within an urban area. Provisions of both ecosystem services may not follow the same pattern as in the type of area studied here. This calls for further studies in different urbanization contexts.

Caractéristiques	Choix 1	Choix 2	Choix 3
Type de voisinage			
Vue sur le vert			
Distance au centre	6km	6km	3km
Présence d'un jardin	oui	non	oui
Taille du logement	-10%	actuelle	+10%
Prix du logement	-10%	-10%	-10%

	Choix 1	Choix 2	Choix 3
vous préférez :	○	○	○

FIGURE 2.1 – Example of a choice situation

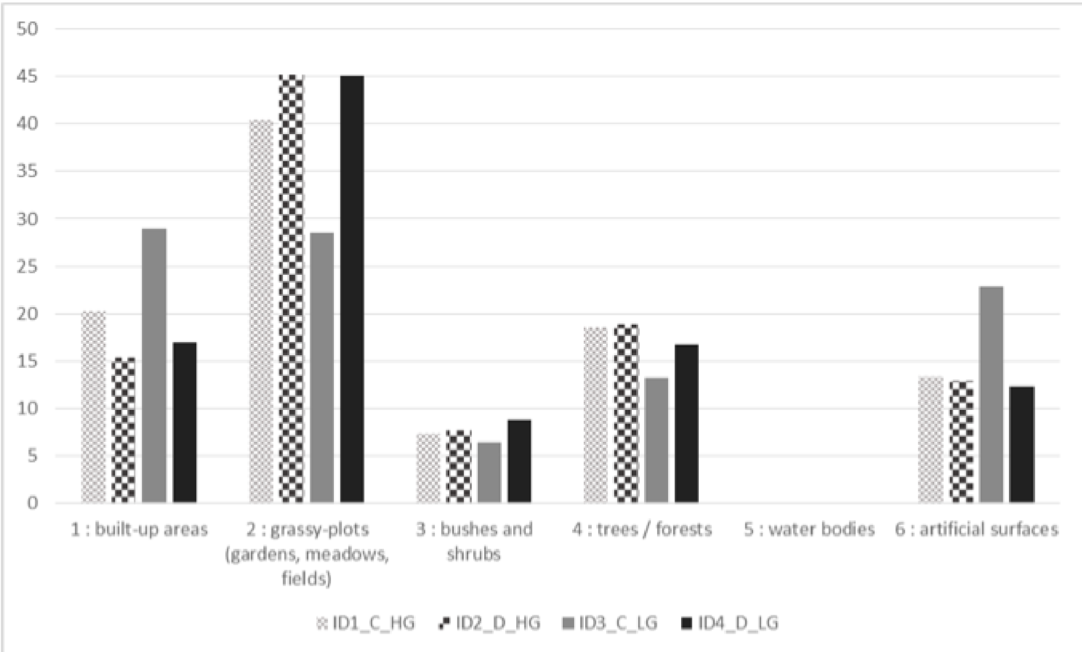

FIGURE 2.2 – Land cover (%) in the first landscape plan (0-150 m)

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Chapitre 3

Open space preservation in an urbanization context

3.1 Introduction

An increasing share of the world population locates in urban areas. People choose to live in cities because they find jobs and commodities, but at the same time, the expansion of cities is responsible for a range of environmental issues, in particular due to the destruction of natural land and the loss of urban open space. The term « urban open space » encompasses a range of land uses including parks, public and private gardens, forests, undeveloped land and agricultural land at the urban fringe (Brander and Koetse, 2011). Open spaces play an important role in cities because they provide several ecosystem services. They are places of relaxation and enjoyment for population and thus provide cultural services, they moderate the impact of human activities by, for example, absorbing pollutants and releasing oxygen, and they preserve local natural heritage and biodiversity by providing habitats for urban wildlife.

In France, public authorities have recognized the role of open space, as illustrated by the circular dating from February 8th 1973 which fixed precise objectives regarding the accessibility of open space : each urban dweller should have access to $10m^2$ of « proximity open spaces » such as parks or public gardens, and $25m^2$ of « weekend open spaces » such as forests or natural land located farther from their home.

Economists have been interested in the role of open spaces and their preservation. Brueckner (2000) explains that the social value of open space is not taken into account by households when they make their choice of localisation, leading to an excessive extension of city known as urban sprawl. Hence, he recommends to limit urban sprawl in order to preserve open spaces that are located at the outskirts of cities, such as agricultural plains or forests. However, he does not take into account the intra-urban open space. In that case, sprawl may be the consequence of households' preference for small open space available just near their place of residence. Indeed, several studies show that households value open space that is located directly next to their habitations (see Brander and Koetse (2011) for a review). In a hedonic price study, Joly et al. (2009) show that only forest and farmland in the immediate vicinity of houses have positive prices, and landscape located more than 200 meters away have insignificant hedonic prices.

In a theoretical framework, Turner (2005) analyzes the equilibrium and optimum city structure when households value local open space, and he shows that the optimal city is less compact than at the private equilibrium. According to him, public policies such as urban growth boundaries are not fitted when households value local open space. Cavailhès et al. (2004) also demonstrate that the sprawled pattern of cities and the existence of a periurban area is the consequence of households' preferences for natural amenities and thus is not necessarily an inefficient pattern of development. In a recent study, Caruso et al. (2015) analyse urban forms in a 2D microeconomic model where households value open space at a neighborhood scale ; they show that high preferences for green spaces increase both leapfrog development and the size of the leaps.

A possible contradiction between the preservation of different types of open spaces arises : the preservation of intra-urban open space in small patches could be responsible for an extension of the city's limit, while the preservation of large natural open space at city's outskirts would work for a more compact city. This question fits in the recent land sharing versus land sparing framework. This framework was first proposed by Green et al. (2005) in the literature on the impact of agriculture on biodiversity and aimed at understanding the extent to which agriculture should be concentrated on intensively farmed land in order to conserve more biodiversity-rich natural spaces elsewhere (*land sparing*) or conversely, be more wildlife-friendly but less productive, hence conserving fewer natural spaces (*land sharing*) (Desquilbet et al., 2015). This framework was extended to the context of cities recently : land sparing minimizes the spatial extent of developed areas, such that residential areas are developed as intensively as possible, enabling the maintenance of large open spaces. Under land sharing, development is more evenly but less intensively distributed, such that a larger land area is needed to accommodate a given number of households, and open spaces tend to be more fragmented but on average closer to residential areas (Brenda and Fuller, 2013; Soga et al., 2014; Stott et al., 2015). From an ecological perspective, the question of which urban structure is preferable for biodiversity conservation is far from being completely answered. To broaden the debate, we propose in this paper an economic analysis of these questions, in order to understand how the behavior of economic agents influence the city's structure and the existence and preservation of different types of open space.

Several papers have already studied the effect of open spaces in a spatial urban context. For example, Wu (2001) and Wu and Plantinga (2003) consider city formation when people have a taste for proximity to exogenously located open space, such as a park. Their analyses focus on the role of open spaces in city structure, but they do not consider the possibility for the available amount of open spaces to be modified by the choice of localisation of people, concealing the fact that people impose external costs on each other. Strange (1992) and Marshall (2004) consider the question of open space in city in a model with housing externalities but they do not model a land market. Walsh (2007) proposes a Tiebout model in which people have preferences over the characteristics of neighborhood landscape (the amount of open spaces in particular) but the Tiebout framework does not allow to analyse the micro-structure of urban development that we want to develop here.

This paper departs from the previous literature by developing a theoretical urban model which takes into account explicitly the existence of two different types of open spaces for which preservation strategies may be conflicting. Firstly, we study the impact of households' preferences for proximity open spaces - such as parks, greenways, public gardens and periurban agricultural land directly visible from their place of residence - on the equilibrium city structure. In a second step, we introduce the role of large open spaces outside of cities such as forests, meadows and agricultural land, which are valued by a social planner for their ecological interest. We study the optimal city structure when the social planner takes into account biodiversity conservation.

The remainder of the paper is organized as follows. Section 2 presents the general structure of the model. Section 3 provides an application with linear functional forms. Section 4 develops the welfare analysis. Finally, section 5 concludes.

3.2 The model

3.2.1 Residential behavior

Consider a city liying on a uni-dimensional space $X = [0, +\infty[$. The city is monocentric : all the firms locate at the central business district (CBD), located at 0 and which size is neglected[1]. At each location $x \in X$, the quantity of available land is equal to one. Our objective is to describe the pattern of the residential area in this city, that we assume closed : the number of households is fixed and the equilibrium utility level varies endogenously. The assumption of a closed city is relevant in order to study the possible allocations of different types of open space within the city.

All households are assumed to be homogeneous, meaning that each household's income level and utility function are identical.

Households divide their entire income between the consumption of a composite good, a house, and transportation cost. The lot size of each house is assumed to be exogenously fixed, and the transport cost is proportional to the distance to the CBD.

We consider that households have preferences for natural amenities : they care about local open space, available directly at their place of residence. In other words, they prefer to live in a place with a low level of residential development, all else being equal. Thus, the features of each house are heterogenous across the city.

Natural amenities are considered as spatial attributes of housing, which affect the households' utility function but not their budget constraint.

1. Several models where firms' location is endogenous exist in the economic literature (Fujita, 1989), the location of firms may matter when they affect environmental damage, as for instance air pollution (see chapter 4). However we assume here that the location of firms is not relevant since their location choice is not influenced by open space.

Following Fujita (1989), households' maximization program is given by :

$$\begin{cases} \max\limits_{m,x} & u(m,q,d(x)) \\ s.t. & p(x)q+m+t(x)\leq w \end{cases}$$

whith

$u(\cdot)$: the utility function

x : the distance from the CBD

m : the amount of the composite good which price is the numéraire

q : the lot size of the house assumed to be fixed

$d(x)$: the level of urban development at location x, with $0 \leq d(x) \leq 1$

$p(x)$: the rental price of a house at distance x

$t(x)$: the transport cost for a household at distance x

w : the income

The amount of local open space is a decreasing function of $d(x)$.

At equilibrium, the utility level is given by u^*, and is similar among all households no matter their residential location as they are identical and mobile without cost. The household's demand function for the composite good m is obtained by solving :

$$u(m,q,d(x)) = u^* \tag{3.2.1}$$

We can now derive the residential bid-rent function $p(x)$, which indicates the maximum amount a household is willing to pay at location x while receiving the utility level u^* :

$$p(x) = \frac{w - t(x) - m^*(q, d(x), u^*)}{q} \tag{3.2.2}$$

Where $m^*(q, d(x), u^*)$ is the solution to $u(m, q, d(x)) = u^*$. The residential bid-rent is an implicit function of the income, the transport cost, the lot size, and the level of urban development :

$$p(x) \equiv p(w, t(x), q, d(x), u^*) \tag{3.2.3}$$

With $\frac{\partial p}{\partial w} > 0$, $\frac{\partial p}{\partial t(x)} < 0$, $\frac{\partial p}{\partial q} > 0$, and $\frac{\partial p}{\partial d(x)} < 0$. When prices vary according to (3.2.3) across the city, households' utilities are identical across locations and households have no incentive to move. The bid-rent function reveals the difference between our model and the standard monocentric city model. In the standard model, natural amenities are assumed to be distributed uniformly across the landscape : residential rents always fall with the distance from the CBD, compensating residents for their increasing cost of commuting. However, with spatial variations in amenities, the spatial pattern of the rent is more complicated. A household may be willing to sacrifice proximity to the workplace for amenities, with the result that the willingness to pay for housing may no longer be a monotonically decreasing function of the distance to the CBD.

3.2.2 Development decision

On the supply side, housing is produced with land, labor and materials under constant returns to scale. The house size, q, is fixed, and outside developers choose the level of development (or development density) $d(x)$ at each location, which is equivalent to the number of dwellings per acre. We make the assumption that at each location, one and only one developer is the landowner of the parcel and takes the development decision. Moreover, we suppose that the cost of development $c(d(x))$ is a linear function of the development density $d(x)$ such that $c(d(x)) = Cd(x)$ where

C is a positive constant, meaning that the cost increases at the same rate as $d(x)$. At each location, the developer chooses the development density to maximize profit :

$$\max_{d(x)} \pi(d,x) = p(w,t(x),q,d(x))d(x) - Cd(x)$$

The equilibrium development density is the solution of the first order condition given by :

$$\frac{\partial p(\cdot)}{\partial d(x)} d(x) + p(w,t(x),q,d(x)) = C \tag{3.2.4}$$

The second order condition gives $\frac{\partial^2 \pi}{\partial d(x)^2} < 0$: as long as the rent is a decreasing and concave or decreasing and linear function of $d(x)$, the profit function reaches its maximum when $d(x)$ is the solution of the differential equation (3.2.4).

Using the implicit function theorem, we derive the variation of the level of development along the city :

$$\frac{\partial d(x)}{\partial x} = \frac{\frac{\partial^2 \pi}{\partial d \partial x}}{\frac{-\partial^2 \pi}{\partial x^2}} \tag{3.2.5}$$

Using the second order condition, we know that the denominator of the above equation is always positive. The sign of (3.2.5) depends on the sign of the numerator :

$$\frac{\partial^2 \pi}{\partial d \partial x} = \frac{\partial^2 p}{\partial d \partial x} d(x) + \frac{\partial p}{\partial x} \tag{3.2.6}$$

The first part of the right hand side of (3.2.6) corresponds to a cross effect. It is interpreted as how the variation of the bid-price with respect to x changes along the city gradient. The sign of this term is unknown and depends on the functional from specified in the household's program. The second term of (3.2.6) corresponds to the variation of the price along the city that does not depend on the level of development $d(x)$, so it is the effect passing trough the transport cost and it is always negative. Finally, the sign of the total variation of the development level with respect to the distance to the city center depends on the sign of the cross effect. If the cross-effect is nul or negative, the level of development always fall along the city gradient. If the cross-effect is positive, the level of development might increase as we move away from the city center.

The first order condition is a second order differential equation of the variable $d(x)$, its solution is given by :

$$d^*(x) = \frac{p(w, t(x), q, d^*(x)) - C}{K} \tag{3.2.7}$$

K is an unknown constant, as we have not defined any specifical functional form.

The development density is a function of the residential rent and, through it, the level of amenities at each location.

Further, an increase in residential rent would increase the development density. However, households have preferences for local open space, as indicated by (3.2.3), meaning that the development density is a disamenity for households and an increase in development density reduces households' willingness to pay for housing. In that case, the developer chooses the number of houses built by balancing households' taste for local open space and her own interest for high density. Thus, when households value local open space, the level of development at equilibrium is not maximal in each location x of the city. For some x, only a part of the parcel is converted to residential use. This result is fully developed for a linear application in section 3. It is also interesting to note that by choosing the level of urban development, developers are able to influence the value of the residential rent, thus they have market power as they can influence market price. In that way, they make a positive mark-up (see equation (3.2.4)) leading to a market imperfection. In this respect, developers' decisions are made under imperfect competition, and this affects the land market. These impacts are detailed below.

3.2.3 Total value of land at equilibrium

At equilibrium, housing prices are bid up until no household has any incentive to move. This condition is satisfied when housing prices are represented by (3.2.3) since the household's bid function is the maximum willingness to pay for housing.

The return per acre in residential use at a particular location x is given by the developers' profit at equilibrium and defined as :

$$r_c(w, t, q, u^*, d^*(x)) = p(w, t, q, u^*, d^*(x))d^*(x) - Cd^*(x) \tag{3.2.8}$$

The return per acre in residential use varies with distance to the city center according to :

$$\frac{\partial r_c}{x} = \underbrace{\left(\frac{\partial p}{\partial t}\frac{\partial t}{\partial x} + \frac{\partial p}{\partial d^*}\frac{\partial d^*}{\partial x}\right) d^*(x)}_{\text{price effect}} + \underbrace{p(\cdot)\frac{\partial d^*}{\partial x} - C\frac{\partial d^*}{\partial x}}_{\text{size effect}}$$

We can decompose this expression as follows :

The first part of the right hand side is a« price effect ». The price paid by households varies with distance according to variations of transport cost and urban development. Both transport cost and urban development act as negative forces on households' bid-rent function. However, the transport cost increases with distance, while the level of urban development can increase or decrease, as demonstrated above. If the level of development increases with distance, the price effect is always positive. However, if the level of development decreases with distance, the total effect on the price paid by households is unknown, and it depends of the rate of variation of transport cost relative to that of urban development. This result is similar to the one demonstrated in the seminal paper of Richardson (1977), who studies the variation of residential rent in the presence of externalities.

The second part of the right hand side corresponds to a « size effect », and it means that the return in residential rent depends on the part of land that developers choose to built ($d(x)$) which is decreasing with distance. Thus, the revenue of developers decreases with distance, but as well as their costs. In a classic model of production the size effect is nul as the marginal revenue equals the marginal costs at equilibrium. However in our model the size effect is negative, because of the market power held by developers (see (3.2.4)).

The total variation of the residential return with respect to the distance to the city center is thus uncertain. We develop this result in the section 3 in the particular case of a linear utility function.

At each location x, landowners choose the use that maximizes the return of their plot of land. Therefore, land is developed if the return in residential use exceeds the return of land in its previous state (agricultural or natural), which is supposed to equal zero.

The first closing condition of the model states that residential rent must equal the exogenous agricultural rent at the city boundary x_m :

$$r_c(w, t, q, u^*, d^*(x_m)) = 0 \tag{3.2.9}$$

The second closing condition requires that all households live in the city :

$$\int_0^{x_m} n(x)dx = N \tag{3.2.10}$$

Where $n(x)$ is the equilibrium number of households at any location and equals the equilibrium development density divided by floor space per household : $n(x) = d^*(x)/q$, and N is the total number of households in the city and is fixed exogenously. Moreover, the following condition must be satisfied : $Nq \leq L$, where L is the maximum boundary of the city (either for physical or administrative reasons). This conditions means that the total floor space occupied by city's resident cannot exceed the maximum boundary of the city.

The total value of land in the city, R, is given by the total value of land in residential use :

$$R = \int_0^{x_m} r_c(w, t, q, u^*, d^*(x))dx \tag{3.2.11}$$

3.3 Application with linear functions

In this section, we develop the model with linear functional forms, in order to derive tractable analytical results.

3.3.1 Households

The utility function of households takes the following form :

$$U(m, q, d(x)) = m + q + \gamma(1 - d(x)) \tag{3.3.1}$$

Where γ is a positive constant. Each household maximizes the utility function with respect to the budget constraint as established in section 2. We derive the bid-rent function of households by solving the maximization program, which gives :

$$p(x) = \frac{1}{q}(w - Tx - u^* - q - \gamma(1 - d(x))) \tag{3.3.2}$$

The bid rent function of households has the following properties :

— it is decreasing with transport cost T according to $\frac{\partial p}{\partial T} = \frac{-x}{q}$,

— it is decreasing with the level of development density in each x such that : $\frac{\partial p}{\partial d(x)} = \frac{-\gamma}{q}$.

3.3.2 Developers

The equilibrium level of development is derived by solving the maximization program of developers and given by :

$$d^*(x) = \frac{1}{2\gamma}\left[w - Tx - Cq + q - u^* + \gamma\right] \tag{3.3.3}$$

Furthermore, we see that $\frac{\partial d^*(x)}{\partial x} = \frac{-1}{2}\frac{T}{\gamma}$. This result means that at equilibrium, the level of development always decreases with distance to the city center. The negative slope of the development density result from a trade-off between the transport cost and the level of open space in each x. This trade-off reflects households' preferences for open space, and it affects the equilibrium level of development chosen by the developer. Thus, this equilibrium development density is also the result of the developer's trade-off between maximizing the number of houses built and gaining the maximum possible rent from each house.

3.3.3 The urban-periurban-rural equilibrium

Here we investigate in more details the possible configurations of the city at equilibrium, especially we demonstrate that a urban-periurban-rural equilibrium can arise.

3.3.3.1 Equilibrium level of development

The compact built-up area At equilibrium the level of urban development in each x is given by (3.3.3), reflecting the trade off between transport cost and the amount of open space in each x. It is possible that for some x, the transport cost is so low that the level of development x reaches its maximum level, so equal to 1 :

$$d^*(x_u) = \frac{1}{2\gamma}\left[w - Tx_u - Cq + q - u^* + \gamma\right] = 1 \tag{3.3.4}$$

$$\Leftrightarrow x_u = \frac{1}{T}\left(w - Cq + q - u^* - \gamma\right) \tag{3.3.5}$$

Thus, for every $x \leq x_u$, there is no open space left, and the level of development $d^*(x)$ is equal to 1. The parcel x_u delimitates the frontier of the compact built-up area in the city. We need to check under which condition this frontier x_u is greater than zero to ensure that there exists a compact built-up area at equilibrium :

$$x_u > 0 \tag{3.3.6}$$

$$\Leftrightarrow \gamma < (w - Cq) + q - u^* \tag{3.3.7}$$

If γ is low enough, meaning that households have moderate preferences for open space available at their place of residence, there exists a compact built-up area at equilibrium. Otherwise, if γ is too high, households have very strong preference for open space and there is no possibility for a compact built-up area to exist at equilibrium.

The periurban area The periurban area is where the level of development varies between 0 and 1. Recall that $\frac{\partial d(x)}{\partial x} = \frac{-1}{2}\frac{T}{\gamma}$, meaning that close to x_u, the level of development is high and close to 1, and it decreases along the city until it equals zero at the city's limit x_m.

The rural area The city's limit x_m is reached when the level of development $d^*(x)$ is equal to zero :

$$d^*(x_m) = \frac{1}{2\gamma}\left[w - Tx_m - Cq + q - u^* + \gamma\right] = 0 \tag{3.3.8}$$

$$\Leftrightarrow x_m = \frac{1}{T}\left(w - Cq + q - u^* + \gamma\right) \tag{3.3.9}$$

Thus, for every $x \geq x_m$, the level of urban development is null. The condition that $d^*(x) = 0$ is equivalent to the condition $R_c(x) = 0$, in other terms, when $x \geq x_m$ developers have no interest to develop houses because the residential return is no longer higher than the agricultural return, thus they let land in its agricultural state. The level of development along the city is depicted in Figure 1.

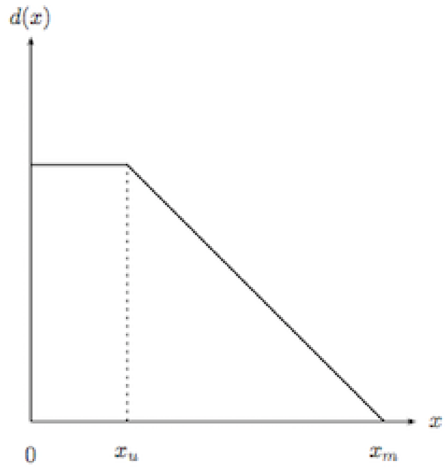

FIGURE 3.1 – Variation of urban development along the city

3.3.3.2 Equilibrium residential return

At equilibrium, the return of land in residential use is given by :

$$r_c(x) = \left[\frac{1}{q}(w - Tx - (u^* - q) - \gamma(1 - d^*(x))\right] d^*(x) - Cd^*(x)$$

In the compact built-up area, the level of development $d^*(x)$ is equal to one. In that case, their is no difference with the classic urban economics model with no open space and fixed lot size, and the rent is linearly decreasing with the distance to the CBD according to the variation of transport cost :

$$\frac{\partial r_u^*(x)}{\partial x} = \frac{-T}{q} \tag{3.3.10}$$

In the periurban area, the level of development $d^*(x)$ varies between zero and one and it affects the equilibrium residential bid-rent. Here, we see that the slope of the residential return is given by :

$$\frac{\partial r_p^*(x)}{\partial x} = -\frac{d^*(x)T}{q} \tag{3.3.11}$$

The residential rent decreases with distance to the CBD, but at a slower rate than in the compact built-up area. This phenomenon is explained by households' preference for open space : when households locate far away from the center, they pay high transport cost, but they trade-off with the amount of open space enjoyed. Thus, the rent is decreasing slowly because open spaces create a positive force on the equilibrium rent. When households have preference for proximity open space, the city extendsmore than in the classic Muth-Mills model of urban economics. In our case however the slope of the rent remains negative, because the rate of variation in the amount of open space is not greater than the rate of variation in the transport cost.

Finally, in the rural area, for $x \geq x_m$, the equilibrium rent is equal to the land rent in its agricultural state, here equal to zero for simplicity. The variation of the residential return along the city is depicted in figure 2, where x_c represents the city's limit in the classic urban economics model.

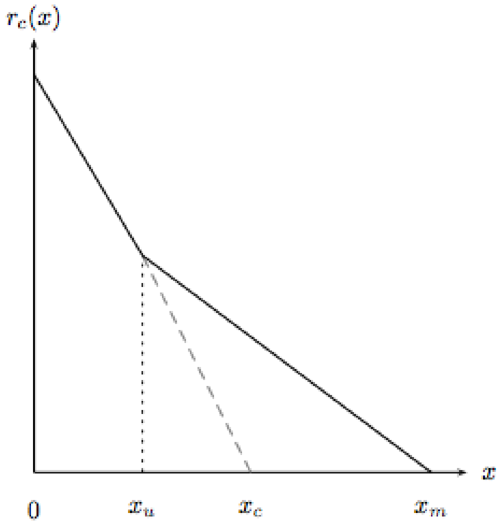

FIGURE 3.2 – Residential return gradient

3.4 Effects on biodiversity and welfare analysis

Until now, we have considered only the presence of intra-urban open space that are valued by households when they make their choice of localisation. However, the social planner cares also for big natural open space at the outskirts of city (Brueckner, 2000). Indeed, he values both type of open spaces because they offer provision and regulation ecosystem services, such as habitats for natural species. We define the level of biodiversity as follow :

$$B(d(x), x_m) = \int_0^{x_m} w_1[1 - d(x)]dx + w_2(L - x_m) \tag{3.4.1}$$

The first term of the right hand side of the equation represents the contribution of intra-urban open space, while the second term represents the contribution of the big open space at city's outskirts ; w_1 and w_2 are the weights associated with each type of open space regarding biodiversity conservation. These weights depend on the social planner's priorities on biodiversity conservation. Indeed, the presence of some species may be favored with small patches of intra-urban open space, while other species may prefer large open space.

Drawing upon the methodology of Fujita (1989), the problem of the social planner is to choose the level of urban development $d(x)$ at each x and the urban fringe distance x_m so as to maximize the sum of the total surplus and the biodiversity level while achieving the target utility u for N households.

$$\begin{cases} \max\limits_{d(x),x_m} & \displaystyle\int_0^{x_m} [(w-u+q)-td(x)-\gamma(1-d(x))]\frac{d(x)}{q}dx - \int_0^{x_m} Cd(x)dx + B(d(x),x_m) \\ \\ s.t. & \displaystyle\int_0^{x_m} \frac{d(x)}{q}dx = N \end{cases}$$

The Lagragian function associated to the above maximization program is :

$$\begin{aligned} \mathcal{L}(d(x),x,\lambda) = &\int_0^{x_m} [(w-u+q)-td(x)-\gamma d(x)]\frac{d(x)}{q}dx - \int_0^{x_m} Cd(x)dx \\ &+ w_1\int_0^{x_m}(1-d(x))dx + w_2(L-x_m) + \lambda(N - \int_0^{x_m}\frac{d(x)}{q}) \end{aligned} \tag{3.4.2}$$

The optimal conditions of this problem are given by :

$$d(x) = \begin{cases} 1 & \text{for } x \leq x_u \\ \dfrac{(w-Cq+q-u-tx-w_1q+\lambda)}{2q\gamma} & \text{for} \quad x_u \leq x \leq x_m \\ \dfrac{w_2-w_1}{p(\cdot)-C-w_1+\lambda/q} & \text{at} \quad x = x_m \quad \text{boundary condition} \\ 0 & \text{for } x > x_m \end{cases} \tag{3.4.3}$$

$$\int_0^{x_m} \frac{d(x)}{q}dx = N \tag{3.4.4}$$

We now compare the optimal conditions with the equilibrium results. We see that the level of urban development inside the peri-urban area is different at the optimum than at equilibrium. Indeed, the optimal level of urban development decreases with w_1, which is the marginal contribution of the intra-urban open spaces to the preservation of biodiversity, and increases with λ which is linked to the population constraint and represents the marginal net cost of a household in the city.
Moreover we see that $\frac{\partial d(x)}{\partial x} = \frac{-t}{2q\gamma}$ for $x_u \leq x \leq x_m$, meaning that at the optimum the urban development decreases at a lower rate with the distance to the city center compared to equilibrium.
The second main difference between optimum and equilibrium comes from the boundary condition. At the optimum, the level of urban development does not longer equal zero at the urban fringe. The level of urban development at the urban fringe is greater than zero and depends on the marginal contributions of the two different types of open spaces captured by w_1 and w_2, and of the net cost of a household in the city captured by λ.

Solving this boundary condition, we obtain the optimal city's limit, that we called x_{m_o} :

$$x_{m_o} = \frac{(2q-1)(w_1 q + Cq - q - w + u + \lambda) - 2\sqrt{q^3\gamma(w_2 - w_1)(1-2q)}}{t(2q-1)} \tag{3.4.5}$$

Supposing that $q > \frac{1}{2}$ and that $w_1 q + Cq - q - w + u + \lambda < 0$ ensure that the optimal city's limit is positive. Using the first two equations of system (3.4.3), we also obtain x_{u_o}, the optimal limit of the compact built-up area :

$$x_{u_o} = \frac{1}{T}\left(w - Cq + q - u - \gamma - w_1 q + \lambda\right) \tag{3.4.6}$$

It is easy to compare the limit of the urban core at equilibrium x_u, with the one at optimum x_{u_o}. We see that two new terms appears in x_{u_o} : one related to the biodiversity provided by proximity open space, and the other related with the population constraint. More precisely, the compact built-up area becomes smaller when the marginal gain of biodiversity provided by local intra-urban open spaces increases, and becomes larger when the net cost of a households in a city increases. The size of the compact built-up area is not directly related to the marginal gain of biodiversity provided by big open spaces.

Comparing the optimal and the equilibrium limits of the whole city is more complicated, but we can see that at optimum, the city's limit x_{m_o} depends on w_1, w_2 and λ as follows :

$$\frac{\partial x_{m_o}}{\partial w_1} = -\frac{1}{t(2q-1)}(q-2q^2) - \frac{q^3\gamma}{t\sqrt{q^3\gamma(w_2-w_1)(1-2q)}} \tag{3.4.7}$$

If we suppose as previously that $q < \frac{1}{2}$, the variation of x_{m_o} with respect to w_1 is always positive. The higher the marginal contribution of intra urban open space to biodiversity and the larger the city.

$$\frac{\partial x_{m_o}}{\partial w_2} = \frac{q^3\gamma}{t\sqrt{q^3\gamma(w_2-w_1)(1-2q)}} \tag{3.4.8}$$

The variation x_{m_o} with respect to w_2 is always negative. The higher the marginal contribution of big outskirts open space to biodiversity is, the smaller the city is.

$$\frac{\partial x_{m_o}}{\partial \lambda} = \frac{1}{t} \tag{3.4.9}$$

The variation x_{m_o} with respect to λ is always positive. The higher the net cost of a household in the city, the larger the city. The net cost of a household in the city, λ can intuitively be interpreted as the strength of the population constraint. Thus, the stronger the population constraint, the larger the city to accommodate all the households.

Proposition 1. *1. If the marginal gain of biodiversity provided by intra-urban open space, w_1, is large relatively to the marginal gain of biodiversity provided by big outskirts open space, w_2, such that $\frac{w_1}{w_2}$ is higher than $(\frac{w_1}{w_2})^h$, the optimal city structure is complete land sharing.*

2. If the marginal gain of biodiversity provided by intra-urban open space, w_1, is low relatively to the marginal gain of biodiversity provided by big outskirts open space, w_2, such that $\frac{w_1}{w_2}$ is lower than $(\frac{w_1}{w_2})^l$, the optimal city structure is complete land sparing.

3. If $(\frac{w_1}{w_2})^h \geq \frac{w_1}{w_2} \geq (\frac{w_1}{w_2})^l$, the optimal city structure is a mixed between complete land sharing and complete land sparing. The closer $\frac{w_1}{w_2}$ is to $(\frac{w_1}{w_2})^h$, the more the land is spared, and the closer $\frac{w_1}{w_2}$ is to $(\frac{w_1}{w_2})^l$, the more the land is shared.

See figure 3 for illustration and Appendix 1 for demonstration.

Proposition 1 and figure 3 show that the optimal city structure can take several forms. The equilibrium city structure can either be too compact, or too sprawled compared to the optimum, depending on the relative relative marginal contricution of the different types of open spaces on biodiversity conservation.

This result suggests that public policies must be carefully designed if the objective is to preserve biodiversity. In the case where optimum is obtained through land sparing configuration, a policy which provides incentives for infill development of vacant locations would be welfare increasing. Densification of the core city associated to creation of greenbelts by prohibiting development in wide regions of the periphery appears to be the best option to increase welfare.

However, the recommendation are different when intra urban open space provide a high marginal gain of biodiversity : in that case, land sharing should be promoted,

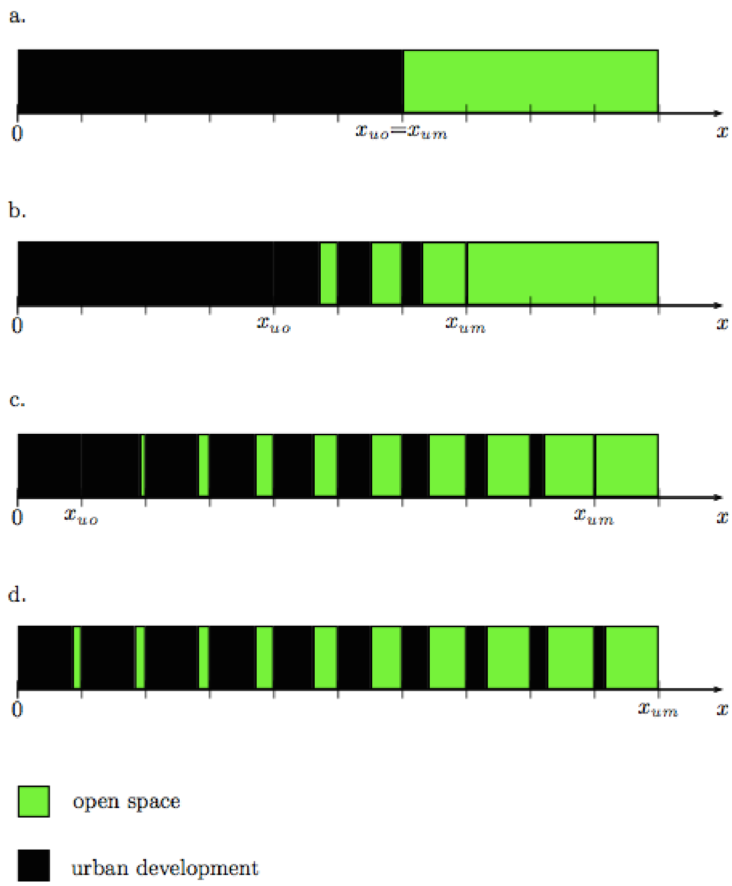

FIGURE 3.3 – Optimal city structure
a. $\frac{w_1}{w_2} \geq (\frac{w_1}{w_2})^h$: complete land sparing. b. $(\frac{w_1}{w_2})^h \geq \frac{w_1}{w_2} \geq (\frac{w_1}{w_2})^l$ and close to $(\frac{w_1}{w_2})^h$: land sparing. c. $(\frac{w_1}{w_2})^h \geq \frac{w_1}{w_2} \geq (\frac{w_1}{w_2})^l$ and close to $(\frac{w_1}{w_2})^l$: land sharing. d. $\frac{w_1}{w_2} \leq (\frac{w_1}{w_2})^l$: complete land sharing.

and a policy aimed at fighting urban sprawl would be welfare decreasing. In that case, creating a series of urban parks is the best solution to enhance welfare.

3.5 Conclusion

We developed a model in which open space can be split into two categories : local intra-urban open space that are directly valued by households as cultural ecosystem services, and large open space at city's outskirts valued by the social planner for environmental reasons. Our aim was to understand how households' preferences affect the equilibrium city structure, we show that when households value local open space, the city is first composed of a pure urban core where all the land is developed, followed by a periurban area where a part of the land is not developed forming intra-urban open spaces. Finally a rural area completes the equilibrium land-use pattern. This result entails that the city extends more when households value local open spaces, which is directly responsible for the loss of large open spaces at city's outskirt. We then study what is the optimal city structure when a social planner maximizes social welfare taking into account biodiversity conservation and both types of open spaces. We show that the optimal structure of the city can be either land sharing or land sparing, depending on the relative marginal impact of each type of open spaces on biodiversity conservation. Our analysis is a first step in the land-sharing vs. land-sparing debate in an urban context with economic tools. However, several questions still need to be addressed. In particular, it would be particularly interesting to take into account the possibility of « vertical » densification, or to extend the model in a dynamic analysis to better understand the processus of urban development and not only the resulting city structure.

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Chapitre 4

Urban structure and air quality

4.1 Introduction

In a world were distance is almost eliminated by innovations in telecommunication, people live closer and closer to each other : more than half the human population resides in urban areas (UNFPA, 2007). However living in cities involves health risks, in particular relating to degraded air quality. A study conducted by the European Commission reveals that pollution is responsible for forty-two thousand deaths per year in European cities (Watkiss et al., 2009). The World Health Organization recently highlighted that air pollution lowers life expectancy by seven months for a thirty-year-old individual in Paris (Declercq et al., 2012). The recent pollution event in Paris in March 2014 and 2015, that led to the implementation of traffic restrictions, put in perspective the debated role of multiple pollution sources, both local and regional, to the pollution load measured in Ile-de-France. The question of how to manage emission sources from different sectors is of crucial importance. Indeed, atmospheric pollution (PM10, PM5, NOx, etc.) and greenhouse gases (GHG) are emitted by various sectors, in particular transport, residential and industrial, at different levels.

4.1 Introduction

Environmental economists have been concerned with the deterioration of air quality for a long time and analyses of public policies for air pollution management in an aspatial context are numerous. Analyses of multiple interacting pollution sources are more scarce. Caplan and Silva (2005) introduced the notion of « correlated externalities » in a context where a single source is responsible for emitting multiple pollutants that may have local or regional impacts. They analyzed the properties of different policy instruments to manage efficiently such correlated externalities in the context of a global federation with decentralized leadership in a series of papers (Caplan and Silva (2005); Caplan (2006); Caplan and Silva (2007)). However, there exist different types of correlations between atmospheric pollutants, since they can interact during or after the production process in various manners : complement or substitute abatement technologies, interactions between stocks, interacting damage, etc. A range of papers tackle this issue, framed in the context of GHG policy design, based on dynamic models of pollutant accumulation where the interactions between pollutants are described in different manners (Yang (2006); Moslener and Requate (2007, 2009); Legras (2011)). However, they all point out to the importance of carefully characterizing the interactions between pollutants in the design of policy instruments. Ren et al. (2011) address the correlation between pollutants resulting from different industries and linked to one another through market demands rather than technical production relationships, « interacting externalities », and analyze how this interaction affects the design of taxes to manage each externality. They show that the optimal second best policy depends on the nature of the market relationship between the goods whose production causes the externalities. All these studies are particularly relevant regarding urban air quality because there are several sources of pollution in cities (mostly industries and transports) and several types of both local pollutants (such as particular matter or heavy metals) and global pollutants (such as greenhouse gases).

However, the previously cited papers do not study air pollution in an explicit spatial model and thus overlook some issues specific to cities.

This paper examines the policy implications of multiple simultaneous externalities in a spatially explicit context of urban development. It extends the above-cited literature to a spatial framework, and introduces multiple environmental issues in an urban economics framework.

Some studies have analyzed air pollution in an explicit spatial setting, by studying either industrial or transport-related pollution, which are the two main sources of the deterioration of urban air quality. Henderson (1977) is the first to study air pollution caused by industrial sources in a monocentric setting. Arnott et al. (2008) and Kyriakopoulou and Xepapadeas (2011) extend the study of industrial pollution to non-monocentric cities. Kyriakopoulou and Xepapadeas (2013) and Verhoef and Nijkamp (2002) also develop this model to incorporate agglomerations economies. The important result shared by all these papers is the existence of a defensive behavior by households : as they dislike pollution, households choose to locate farther from polluting firms. But issues can arise when there is an excessive defensive behavior by households : the tendency to choose a more remote location entails for example larger travel costs and increased car use. The use of cars as a means of transportation is also directly responsible for the emission of local pollutants and GHG in cities. Robson (1976) shows that the equilibrium land use pattern is distorted from optimum because of transport pollution. Then policy instruments, such as a tax on commuting, should be implemented to decentralize the optimum i.e. the land use pattern than internalizes transport pollution (Robson, 1976; McConnell and Malhon, 1982; Verhoef and Nijkamp, 2003).

4.1 Introduction

To the best of our knowledge, interactions between industrial pollution and transport pollution have not been explicitly examined yet in the economic literature. However these two externalities are linked through the land market. Indeed air pollution resulting from industries' emissions affect the locational decision of households by pushing them away from polluting firms, while an optimal policy instrument to manage GHG emissions from commuting leads to more concentrated cities. If we take into account both types of pollution in a single model the conclusion is different and the effect of a tax on transport is in contradiction with the defensive behavior by households suffering from industrial pollution : the correction of one market failure exacerbates welfare loss from the other Bennear and Stavins (2007).

This paper departs from the previous literature by developing a theoretical model incorporating two environmental externalities that interact through the land market in an explicit spatial setting. The objectives of this paper are : (i) to identity the effect of industrial pollution on households' choice of localization when neither employment nor residential locations are specified a priori, (ii) to assess the level of GHG emissions resulting from the equilibrium city structure, (iii) and to find the optimal policy mix to manage polluting emissions from both the industrial and the transport sectors.

The remainder of the paper is organized as follows. Section 2 presents the structure of the model, based on the Ogawa and Fujita (1982) model of linear city with endogenous center. Section 3 deals with the equilibrium land use pattern, and section 4 focuses on the design of an optimal policy mix, composed of an industrial pollution abatement norm and a tax on commuting paid by households. Section 5 concludes.

4.2 The model

A linear city lies on a uni-dimensional space $X =]-\infty, +\infty[$. At each location $x \in X$, the quantity of available land is equal to one. Two types of agents interact inside the city : firms and households. Each household provides one unit of labor to a firm, and receives a wage in exchange.

Firms produce a good using a polluting technology and export it outside the city. Households consume a good z imported from outside and are affected by industrial pollution. In addition, both types of agents compete for land, owned by absentee landowners, either for residential or production purposes. These interactions take place through labor and land markets, both of which are assumed to be perfectly competitive at each point $x \in X$ of the city.

Commuting by households from their place of residence to their workplace generates GHG emissions, proportional to the aggregate distance travelled. It is assumed in this paper that GHG emissions are not accounted for by the households in their residential location choice due to their global, rather than local, effects. Commuting also contributes to polluting emissions (particular matter, NOx, etc.) that affect households' utility, but we do not incorporate them in our model. Indeed, our model of a linear city with one transportation means and a single road does not allow us to capture the localized effects of traffic-related pollution in a satisfactory manner (see for instance Schindler and Caruso (2014) for a discussion on this issue). In the simplest manner, without accounting for distance-based emission factors (such as the cold engine effect), they would be incorporated as proportional to the amount of traffic passing by each residential location, which decreases with the distance from the CBD. Hence, they would reinforce the defensive behavior of households that induces them to locate further from the CBD. A more detailed model would be necessary to fully grasp the emission/exposure tension in the management of traffic-related local pollution.

4.2.1 Households

We assume that there are N identical households in the city, where N is fixed and exogenously determined. Thus, we focus on a closed-city model, where the total population is given, and any modification of the economic environment impacts households' utility. In an open-city context, such a modification would entail a change in total population, while the utility level would remain equal to that of the rest of the world. Since our interest rests on the impact of environmental externalities on the internal structure of the city, we pursue the analysis within a closed-city framework.

All households have identical preferences and derive utility from the consumption of a composite good Z, land S_h, and perceived environmental quality E. The amount of land consumed by each household, S_h, is assumed to be given exogenously. We choose a quasi-linear functional form to describe households' utility :

$$U(Z(x), S_h, E(x)) = Z(x) + E(x) + \gamma \ln S_h \tag{4.2.1}$$

Households choose a residential location x and a job site x_w to maximize their utility under a budget constraint. Each household provides one unit of labor to a business firm located in x_w and earns a wage $W(x_w)$ in return. This wage is used to pay a land rent $R(x)$, and to consume a composite commodity. The composite commodity is chosen as a numeraire so its price $p_z = 1$. Each household commutes to the firm everyday at a cost t per kilometer travelled between residential location and job site.

Environmental quality is considered as a spatial attribute of housing, which affects the households' utility function directly but not its budget constraint.

Since all households are assumed to be identical, in equilibrium they must all achieve the same maximum utility level, independent of location. The common maximum utility level, called the *equilibrium utility* and denoted U^*, is the solution of the following program :

$$\begin{cases} \max\limits_{x,x_w} & U(Z(x), S_h, E(x)) \\ s.t. & W(x_w) = R(x)S_h + Z(x) + t|x - x_w| \end{cases}$$

The environmental quality perceived by the households is assumed to be directly linked to industrial activities ; at each point x it is described by a linear function [1] :

$$E(x) = \bar{E} - \int_X \left[e - \eta|x-y|\right] b(y)dy \qquad (4.2.2)$$

Where $\bar{E}$ is an ambiant quality level with no pollution, e represents the quantity of pollution emitted by one firm, η is a measure of dispersion of pollution into the atmosphere, $|x-y|$ is the distance between households located at x and firms located at y, and $b(y)$ is the density function of firms at location y. Households located in x suffer from a negative effect of pollution emitted by firms located at y. As emissions disperse into the atmosphere at a constant rate, households can choose to benefit from a better environmental quality by locating further away from firms. In doing so, however, they incur higher transport costs. Transport cost acts as a centripetal force, while pollution acts as a centrifugal one. Households' well-being is determined by the

1. The choice of a linear function allows us to compute in a comprehensible manner the following results analytically. Until a given point, similar results can be found using an exponential functional form.

trade-off between the accessibility to the workplace and the amount of environmental quality at the residential location.

This trade-off appears in the *bid-rent function* of households, which is a generalized form of the bid rent function originally defined by Alonso (1964) in the context of a monocentric city. The individual bid-rent function of a household located at x gives the highest price that he is willing to pay for one unit of land at x while deriving the utility level U^* and given the wage profile $W(x_w)$. It is expressed as follows :

$$\Psi(x) \equiv \quad \Psi(x|W(x_w), U^*) = \quad \max_{x_w} \left\{ \frac{1}{S_h} \left[W(x_w) - t|x - x_w| - Z^*(S_h, E(x), U^*) \right] \right\}$$

Where $Z^*(S_h, E(x), U^*)$ is the solution to $U(Z(x), S_h, E(x)) = U^*$ and represents the amount of composite good necessary to achieve the equilibrium utility level U^* when lot size is equal to S_h and environmental quality to $E(x)$. With the specified utility function defined in (4.2.1) we obtain :

$$\Psi^*(x) = \max_{x_w} \left\{ \frac{1}{S_h} \left[W(x_w) - t|x - x_w| - U^* + E(x) + \gamma \ln(S_h) \right] \right\}$$

Note that here, each household locating at x optimally chooses its job site x_w, considering the trade-off between commuting cost $t|x-x_w|$ and wage $W(x_w)$. The equilibrium wage profile is given by [2] :

$$W(x) = W(0) - tx \tag{4.2.3}$$

Where $W(0)$ is the wage provided by the firm located at the city's central loca-

2. Due to the no cross commuting property, the equilibrium wage profile is a linear function of the distance to the center. Refer to (Ogawa and Fujita, 1980) for proofs of these two propositions. They are not altered by the introduction of industrial pollution in the model as the consumption of environmental quality does not enter into the budget constraint and the net income remains the same.

tion.Then, using (4.2.3) we conclude that at equilibrium the bid-rent function of households is :

$$\Psi^*(x) = \frac{1}{S_h}\left[W(x) - U^* + E(x) + \gamma \ln(S_h)\right] \tag{4.2.4}$$

The bid-rent of households depends positively on wage and the environmental quality, but negatively on transport cost, revealing the trade-off between accessibility and environmental quality. In a general way, this trade-off leads to the possibility of positive land-rend gradient depending on the curvature of the environmental quality function and the transport cost function ; the seminal paper by Richardson (1977) explores in detail this possibility [3].

4.2.2 Business firms

We suppose that there are M identical firms. Each firm produces one good using land, labor, and a polluting technology. Production output is exported from the city at a unitary price. Following Ogawa and Fujita (1982), we assume that the amounts of land S_b and labor L_b used for production by each firm are fixed. We assume that there is no unemployment in the city, so that at the equilibrium we have the following relation :

$$M = N/L_b$$

Firms benefit from agglomeration economies, measured by the locational potential function $F(x)$ defined by :

$$F(x) = \int_X \left[\alpha - \tau|x-y|\right] b(y)dy \tag{4.2.5}$$

3. In our case however, with a proper choice of parameters, the rent gradient can remain negative. We adopt this hypothesis for the remaining of the paper in order to keep the analytical results tractable.

where α is a parameter representing agglomeration economies, $b(y)$ is the density of business firms at y, and $|x - y|$ is the distance between firms locating at x and firms locating at y.

Firms use a polluting technology. They have to pay a cost $C(a)$ to abate an amount a of pollution [4]. The level of abatement is the difference between the laissez-faire level of pollution emission e^e and a lower level given by $\bar{e}$: $a = e^e - \bar{e}$. At the laissez-faire situation, abatement level and abatement cost both equal zero.

Each firm seeks to maximize its profit and solves the following program :

$$\max_{x} \ \pi = F(x) - R(x)S_b - W(x)L_b - C(a)$$

From the maximization problem we can define the bid-rent function of firms. It is the maximum land rent that a business firm is willing to pay to locate at x while deriving a profit π^* and given the distribution of firms $b(x)$. It is written as follows :

$$\Phi^*(x) \equiv \quad \Phi(x|b(x), W(x), \pi^*) = \quad \frac{F(x) - \pi^* - W(x)L_b - C(a)}{S_b}$$

Markets are perfectly competitive then profit is driven to zero at equilibrium, and firms choose their amount of abatement freely so the bid-rent function is rewritten as :

$$\Phi^*(x) = \frac{F(x) - W(x)L_b}{S_b} \tag{4.2.6}$$

The bid-rent function of firms depends positively on the locational potential but negatively on wage.

4. The cost of abatement is positive, and increasing and convex with respect to the level of abatement : $C(a) > 0$, $C'(a) > 0$, $C''(a) > 0$, for every $a > a^e$ where a^e corresponds to the laissez-faire situation.

4.2.3 Equilibrium conditions

Equilibrium land use describes a state of the urban system that shows no propensity to change. It implies that there is no utility to gain by changing location, neither for firms nor for households. At the equilibrium, land is allocated to the highest bidder. Beyond the city's limits, there is only agricultural land, characterized by an exogenous agricultural land rent R_a. Each equilibrium spatial structure of the city is described by a system where the unknowns are the household density function $h(x)$, the firm density function $b(x)$, the land rent profile $R(x)$, the wage profile $W(x)$, the commuting pattern $P(x, x_w)$, and the utility level U^*, with :

$$P(x, x_w) = \frac{\text{number of households locating at } x \text{ and commuting to job site } x_w}{\text{total number } h(x) \text{ of households locating at } x}$$

The necessary and sufficient conditions for the system to be an equilibrium land use pattern are summarized as follows :

(i) Land market equilibrium conditions at each x :

$$R(x) = \max\{\Psi^*(x), \Phi^*(x), R_a\}$$

$$R(x) = \Psi^*(x) \quad \text{if} \quad h(x) \geq 0$$

$$R(x) = \Phi^*(x) \quad \text{if} \quad b(x) \geq 0$$

$$R(x) = R_a \quad \text{at the urban fringe}$$

$$S_h h(x) + S_b b(x) \leq 1$$

$$S_h h(x) + S_b b(x) = 1 \quad \text{if} \quad R(x) > R_a$$

(ii) Labor market equilibrium condition at each x :

$$b(x)L_b = \int_X h(y)P(y,x)dy$$

(iii) Total unit number constraints :

$$\int_X h(x)dx = N, \quad \int_X b(x)dx = M$$

(iv) Non-negativity constraints :

$$h(x) \geq 0, \quad b(x) \geq 0, \quad R(x) \geq 0, W(x) \geq 0, \quad 1 \geq P(x,x_w) \geq 0,$$
$$\int_X P(x,x_w)dx_w = 1$$

4.3 Equilibrium land use pattern with industrial pollution

In this section we examine the conditions under which different urban configurations are the equilibrium market outcome, an extension of the analysis of (Ogawa and Fujita, 1980) to the case where households take into account industrial pollution. The endogenous urban configuration may be concentrated (a monocentric city), dispersed (a completely residential/industrial mixed city) or an intermediate (a city with both specialized and mixed residential and industrial areas). We analyze how households' residential and job location choice is affected by their consideration of industrial pollution, hence how the equilibrium urban structure is affected. We also derive the total distance travelled in each urban configuration, to assess the intensity of GHG emissions resulting from households' and firms' location choices.

4.3.1 Monocentric urban configuration

We start with the basic monocentric configuration, which corresponds to a city where the majority of households lives in the suburbs while firms occupy the center. Formally, we assume that the origin is the center of the city. All firms are located around 0 between -f_{1M} and f_{1M}, the *business district* (BD). Households are located in two zones, between -f_{1M} and -f_{2M} and between f_{1M} and f_{2M}, the *residential areas* (RA). Beyond urban fringes -f_{2M} and f_{2M} there are only agricultural lands. Figure 1 represents the monocentric configuration of the city.

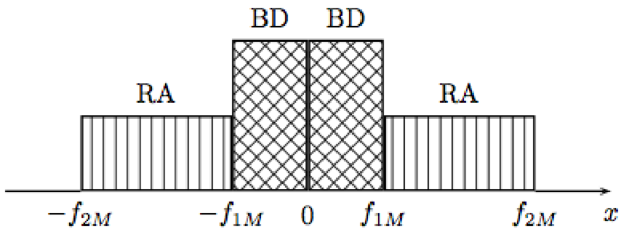

FIGURE 4.1 – Monocentric urban configuration

We assume that the city is perfectly symmetric, then it is sufficient to examine the equilibrium conditions on the right-half of the city, where $x \geq 0$. Since land uses are exclusive, the following density functions apply :

$$h(x) = 1/S_h, \quad b(x) = 0, \quad \forall x \in RA$$

$$h(x) = 0, \quad b(x) = 1/S_b, \quad \forall x \in BD$$

Thanks to the total unit number constraints and the full employment assumptions, we can derive the equilibrium center boundary f_{1M} and the urban fringe f_{2M} :

$$f_{1M} = \frac{S_b M}{2}, \qquad f_{2M} = \frac{M}{2}(S_b + L_b S_h)$$

Using its definition in equation (4.2.5), the locational potential function in the monocentric city is :

$$F(x) = \begin{cases} \alpha M - \frac{\tau}{S_b}(f_{1M}^2 + x^2) & \text{if} \quad x \in [0, f_{1M}] \\ \alpha M - \frac{2\tau}{S_b} x f_{1M} & \text{if} \quad x \in [f_{1M}, f_{2M}] \end{cases} \tag{4.3.1}$$

$F(x)$ is decreasing and concave with x on BD and decreasing and linear on RA, meaning that agglomeration externalities are stronger when firms are close to each other : the potential location function acts as a centripetal force for firms.

To define the environmental quality in the monocentric configuration, we use equation (4.2.2) and the definition of industrial density. We obtain the following environmental quality function :

$$E(x) = \begin{cases} \bar{E} - eM + \frac{\eta}{S_b}(f_{1M}^2 + x^2) & \text{if} \quad x \in [0, f_{1M}] \\ \bar{E} - eM + \frac{2\eta}{S_b} x f_{1M} & \text{if} \quad x \in [f_{1M}, f_{2M}] \end{cases} \tag{4.3.2}$$

$E(x)$ is increasing and convex in x on BD and increasing and linear on RA. Environmental quality perceived by households located at x is inversely correlated with the aggregation of pollution emitted by firms in the city, given by eM. However it increases with the distance to the center because pollution disperses into the atmosphere at a rate η.

The property of no cross-commuting allows us to rewrite the equilibrium conditions on the land market as follows :

$$R(x) \quad = \Phi^*(x) \geq \Psi^*(x) \quad \forall x \in [0, f_{1M}] \tag{4.3.3a}$$

$$R(x) \quad = \Phi^*(x) = \Psi^*(x) \quad \text{at} \quad x = f_{1M} \tag{4.3.3b}$$

$$R(x) \quad = \Psi^*(x) \geq \Phi^*(x) \quad \forall x \in [f_{1M}, f_{2M}] \tag{4.3.3c}$$

$$R(x) \quad = \Psi^*(x) = R_a \quad \text{at} \quad x = f_{2M} \tag{4.3.3d}$$

where $\Psi^*(x)$ and $\Phi^*(x)$ are given by equation (4.2.4) and (4.2.6) respectively. Then the equilibrium conditions on the land market can be simplified :

$$R(0) = \Phi^*(0) \geq \Psi^*(0)$$

$$R(f_{1M}) = \Phi^*(f_{1M}) = \Psi^*(f_{1M})$$

$$R(f_{2M}) = R_a = \Psi^*(f_{2M}) \geq \Phi^*(f_{2M})$$

Which implies

$$\Phi^*(0) - \Phi^*(f_{1M}) \geq \Psi^*(0) - \Psi^*(f_{1M}) \tag{4.3.4}$$

$$\Phi^*(f_{1M}) - \Phi^*(f_{2M}) \geq \Psi^*(f_{1M}) - \Psi^*(f_{2M}) \tag{4.3.5}$$

Using equations (4.2.4) and (4.2.6), we can rewrite (4.3.4) and (4.3.5) as follows, where A_M and A'_M correspond to the conditions derived in (Ogawa and Fujita, 1982) when there is no environmental externality and B_M and B'_M appear with the introduction of pollution in the model :

$$t \leq \underbrace{\frac{S_h}{S_b + S_h L_b} \cdot \frac{(F(0) - F(f_{1M}))}{f_{1M}}}_{A_M} + \underbrace{\frac{S_b}{S_b + S_h L_b} \cdot \frac{(E(f_{1M}) - E(0))}{f_{1M}}}_{B_M} \qquad (4.3.6a)$$

$$t \leq \underbrace{\frac{S_h}{S_b + S_h L_b} \cdot \frac{(F(f_{1M}) - F(f_{2M}))}{(f_{2M} - f_{1M})}}_{A'_M} + \underbrace{\frac{S_b}{S_b + S_h L_b} \cdot \frac{(E(f_{2M}) - E(f_{1M}))}{(f_{2M} - f_{1M})}}_{B'_M} \qquad (4.3.6b)$$

B_M and B'_M are positive constants, which means that the condition on t is easier to sustain. Moreover, they increase with the value of η. Industrial pollution pushes households to locate farther from the business district, and leads to a greater spatialisation of activities.

Since $A_M + B_M < A'_M + B'_M$, we obtain only one conditions on t for the monocentric configuration to constitute an equilibrium :

$$t \leq \frac{1}{2} \frac{(S_h \tau + S_b \eta) N}{L_b (S_b + S_h L_b)} = \bar{t_1} \qquad (4.3.7)$$

This leads to the following proposition.

Proposition 2. *The monocentric configuration is a more likely equilibrium when households take industrial pollution into account.*

The pollution effect reinforces the locational potential effect, the former acting as a centripetal force for households and the latter as a centrifugal force for firms.

The total distance travelled in a monocentric configuration is given by the aggregation of households' commuting trips :

$$D_M(x, x_w) = \int_0^{f_{1M}} \int_{f_{1M}}^{f_{2M}} P(x, x_w)(x - x_w) dx dx_w \tag{4.3.8}$$

where the commuting pattern $P(x, x_w)$ in the monocentric city case is :

$$P(x, x_w) = \frac{(f_{2M} - f_{1M})/S_h}{f_{1M}/S_b} \cdot \frac{1}{1/S_h}$$

This leads to :

$$D_M = \frac{1}{2} S_b f_{2M} (f_{2M} - f_{1M})^2 \tag{4.3.9}$$

The total distance travelled in a monocentric urban configuration increases with the population, residential and industrial lot sizes, and labor intensity.

4.3.2 Completely mixed urban configuration

Now we analyze a situation where households and firms coexist at every point x in the city. This type of configuration may be considered as analogous to a highly densified city in a model with endogenous lot size : firms and households are close to each other and both types of configurations present the same characteristics. The limits of the city are given by the frontiers $-f_{1c}$ and f_{1c}. There is only one area between these two limits called the *integrated district* (ID), as represented in figure 2, where households' residential location and job site are the same $x = x_w$.

This implies no commuting. Consequently, the equilibrium condition in the labor market is satisfied, and the total distance travelled D_c is equal to zero. Under this configuration, the density function of firms and households are :

$$h(x) = \frac{L_b}{S_b + S_h L_b}, \qquad b(x) = \frac{1}{S_b + S_h L_b}, \qquad \forall x \in [-f_{1c}, f_{1c}]$$

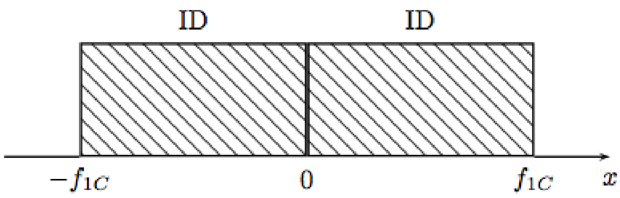

FIGURE 4.2 – Completely mixed urban configuration

We focus again only on the right-half of the city where $x \geq 0$. The environmental quality perceived by households located at x is given by :

$$E(x) = \bar{E} - eM + \frac{\eta}{S_b + S_h L_b}(f_1^2 + x^2) \quad \forall x \in [0, f_{1c}] \tag{4.3.10}$$

Environmental quality is increasing and convex inside ID. The locational potential function is expressed as follows :

$$F(x) = \alpha M - \frac{\tau}{S_b + S_h L_b}(f_{1c}^2 + x^2) \quad \forall x \in [0, f_{1c}] \tag{4.3.11}$$

It is decreasing and concave inside ID. In the land market the equilibrium conditions are written :

$$R(x) = \Psi^*(x) = \Phi^*(x) \quad \forall x \in [0, f_{1c}] \tag{4.3.12a}$$

$$R(x) = R_a \qquad \text{at} \quad x = f_{1c} \tag{4.3.12b}$$

From (4.2.4), (4.2.6) and (4.3.12a) we obtain the wage profile on the integrated district :

$$W(x) = \frac{S_h F(x) + S_b(U^* - \gamma \ln S_h) - \overbrace{S_b E(x)}^{C}}{S_b + S_h L_b} \tag{4.3.13}$$

Part C is due to the introduction of environmental externalities in the model : the equilibrium wage decreases with environmental quality. In this configuration households cannot respond to the pollution damage by choosing a location farther from firms, so firms must offer a higher wage to provide an incentive for households to locate where environmental quality is low.

Plugging (4.3.13) into (4.2.4) or (4.2.6), we obtain the equilibrium land rent :

$$R(x) = \frac{F(x) - L_b(U^* - \gamma \ln S_h) + L_b E(x)}{S_b + S_h L_b} \tag{4.3.14}$$

Again, the rent function is increasing with the level of environmental quality, $W(x)$ is positively correlated with $F(x)$ and negatively correlated with $E(x)$. It implies that the wage $W(x)$ is a strictly concave function of x. As there is no commuting in the completely mixed configuration, households have no incentive to change their job site only if $|W'(x)| \leq t$. This condition is equivalent to $W'(f_1) \geq -t$ because of the strict concavity of $W(x)$. Then, from this condition and with equations (4.3.10) and (4.3.11) we obtain that the completely mixed configuration is an equilibrium if :

$$t \geq A_c + B_c = \frac{N\tau S_h}{(S_b + S_h L_b)L_b} + \frac{N\eta S_b}{(S_b + S_h L_b)L_b} = \frac{N(\tau S_h + \eta S_b)}{(S_b + S_h L_b)L_b} = \bar{t_2} \tag{4.3.15}$$

where A_c is the condition without pollution as in Ogawa and Fujita (1982), and B_c is due to the introduction of pollution in the model. B_c is a positive constant meaning that the condition on t for the completely mixed urban configuration to be an equilibrium is stronger.

Proposition 3. *The completely mixed urban configuration is a less likely equilibrium when households take industrial pollution into account.*

Even if the locational potential τ is very low, the completely mixed urban configuration might not be an equilibrium because of the presence of the negative environmental externality, which pushes households far from polluting firms.

4.3.3 Incompletely mixed urban configuration

An incompletely mixed urban configuration is a generalization of the monocentric and the completely mixed configurations. There are three sections in the city. As the city is perfectly symmetric we focus only on the right-half. Between 0 and f_{1I}, firms and households are mixed in the integrated district (ID). The business district (BD), between f_{1I} and f_{2I}, and the residential area (RA), between f_{2I} and f_{3I}, are specialized areas. Figure 3 represents the incompletely mixed city structure.

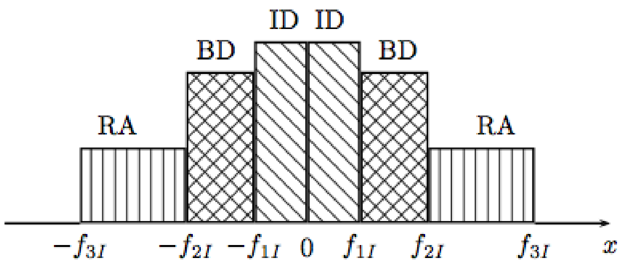

FIGURE 4.3 – Incompletely mixed urban configuration

The city boundaries are given by :

$$f_{1I} \in \left(0, \frac{S_b + S_h L_b}{2L_b} N\right), \quad f_{2I} = \frac{S_h L_b}{S_b + S_h L_b} f_{1I} + \frac{S_b N}{2L_b}, \quad f_{3I} = \frac{S_b + S_h L_b}{2L_b} N.$$

It is straightforward to note that the incompletely mixed urban configuration approaches the monocentric configuration as f_{1I} tends to zero, and it approaches the completely mixed configuration as f_{1I} tends to $N(S_b + S_h L_b)/2L_b$. Each segment of the city is characterized by the density, environmental quality and locational potential functions described in Appendix 1.

The equilibrium conditions in the land market for the incompletely mixed urban configuration allow us to derive the equilibrium value of f_{1I} as well as the conditions for this urban configuration to constitute an equilibrium. They are summarized, for $x \geq 0$, as follow :

$$R(x) = \Phi^*(x) = \Psi^*(x) \quad \forall x \in [0, f_1] \tag{4.3.16a}$$

$$R(x) = \Phi^*(x) \geq \Psi^*(x) \quad \forall x \in [f_{1I}, f_{2I}] \tag{4.3.16b}$$

$$R(x) = \Phi^*(x) = \Psi^*(x) \quad \text{at} \quad x = f_{2I} \tag{4.3.16c}$$

$$R(x) = \Psi^*(x) \geq \Phi^*(x) \quad \forall x \in [f_{2I}, f_{3I}] \tag{4.3.16d}$$

$$R(x) = \Psi^*(x) = R_a \quad \text{at} \quad x = f_{3I} \tag{4.3.16e}$$

Where $\Psi^*(x)$ and $\Phi^*(x)$ are given by (4.2.4) and (4.2.6) respectively.

Appendix 2 presents the resolution process that leads to the following conditions on t for the incompletely mixed configuration to be an equilibrium :

$$t = \tfrac{S_h}{S_b+S_h L_b} \cdot \tfrac{(F(f_{1I})-F(f_{2I}))}{f_{2I}-f_{1I}} + \underbrace{\frac{S_b}{S_b + S_h L_b} \cdot \frac{(E(f_{2I}) - E(f_{1I}))}{f_{2I} - f_{1I}}}_{B_I} \tag{4.3.17a}$$

$$t \leq \tfrac{S_h}{S_b+S_h L_b} \cdot \tfrac{(F(f_{1I})-F(f_{3I}))}{(f_{3I}-f_{1I})} + \underbrace{\frac{S_b}{S_b + S_h L_b} \cdot \frac{(E(f_{3I}) - E(f_{1I}))}{f_{3I} - f_{1I}}}_{B'_I} \tag{4.3.17b}$$

Parts B_I and B'_I are positive constants capturing the effect of an environmental externality on the equilibrium outcome. Finally, no commuting in ID implies again that $|W'(x)| \leq t$ for $x \in ID$, which is equivalent to the following conditions :

$$t \geq \frac{S_h}{S_b + S_h L_b} F'(f_{1I}) + \frac{S_b}{S_b + S_h L_b} E'(f_{1I}) \tag{4.3.18}$$

Plugging the definitions of $F(x)$ and $E(x)$ into (4.3.17a), we can compute the value of the integrated district's limit, f_{1I} :

$$f_{1I} = \frac{t(S_b + S_h L_b)^2}{\tau S_h + \eta S_b} - \frac{(S_b + S_h L_b)M}{2} \tag{4.3.19}$$

It is clear that with pollution ($\eta > 0$), the integrated district is smaller than without pollution. Then, the spatialization of activities tends to be more important with negative environmental externalities. At the equilibrium, the city is less integrated and more spatialized.

Using the definition of f_{1I} and (4.3.17b) and (4.3.18), we obtain the following necessary conditions on t for the incompletely mixed land use pattern to be an equilibrium :

$$\bar{t_1} \leq t \leq \bar{t_2} \tag{4.3.20}$$

Where $\bar{t_1}$ and $\bar{t_2}$ were defined previously (see Equations 4.3.7 and 4.3.15)

Proposition 4. *With the presence of a negative environmental externality caused by industrial pollution, the integrated district of an incompletely mixed city is smaller, while the business district and the residential area are larger at equilibrium. Furthermore, the values of t for which the incompletely mixed urban configuration is an equilibrium are higher than in the no pollution case.*

The total distance travelled is given by the following function :

$$D_I(x, x_w) = \int_{f_{1I}}^{f_{2I}} \int_{f_{2I}}^{f_{3I}} P(x, x_w)(x - x_w) dx dx_w \tag{4.3.21}$$

Following the same reasoning as in section (3.1), the commuting pattern is written :

$$P(x, x_w) = \frac{(f_{3I} - f_{2I})/S_h}{(f_{2I} - f_{1I})/S_b} \cdot \frac{1}{1/S_h} \tag{4.3.22}$$

Plugging this expression into (4.3.21) gives the total distance travelled in the incompletely mixed configuration :

$$D_I = \frac{1}{2}(f_{3I} - f_{2I})^2 (f_{3I} - f_{1I}) S_b \tag{4.3.23}$$

Proposition 5. *With the presence of a negative environmental externality caused by industrial pollution, the aggregate commuting distance is larger in a monocentric configuration than in the incompletely mixed case.*

Refer to Appendix 3 for the demonstration. Then, the defensive behavior exhibited by households towards industrial pollution generates higher commuting damage, that they do not incorporate but that enters the policy maker's program. The next section investigates the policy implications of accounting for both industrial and commuting damage.

4.4 Policy implications

The presence of externalities leads to non-optimal equilibrium land use. When they maximize profits firms do not take into account households' disutility caused by their emissions of industrial pollution. The resulting defensive behavior of households is responsible for an increase in car use, hence in GHG emissions that households do not consider in their residential location choice. This section explores the issue of how to design appropriate incentive schemes to induce households and firms to make socially optimal decisions.

Specifically, we consider a policy maker willing to maximise the social welfare defined as the sum of residents' utility minus the aggregate damage due to commuting and industrial production [5] :

$$SW = NU_T^* - \gamma_c TDC - \gamma_f TDF \tag{4.4.1}$$

where γ_c and γ_f are the social weights associated with each term of damage. The environmental damage created by commuting is proportional to the total distance travelled in the city. If k is the GHG emission factor, the total environmental damage created by GHG emissions, denoted TDC, in the urban structure j is :

$$TDC = kD_j(T)$$

where the distances D_j are as computed in the previous section. The second source of pollution, coming from industry, is partly accounted for by households who decide to locate farther from polluting firms. However, each household only take into account the damage created by industrial pollution at its own place of residence, whereas pollution emitted by one firm has an impact on the whole city. Thus, the total damage of industrial pollution created by firms cannot be fully taken into account by households, that are only able to influence the damage that they confront. The

5. Since markets are perfectly competitive, firms' profit is driven to zero at equilibrium, consequently it does not enter the regulator's program.

total damage created by industrial pollution, denoted TDF, is the aggregation of individual damage at each point x ($x \geq 0$) of the city :

$$TDF = \int_X \int_X [e - \eta|x - y|]b(y)dydx$$

To maximise social welfare, the regulator may have recourse to two types of policy instruments : a tax on commuting and an abatement norm. The tax on commuting is a price-based instrument and creates direct incentives for households to limit their commuting distance. In practice, this instrument can take several forms : an urban toll as in London or Singapore, or a kilometric tax as recently experimented in Brussels. In our model, the commuting tax takes the form of a cost T linearly proportional to the distance travelled by each household.

The abatement norm on industrial emissions is a quantity-based instrument. The social planner chooses a minimal level of pollution abatement that all firms must respect. If they do not comply with the norm, firms face the risk of paying a fine [6]. In practice, such norms are enforced, for instance in the USA as part of the Clean air act : the National Emission Standard for Hazardous Air Pollution (NESHAP) for example imposes a regulatory limit on the emission of industrial firms. In Europe, the European Commission also adopted in 2010 a new legislation to lower the norm on industrial emissions (such as nitrogen oxide or heavy metals). In our model, the abatement norm is denoted $\bar{a}$ and is superior to the laissez-faire level of abatement, so $\bar{a} > 0$. We consider a simple, homogenous norm on abatement common to all the firms, rather than more complex industrial pollution management options due to our modeling choice of a simple production side (following Ogawa and Fujita (1982)).

6. We assume in the remainder of the paper that it is sufficiently high to ensure complete compliance.

Indeed, our aim in this paper is primarily to analyse households and their behavior faced with exposure to industrial pollution. To analyse the socially optimal urban structure and associated policy instruments, we compute the socially optimal policy for each urban configuration (M, I, C) and compare the resulting social welfares. According to the economic parameters of the model (social valuation of the damages, commuting cost, etc.) the highest social welfare level may be achieved through either a C, M or I urban configuration.

Before deriving the social optimum in each configuration, we briefly introduce in the next section how the commuting tax and the abatement norm affect the residents, the firms and consequently the urban structure.

4.4.1 Impact of the policy mix on the urban structure

The tax on commuting impacts the budget constraint of households directly. It changes the utility maximization program of households and leads to new bid-rent functions. Following the same reasoning as in section 3 and denoting the unitary tax T with $T \geq 0$, the new bid-rent function of households is written as follows :

$$\Psi^*(x) = \max_{x_w} \left\{ \frac{1}{S_h} \left[W(x_w) - (t+T)|x - x_w| - U^* + E(x) + \gamma \ln(S_h) \right] \right\} \tag{4.4.2}$$

A tax on commuting lowers the bid-rent function of households by increasing their transport expenditures.

The norm on firms' emissions impacts directly the profit function of firms. The cost $C(\bar{a})$ of abating more than in the laissez-faire situation is positive. The new bid-rent function of firms is given by :

$$\Phi^*(x) = \frac{F(x) - W(x)L_b - C(\bar{a})}{S_b} \tag{4.4.3}$$

A norm on industrial emissions lowers the bid-rent function of firms by increasing their pollution abatement cost.

Following the same resolution process as in the previous section, we show that the equilibrium urban configuration depends on how the total commuting cost, including the tax, $t + T$ compares with $\bar{t_1}$ and $\bar{t_2}$ defined in the previous section. In particular, the urban configuration is monocentric as long as $t + T < \bar{t_1}$: the implementation of a commuting tax makes it more difficult to sustain this configuration in equilibrium. At the other extreme, the urban configuration is completely mixed when $t + T > \bar{t_2}$, meaning that the implementation of a commuting tax increases the probability of a completely mixed city. Furthermore, the boundary between the integrated district and the business district in the incompletely mixed case is now given by :

$$f_{1I}^T = \frac{(t+T)(S_b + S_h L_b)^2}{\tau S_h + \eta S_b} - \frac{(S_b + S_h L_b)M}{2} \tag{4.4.4}$$

Comparing (4.3.19) and (4.4.4) highlights that the implementation of a commuting tax raises the size of the integrated district. The tax increases transport expenditures of households and induces them to locate closer to their place of work.

The abatement norm $\bar{a}$ has no direct effect on the city structure. The level of industrial pollution decreases simultaneously at every point x of the city so that environmental quality is proportionally higher everywhere. The norm does not change the city structure, but it affects the level of industrial pollution directly and therefore the damage and the equilibrium utility. We develop theses results in the following section.

4.4.2 Optimal policy design

The decision maker's program is to maximise social welfare with respect to the abatement norm and the commuting tax, over all possible urban configurations :

$$\max_{j,\bar{a},T} SW_j = U_j^* - \gamma_c TDC_j - \gamma_f TDF_j$$

Where $j = M, C, I$ represents the urban configuration. The analytical forms of the utilities and damage terms are presented in Appendix 4. The abatement cost function is defined as : $C(a) = a_2 a^2 + a_1 a + a_0$.

Monocentric case The solution to the decision makers' program is (T, a_M^*) with T undetermined and :

$$a_M^* = \frac{N - a_1}{2a_2} + \gamma_f \frac{M(S_h L_b + S_b)^2}{4S_b a_2}$$

An increase in the social valuation of industrial damage or a decrease in the cost of abatement lead to a higher abatement norm. Since $\frac{\partial SW_M}{\partial T} < 0$, social welfare is maximized in the monocentric urban structure with a nul commuting tax.

Households located in the RA have to bear higher transport expenditures due to the commuting tax. When they choose their workplace x_w optimally they consider the trade-off between the new commuting cost $(t+T)(x - x_w)$ and the wage $W(x_w)$. Equilibrium wages are also impacted by the increase in firms' abatement cost. Firms offer lower wages because a part of their profit is allocated to the payment of this cost. The new equilibrium wage profile is then lower at each point x of the city. The equilibrium utility level is impacted negatively by the decreases in wages. However, the norm on industrial emissions raises environmental quality at each point x of the city, which increases utility. Hence there is a tradeoff between higher environmental quality and lower net revenues. Furthermore, the abatement norm has a positive impact in terms of improvement in air quality over the urban structure. Consequently, in equilibrium it is socially optimal to enforce an abatement norm ; and the higher the social valuation of the industrial pollution, the higher the abatement norm. In the monocentric urban configuration, an increase in commuting costs such that $t+T < \bar{t_1}$ does not bring about any improvement in air quality, since with fixed lot sizes in the monocentric setting the aggregate commuting distance is not affected ; however it decreases the utility since residents have to pay for higher commuting costs. As long as the monocentric urban configuration is the one that provides the highest social welfare, there is no incentive to tax commuting. However, if there is a configuration with higher social welfare, then the regulator may enforce a commuting tax such that total commuting costs are above the $\bar{t_1}$ threshold.

Completely mixed case In this urban configuration, there is no commuting. Then, the abatement norm is the only policy instrument that the regulator may have recourse to and, as in the monocentric case, there is a tradeoff between higher environmental quality and lower net revenues due to the implementation of an abatement norm. The optimal abatement norm is set at :

$$a_C^* = \frac{NS_b - a_1(S_h L_b + S_b)}{2a_2(S_h L_b + S_b)} + \gamma_f \frac{MS_b}{4a_2}$$

As in the monocentric case, a higher valuation of industrial damage increases the optimal norm, which higher abatement costs decrease it. Furthermore, the higher the population and the number of firms, the higher the norm.

Incompletely mixed case The solution to the decision maker's program is (T_I^*, a_I^*) with :

$$a_I^* = \frac{N - a_1}{2a_2} + \gamma_f \frac{M(\eta S_b + \tau S_h)(L_b S_h - S_b) + 2S_b(t+T)(S_h L_b + S_b)}{4a_2(\eta S_b + \tau S_h)}$$

and there are two solutions for T_I^*, since $\frac{\partial SW_I}{\partial T}$ is a second-order equation of T. It is difficult to assess their value relative to $\bar{t_1}$ and $\bar{t_2}$ analytically, but we provide a numerical analysis below[7].

Under the incompletely mixed urban configuration, both the abatement norm and the commuting costs have the potential to alter the social welfare. The abatement norm has the same type of impacts as previously. The commuting tax affects individual utilities negatively : households in the RA have to bear higher transport expenditures. Households in the ID do not pay any commuting cost but suffer from a lower environmental quality. In a general way, as utility must be equal at each point x of the city, the equilibrium utility level with a commuting tax is lower than without tax. The commuting damage is decreasing with T, as the introduction of the tax pushes part of the households to relocate inside the ID. Then, a lower number of households have to commute to work every day, leading to a reduced amount of GHG emitted. Finally, the impact of T on industrial damage can be broken down as follows :

$$\frac{\partial TDF_I}{\partial T} = \frac{\partial f_{1I}}{\partial T}A + \frac{M}{S_h}\frac{\partial f_{3I} - f_{2I}}{\partial T}B + f_{1I}\frac{\partial A}{\partial T} + \frac{M(f_{3I} - f_{2I})}{S_h}\frac{\partial B}{\partial T}$$

with $A = M(e-a) - \frac{\eta}{S_b}(f_{2I}^2 - f_{1I}^2) - \frac{4}{3}\frac{\eta f_{1I}^2}{S_h L_b + S_b} > 0$, $\frac{\partial A}{\partial T} < 0$, $B = e - a - \frac{\eta}{2}(f_{3I} + f_{2I}) > 0$ and $\frac{\partial B}{\partial T} < 0$.

7. Their analytical expression is not provided here but is available upon request from the authors.

The first two terms are related to a *population effect* : an increase in T increases the number of residents, hence the number of persons exposed to pollution, in the ID ($\frac{\partial f_{1I}}{\partial T} > 0$) and reduces those in the RA ($\frac{\partial (f_{3I} - f_{2I})}{\partial T} < 0$).

The two last terms are related to proper a *damage effect* that can also be decomposed into two different effects. On the one hand, an emission effect, related to the fact that the BD shrinks while the ID expands. Thus, polluting emissions decrease in the BD and increase in the ID. This effect is negative, because the density of firms in the BD is more important than in the ID, thus the effect of the decrease in the BD overcompensates the increase in the ID. The other effect is related to distance : households located in the RA are closer to the frontier with the BD, hence more affected by pollution ; while households in the ID are on average farther from the border with the BD. Thus the sign of this effect is difficult to determine. In our model, the overall *damage effect* is negative. Note that whether T affects positively or negatively the industrial damage, a higher commuting tax induces a higher abatement norm : both reduce the net income of households, the former reduces traffic-related damage, and if T increase industrial damage then a higher norm compensates for this effect, while if T reduces industrial damage it reinforces the effect of the norm.

The resulting aggregate effect (population effect and damage effect) is difficult to sign analytically. Thus, the implementation on a tax on commuting could either increase or decrease the damage related to industrial pollution depending on the parameters' values.

Depending on the set of economic and physical parameters that characterize the city, the optimal solution may be obtained with either a concentrated, a dispersed or a mixed configuration. This socially optimal configuration may differ from the one resulting from the private equilibrium analyzed in Section 3 when households are affected by industrial pollution, let alone from the solution derived by Ogawa and

Fujita (1982) without any environmental consideration. These results indicate the direction of change in the spatial structure that would be preferable, but we do not provide a complete analysis of the dynamics at stake, a task outside the scope of this paper. To further the analysis of policy design, we present some numerical simulations that illustrate different configurations of the socially equilibrium urban structure in the next section.

Numerical complements

The parameters used in all the simulations are : $\gamma_c = 0.1$, $C(a) = 10a^2 + 0.4a + 1$, $S_b = 2$, $E = 50,000$, $\alpha = 15$, $e = 600$, $k = 0.6$, $R_a = 1,000$. Table 1 presents the parameters that vary between simulations.

	Simulation 1	Simulation 2	Simulation 3
γ_f	0.1	0.0001	0.0001
S_h	1	4	4
N	100	200	200
L_b	2	100	25
η	0.5	0.1	0.1
τ	175	10	100

TABLE 4.1 – Parameters used in the simulations

In the first simulation presented, the monocentric urban configuration achieves the highest social welfare in equilibrium, with an abatement norm set at $\bar{a} = 5.98$. SW_M is then comprised between 3.44×10^6 and 6.19×10^6, and decreases with t ; while $SW_C = 3.06 \times 10^6$. Furthermore, the optimal tax rates in the incompletely mixed equilibrium are incompatible with the incompletely mixed configuration (either below $\bar{t_1}$ or above $\bar{t_2}$). Consequently the equilibrium social welfare is higher in the monocentric configuration for all values of t that are compatible with the monocentric configuration, i.e. for $t < \bar{t_1} = 1,100$. The chosen parameters are illustrative of a context with a high number of firms, with a strong incentive to agglomerate due to a high value of τ, in which the pollution dispersal rate is rather low and the social valuation of industrial pollution is high. Then, a monocentric setting with a strict separation of industrial and residential activities is socially optimal.

In the second simulation, the completely mixed configuration brings about the highest level of social welfare : $SW_C = 9.895838 \times 10^7 > SW_I = 9.895808 \times 10^7 > 0 > SW_M$ with an abatement norm set at $\bar{a} = 0.029$. The threshold $\bar{t_2}$ is then set at 0.2.

In the third simulation, the highest level of social welfare is achieved under an incompletely mixed configuration, with a commuting tax set such that $t + T = 31.38$ and an abatement norm set at $\bar{a} = 9.98$. Then $SW_I = 9.5686 \times 10^7 > SW_C = 9.5681 \times 10^7 > 0 > SW_M$. Furthermore, over the definition domain of the IM configuration, TDF_I increases with T.

The chosen parameters in the last two simulations depict a context in which there are relatively few firms, the pollution dispersion rate is relatively high, the social valuation of industrial pollution is rather low. However, the two simulations differ with respect to the value of τ : the incentive to agglomerate is higher in simulation 3, so that some firms are induced to form a separated business district, leading to an incompletely mixed scenario.

4.5 Conclusion

We developed an urban economics model in which firms and households are free to chose were to locate, so that the city structure is endogenous. Our first aim was to assess the impact of introducing environmental externalities in the framework developed by (Ogawa and Fujita, 1982) : how does the consideration of industrial pollution affect the internal structure of cities ? We show that when firms emit pollution that is at least partially accounted for by households, then the monocentric city structure is a more likely : the effect of pollution on households' location choice has the capacity to make the monocentric city an attractive option even when agglomeration economies are low. Also, it takes very high transport costs to make the completely mixed city structure an equilibrium solution. Finally, industrial pollution induces a more spatialized incompletely mixed city structure.

Our second aim was to investigate environmental policy design in this spatial context. Besides industrial pollution, a typical point-source pollution, partially taken into account by households, we also considered the impact of households' commuting pattern in terms of GHG emissions. The latter does not enter into households' utility functions, but is of prime importance to the policy maker. We consider the design of two types of instruments to manage the two environmental externalities at stake : an industrial abatement norm and a commuting tax. They have different characteristics, such as the direct or indirect nature of their impact on the city structure. We show that depending on which city structure provides the highest social welfare, the social planner can choose to implement either both instruments, or only one of them. In the incompletely mixed structure, we put in perspective how the commuting tax may also have an indirect impact of the social damage associated with industrial pollution, that it is not implemented to manage in the first place. Indeed, the commuting tax, by the effect it has on households' residential location choice, affect their exposure to industrial pollution. This effect has to be accounted for by the decision maker in order to design the optimal policy mix.

Our analysis rests on a series of simplifying assumptions that call for further studies on the correlation between environmental externalities in a spatial context. First, we set our analysis within a closed-city framework, with a fixed number of households and firms in the city. While it is useful to focus on the analysis of the internal structure of the city, this assumption is also somewhat limiting if the aim is to study the impact of environmental externalities on urban growth. Second, we chose a simple production side model, to concentrate on households and their reaction to the exposure to industrial pollution ; this constrained the range of policy instruments that we could study to manage the emissions of industrial pollution. A straightforward extension of this work could involve the introduction of a more detailed production function to allow us to analyse more complex industrial pollution management policies. Finally, instead of focusing on one type of commuting-related externality, GHG emissions, one could incorporate more localized pollution issues. This would necessitate a more detailed city model, at least in two dimensions, to fully explore the emission/exposure tension at the city scale.

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Chapitre 5

Conclusion

La préservation de l'environnement est plus que jamais le défi à relever pour l'humanité dans les années à venir. Dans un contexte d'urbanisation croissante de notre économie, la problématique de la durabilité des villes modernes fait l'objet de fortes attentes de la société. L'émergence de politiques publiques visant à endiguer l'étalement urbain est en est l'illustration. Cependant, en l'absence de recul suffisant sur ces expériences, la capacité de ces solutions à apporter une réponse adaptée aux enjeux environnementaux reste incertaine. A travers cette thèse, nous avons tenté de fournir un éclairage à cette problématique autour de la structure urbaine durable. En mobilisant à la fois les cadres analytiques de l'économie urbaine et de l'économie de l'environnement, nous avons pu mettre en avant la complexité de la relation entre urbanisation et préservation de l'environnement.

L'étude empirique du chapitre 2 nous a d'abord permis de tester le postulat selon lequel les ménages valorisent les paysages et l'environnement qui les entourent car ils leur procurent des services écosystémiques culturels, notamment car ils sont vecteurs de valeurs esthétiques. En conduisant une étude de choix expérimentaux appliqués au choix résidentiel sur un échantillon de 854 habitants de la région Dijonnaise, nous avons démontré que les ménages valorisent en effet la présence de vert dans le paysage à proximité de la résidence, ainsi qu'une faible densité de bâti dans le voisinage de la résidence. Cette étude nous a également permis de mettre en regard préférences des ménages et valeur écologique des différents paysages urbains. En effet, la présence d'arbres, de pelouses, d'arbustes, etc et d'un bâti plus ou moins dense a un impact sur la fourniture d'autres services écosystémiques, et notamment la provision d'habitat naturel, faisant partie de la catégorie des services de régulation. En comparant la valeur esthétique accordée par les ménages aux différents types d'environnements urbains et leur valeur écologique, nous avons démontré que les préférences des ménages ne sont pas nécessairement contradictoires avec la préservation de l'environnement : il possible de concilier les deux dans des types d'habitat peu denses et entourés de verdures.

Faisant directement écho à ces premiers résultats, nous avons, dans le chapitre suivant, analysé de façon théorique les formes optimales de structure urbaine lorsque le planificateur social a un objectif de préservation des habitats naturels et de la biodiversité. Ici encore, il s'agissait de tester la combinaison possible entre la valorisation de services écosystémiques culturels, et de services de régulation tels que la provision d'habitat par les espaces ouverts. Nous avons démontré que l'optimum social peut être atteint avec des formes urbaines différentes, allant d'une ville très compacte à une ville très étalée, selon la capacité de différents types d'espaces ouverts à produire des habitats naturels.

Enfin, le quatrième chapitre de cette thèse s'est attaché à traiter en particulier la question de la qualité de l'air en ville. Ce chapitre interroge la capacité de différentes formes urbaines à soutenir au mieux ce service. Il est notamment complémentaire au chapitre 3 et nous permet de voir si les conclusions que nous tirons concernant la structure optimale de la ville sont vérifiées lorsqu'un autre service écosystémique est en jeu : celui du maintien de la qualité de l'air. Nous avons démontré que la prise en compte de la pollution industrielle dans le comportement de localisation des ménages amène à un équilibre du marché plus segmenté, distinguant des zones industrielles et des zones résidentielles. La conséquence directe est dès lors l'augmentation de la distance parcourue par les ménages pour les trajets domicile-travail, provoquant une hausse de la pollution atmosphérique émise par les voitures. Nous avons étudié par la suite l'impact d'une taxe sur le carburant, politique publique qui vise à favoriser une structure de ville compacte, sur le bien-être : nous avons démontré que lorsque les externalités environnementales proviennent de sources multiples, des politiques publiques visant à compacter la ville peuvent s'avérer non optimales et avoir des effets néfastes sur le bien-être des individus.

De manière générale les travaux de cette thèse font apparaître l'élément majeur suivant : en raison de la complexité du lien entre les différents services écosystémiques et des interconnexions entre ceux-ci et le développement urbain, les conclusions sur les formes de ville durable ne peuvent se faire qu'en des termes conditionnels. Ce résultat constitue une invitation à engager des recherches adéquates en amont afin de bien saisir et prévoir les potentiels effets indésirables associés à la promotion d'une unique forme de ville durable, comme c'est le cas à l'heure actuelle avec le paradigme de la ville compacte.

Si ces travaux n'offrent eux-mêmes qu'une vue parcellaire de la problématique, ils permettent d'apporter un regard nouveau sur le débat autour des formes de villes durables, en constituant un point de départ pour jeter les bases d'une réflexion plus précise autour de la considération de bouquets de services écosystémiques dans un contexte d'urbanisation. Ce travail ouvre ainsi la voie à de futures recherches, invitant à poursuivre les efforts de modélisation dans le but de mieux cerner encore les interconnexions entre les services écosystémiques et le développement urbain.

Une première piste intéressante serait de poursuivre la modélisation de plusieurs services écosystémiques à la fois, à travers la considération de bouquets plus larges de services écosystémiques. Cette thèse a consenti un premier effort à la prise en compte des possibles interactions entre services, et nous a permis de mettre en avant des arbitrages et des synergies. Il apparait intéressant de poursuivre dans cette voie, notamment en poussant l'analyse empirique pour évaluer les services écosytémiques à la périphérie des villes afin de mesurer de façon précises les arbitrages que peuvent faire les ménages entre différents services.

Une deuxième piste de recherche qui semble prometteuse est la considération de la temporalité des processus à l'oeuvre, aussi bien celui du développement urbain que celui de la modification des écosystèmes. Une modélisation dynamique permettrait ainsi de rendre compte de façon plus précise de la double interaction existant entre développement urbain et fourniture de services écosystémiques : les ménages se localisent à la frange urbaine étant attirés par certains types de services, ce qui a pour conséquence de modifier la fourniture des services à cet endroit, et qui peut donc influer de nouveau sur les choix de localisation des ménages. Comment ces processus dynamiques complexes modifient la structure urbaine ? Existe-t-il des effets d'anticipations de la part des ménages ? Les zones partiellement construites à un instant donné vont-elles être à nouveau développées dans le futur et si oui à quel rythme ? Comment la structure urbaine va-t-elle évoluer dans le temps ? Répondre à ces questions dans de futures recherches nous semble particulièrement pertinent pour avancer dans l'analyse du lien entre urbanisation et environnement.

Annexes

Annexes du chapitre 2

Appendix 1

When x_{uo} equals zero, the city structure is complete land sparing. We have :

$$
\begin{aligned}
& x_{uo} = 0 \\
& \Leftrightarrow \frac{w_1}{w_2} \geq \frac{1}{qw_2}(w - Cq + q - u - \gamma + \lambda) \\
& \Leftrightarrow \frac{w_1}{w_2} \geq (\frac{w_1}{w_2})^h
\end{aligned}
$$

When x_{uo} equals to x_{um} the city structure is complete land sparing. We have :

$$
\begin{aligned}
& x_{uo} = x_{um} \\
& \Leftrightarrow \frac{w_1}{w_2} \leq \frac{1}{2(2q-1)qw_2}(2\gamma q + 4Cq^2 - 2u - 2Cq + 2\lambda + 2w - 4qw - \gamma q^2 + 2q + 4qu - 4q\lambda - 4q^2 - \gamma \\
& + \gamma q^2(4\gamma q - 2\gamma - 8q^2 + 8Cq^2 + 8q^2 w_2 - 4Cq + 4q - 8q\lambda - 4qw_2 - 8q + 4w))^{1/2} \\
& \Leftrightarrow \frac{w_1}{w_2} \leq (\frac{w_1}{w_2})^l
\end{aligned}
$$

Annexes du chapitre 3

Appendix 1

The density, locational potential and environmental quality functions in the incompletely mixed case are :

— In the integrated district :

$h(x) = \frac{L_b}{S_b + S_h L_b}, \quad b(x) = \frac{1}{S_b + S_h L_b}$

$E(x) = \bar{E} - eM + \left\{ \frac{\eta}{S_b}(f_{2I}^2 - f_{1I}^2) + \frac{\eta}{S_b + S_h L_b}(f_{1I}^2 + x^2) \right\}$

$F(x) = \alpha M - \left\{ \frac{\tau}{S_b}(f_{2I}^2 - f_{1I}^2) + \frac{\tau}{S_b + S_h L_b}(f_{1I}^2 + x^2) \right\}$

— In the business district :

$h(x) = 0, \quad b(x) = \frac{1}{S_b}$

$E(x) = \bar{E} - eM + \left\{ \frac{\eta}{S_b}(f_{2I}^2 - 2f_1x + x^2) + \frac{2\eta}{S_b + S_hL_b} f_1x \right\}$

$F(x) = \alpha M - \left\{ \frac{\tau}{S_b}(f_{2I}^2 - 2f_{1I}x + x^2) + \frac{2\tau}{S_b + S_hL_b} f_{1I}x \right\}$

— In the residential area :

$h(x) = \frac{1}{S_h}, \quad b(x) = 0$

$E(x) = \bar{E} - eM + \left\{ \frac{2\eta}{S_b}(f_{2I} - f_{1I})x + \frac{2\eta}{S_b + S_hL_b} f_{1I}x \right\}$

$F(x) = \alpha M - \left\{ \frac{2\tau}{S_b}(f_{2I} - f_{1I})x + \frac{2\tau}{S_b + S_hL_b} f_{1I}x \right\}$

Appendix 2

As in the case of a completely mixed urban configuration, from (4.2.4), (4.2.6) and (4.3.16a), we obtain the wage profile $W(x)$ in the integrated district. On the residential area, the wage profile is a linear function of distance. To summarize, the wage profile in the city is given by :

$$W(x) = \begin{cases} \frac{S_hF(x) + S_b(U^* - \gamma \ln S_h) - S_bE(x)}{S_b + S_hL_b} & \text{if} \quad x \in [0, f_{1I}] \\ W(f_{1I}) - t(x - f_{1I}) & \text{if} \quad x \in [f_{1I}, f_{3I}] \end{cases} \tag{5.0.1}$$

Using (4.2.4) and the second part of (5.0.1), we can compute the value of $W(x)$ at f_{1I} depending on the level of equilibrium utility U^*. Knowing that this value of $W(f_{1I})$ must be equal to the value in the first part of (5.0.1), we can determine the equilibrium utility level U^* as a function of f_{1I} and f_{3I} :

$$U_I^* = \frac{F(f_{1I})}{L_b} + \frac{S_b(E(f_{3I})-E(f_{1I}))-(S_b+S_hL_b)(S_hR_a+t(f_{3I}-f_{1I}))}{S_hL_b} + \gamma \ln S_h + Eq(f_{3I}) \quad (5.0.2)$$

The functional form of $F(x)$ and $E(x)$ allow us to say that $F(x)$ is strictly concave on BD and linear on RA and $E(x)$ is convex on BD and linear on RA. Then, we conclude that $R(x)$ will be concave on BD and linear on RA, so the rest of the land market conditions are equivalent to :

$$R(x) = \Phi^*(x) = \Psi^*(x) \qquad \text{at} \quad x = f_{1I}, f_{2I}$$

$$R(x) = \Psi^*(x) = R_a \qquad \text{at} \quad x = f_{3I}$$

Appendix 3

To compare the aggregate commuting distances in the monocentric and incompletely mixed cases, we plug the definition of f_{1M}, f_{2M}, f_{1I}, f_{2I} and f_{3I} in equation (4.3.9) and (4.3.23) :

$$D_M - D_I = \frac{1}{16}\frac{S_bS_h^2(L_bS_h+S_b)}{L_b(S_b\eta+S_h\tau)^3}[2tL_b((L_bS_h+S_b)-N(S_b\eta+S_h\tau)]D_1 \quad (5.0.3)$$

where D_1 is a second-order equation in t, positive over positive t :

$$D_1 = 4tL_b(L_bS_h+S_)[tL_b((L_bS_h+S_b)-N(S_b\eta+S_h\tau)]+(S_b\eta+S_h\tau)[7N^2-6tL_b(L_bS_h+S_b)] \quad (5.0.4)$$

Hence, $D_M - D_I$ is of the sign of the expression in brackets, which is positive in an incompletely mixed equilibrium.

Appendix 4

In the monocentric case, the regulator maximises $SW_M = NU_M^* - \gamma_c TDC_M - \gamma_f TDF_M$, with respect to a and T, where $TDC_M = \frac{1}{2}kS_b f_{2M}(f_{2M} - f_{1M})^2$, $TDF_M = (e-a)M(f_{2M} - f_{1M}) - \frac{\eta}{S_b}\left[\frac{f_{2M}^3}{3} + f_{1M}^2 f_{2M} - \frac{4f_{1M}^3}{3}\right]$ and the utility is derived from $\Psi(f_{2M}) = R_a$, from which we can express $W(0) = S_h R_a + t f_{2M} + U^* - E(f_{2M}) - \gamma \ln S_h$; plugging it into $\Psi(f_{1M}) = \Phi(f_{1M})$ we obtain U_M^* is :

$$U_M^* = \frac{S_b}{S_h L_b + S_b}\left[-t(f_{2M} - f_{1M}) - S_h R_a + E(f_{2M}) + \gamma \ln S_h + \frac{S_b}{S_h L_b + S_b} U_1\right]$$

with $U_1 = \left(\frac{F(f_{1M}) - C(a)}{S_b} - \frac{E(f_{1M}) + \gamma \ln S_h}{S_h}\right)$.

In the completely mixed case, setting $\Psi(f_{1C}) = \Phi(f_{1C}) = R_a$ we obtain :

$$U_C^* = E(F_1) + \gamma \ln S_h - \frac{S_h}{S_b} F(f_{1C}) + \frac{S_b}{S_h L_b + S_b}\left(\frac{F(f_{1C}) - C(a)}{S_b} - R_a\right)$$

Furthermore, $TDC_C = 0$ and $TDC_F = (e-a)Mf_{1C} - \frac{4}{3}\frac{\eta}{S_h L_b + S_b} f_{1C}^3$.

In the incompletely mixed case, the regulator maximises $SW_I = NU_I^* - \gamma_c TDC_I - \gamma_f TDF_I$ with respect to T and a. The utility level and the new wage profile are determined in Appendix 2. The damage terms are : $TDC_I = kD_I(T) = k \cdot \frac{1}{2} S_b (f_{3I} - f_{1I})(f_{3I} - f_{2I})^2$ and $TDF_I = \int_X \int_Y [e - \eta|x-y|] b(y) dy dx$:

$$TDF_I = f_{1I}\left[M(e-a) - \frac{\eta}{S_b}(f_{2I}^2 - f_{1I}^2) - \frac{4}{3}\frac{\eta f_{1I}^2}{S_h L_b + S_b}\right] + \frac{M(f_{3I} - f_{2I})}{S_h}\left[e - a - \frac{\eta}{2}(f2 + f3)\right]$$