Université Paris-Dauphine
École Doctorale de Dauphine

Thèse

pour l'obtention du grade de
Docteur de l'Université Paris-Dauphine
Discipline : Sciences Économiques

Assurance et prévention des catastrophes naturelles et technologiques / Insurance and Prevention of Natural and Industrial Disasters

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Présentée et soutenue publiquement par

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le 14 février 2012

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A Nicolas

Remerciements

Je tiens en premier lieu à remercier Bertrand Villeneuve d'avoir accepté de diriger cette thèse et de la confiance qu'il m'a témoignée. Sa grande disponibilité et son soutien constant ont joué un rôle déterminant dans l'avancement de mes travaux. Son élégance intellectuelle et son exigence scientifique resteront pour moi une source d'inspiration constante dans la suite de ma carrière professionnelle.

Je remercie également Pierre-Philippe Combes, David Martimort, Philippe Mongin et Sandrine Spaeter pour avoir accepter de participer à ce jury de thèse et d'évaluer mon travail. Je remercie particulièrement Pierre-Philippe Combes et Sandrine Spaeter pour leurs rapports constructifs et détaillés. Je remercie également David Martimort pour ses remarques constructives lors de ma présoutenance.

Cette thèse est le fruit d'un travail collectif. Merci à Bertrand Villeneuve, cette fois-ci en tant que co-auteur, à Sabine Lemoyne de Forges et à Arthur Katossky pour avoir collaboré avec moi, nourri et partagé mon enthousiasme. Travailler et apprendre auprès et avec d'eux fut un plaisir.

Un grand merci à Guy Laroque pour avoir suivi mes avancées sur la sous-assurance dans les DOM. Nos régulières discussions et ses relectures m'ont énormément appris. Merci à Laurence Rioux pour son aide initiale et cruciale en économétrie.

Merci à Alain Trognon et à Sylviane Gastaldo pour m'avoir encouragée à entreprendre cette thèse et pour m'avoir reçue à plusieurs reprises pour monter ce projet de recherche.

Ce travail a été initié dans le cadre de mon poste au ministère de l'Ecologie. Je remercie Louis de Gimel, Françoise Maurel, Christine Lagarenne et Olivier Bommelaer pour m'avoir permis de passer une journée hebdomadaire puis deux au CREST. Non seulement la synergie qui s'est établie entre mon travail quotidien et mon activité de recherche a été extrêmement motivante, mais, sans cet aménagement, je n'aurais pas pu réaliser cette thèse. Merci à Cédric Peinturier pour m'avoir aidée au quotidien à mener ces deux activités de front.

Je remercie les membres du Centre de Recherches en Economie et Statistiques pour leur dynamisme scientifique et amical. Je remercie Christian Gourieroux pour m'avoir accueillie au sein du Laboratoire de Finance Assurance et les membres du Laboratoire d'Economie Industrielle pour m'avoir donné l'opportunité de présenter mes travaux lors de leur séminaire interne et pour leurs commentaires pertinents à ces occasions. Merci au Laboratoire d'Economie de Dauphine pour son accueil, et

tout particulièrement à Françoise Forges et Arnold Chassagnon. Merci au Département des Etudes Economiques d'Ensemble, et surtout à Pauline Givord, pour m'avoir permis d'aménager ces derniers mois de rédaction.

Une mention spéciale pour les membres du CREST et mes collègues dont j'ai partagé le quotidien. Je pense notamment à Sophie Osotimehin, Gulten Mero, Isabelle Méjean, Julien Martin, Erwan Koch, Sophie Bereau, Etienne Lehmann, Lionel Wilner, Xavier d'Haultfoeuille, Guillaume Lepage, Jeremy Dudek, Giuseppe Benedetti et Jean-Cyprien Héam. Un grand merci à Fanda Traore et à Nadine Guedj pour leur aide. Merci à Cédric Peinturier et à Hélène Gaubert pour leur soutien. Merci à Corentin Trevien pour m'avoir accueillie dans son bureau pour les derniers mois de rédaction. Merci à Mathias André pour son soutien final.

Merci à tous ceux qui, dans l'industrie de l'assurance ou dans l'administration, ont pris le temps de m'expliquer leurs métiers. Merci également à Valérie Sanseverino-Godfrin pour ses explications en droit.

Merci enfin à mes proches pour m'avoir accompagnée de leur affection, particulièrement à mes parents qui m'ont transmis le plaisir d'apprendre. Merci à Rémi. Merci surtout, surtout à Nicolas pour son inconditionnel soutien, ses conseils et sa contagieuse soif de compréhension.

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Chapter 1

Introduction

L'objet de cette introduction est double. Il s'agit tout d'abord de présenter les différentes politiques de couverture et de prévention des risques naturels et technologiques mises en place en France et à l'étranger, puis de résumer les éléments d'évaluation de certaines de ces politiques qui sont apportés par cette thèse.

1.1 Les catastrophes naturelles et technologiques

Le bilan humain et économique des catastrophes naturelles et industrielles[1] a augmenté à l'échelle mondiale durant ces dernières décennies. La figure 1.1 illustre l'augmentation des dommages assurés, qui ne représentent qu'une partie des pertes économiques. En 2010, les catastrophes naturelles et techniques[2] ont fait près de 304 000 victimes, engendré des pertes économiques de près de 218 Mds$, dont 43 Mds$ pour les assureurs (Sigma, 2011).

De nombreux éléments contribuent en effet à augmenter le coût de ces catastrophes : le nombre croissant de biens assurés due à la pression démographique et la valeur croissante de ces biens, mais aussi les choix d'installation dans les zones exposées. Les catastrophes naturelles et industrielles ont en effet pour particularité commune d'avoir une forte empreinte géographique, puisque l'exposition à ces risques dépend fortement des choix d'installation, de construction et d'aménagement du territoire. A l'heure actuelle, les conséquences possibles du changement climatique sur certains risques naturels, tels que les inondations[3], ne sont pas encore visibles, en raison

[1] Les termes "technologique" et "industriel" sont ici considérés comme synonymes.

[2] Les catastrophes techniques désignent les sinistres majeurs liés à l'activité humaine. Elles incluent ainsi les catastrophes industrielles, mais aussi d'autres événements tels que les actes terroristes.

[3] Barredo (2009) montre que l'augmentation des dommages dues aux inondations en Europe entre 1970 et 2006 s'explique essentiellement par l'augmentation démographique, l'inflation et la richesse réelle croissante par habitant ; il récuse l'hypothèse selon laquelle le changement climatique contribuerait à expliquer l'augmentation des dommages.

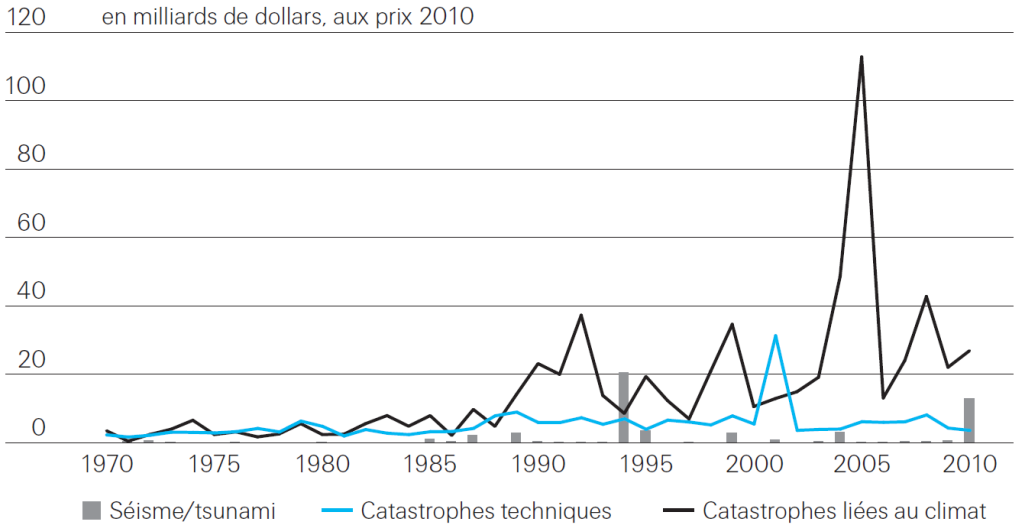


Figure 1.1: Dommages assurés dus à des catastrophes de 1970 à 2010
Source : Swiss Re Economic Research & Consulting

de son caractère progressif. Le changement climatique contribuera probablement significativement à l'augmentation du coût de nombreuses catastrophes naturelles et aussi indirectement à l'augmentation du coût des catastrophes technologiques.

En effet, les phénomènes physiques en jeu lors des catastrophes naturelles et industrielles peuvent être étroitement liés. Des catastrophes naturelles peuvent par exemple causer des catastrophes industrielles. En mars 2011, un tremblement de terre au Japon a déclenché un tsunami de 10 mètres de haut, qui a causé plusieurs accidents nucléaires à Fukushima. D'autres désastres résultent de la combinaison d'aléas naturels et industriels, comme les inondations de boue toxique causées par la rupture d'un réservoir dans une usine d'aluminium en Hongrie en octobre 2010. Les risques naturels et industriels peuvent également s'aggraver mutuellement. Par exemple, les autorités chinoises reconnaissent aujourd'hui que le barrage des Trois Gorges augmente l'activité sismique locale (Garric, 2011). Même les accidents industriels passés peuvent amplifier les conséquences des catastrophes naturelles. En 2010, des feux de forêt en Russie ont brûlé des zones qui avaient été polluées suite à l'accident de Tchernobyl de 1986 ; ceci a conduit à une seconde contamination des populations locales et des cultures agricoles.

Si les risques naturels et technologiques présentent de nombreuses similitudes et interdépendances qui plaident en faveur d'une analyse commune, il est important de tenir compte de leur différence essentielle : la responsabilité qu'ils impliquent. L'indemnisation des risques technologiques relève de la responsabilité privée de l'industriel, alors que celle des risques naturels repose sur une solidarité organisée via des mécanismes de couverture (assurance ou aides publiques). Certes, des populations peuvent s'installer dans des zones exposées en connaissance de cause ; elles peuvent même être parfois précisément attirées vers ces régions du fait des aménités associées au risque (vue sur la rivière ou le littoral, emploi créé par les usines). Par exemple, le site internet d'AZF[4] précise qu'"initialement [en 1924] à l'écart des zones d'habitation, l'usine sera progressivement englobée par l'agglomération toulousaine". Cependant, la loi est claire : il n'y a pas de principe de préoccupation au nom duquel la communauté ou l'industriel pourrait se dégager de leur responsabilité en cas de catastrophe[5]. La société Grande Paroisse à laquelle appartenait l'usine d'AZF a ainsi été reconnue entièrement responsable pour l'explosion du 21 septembre 2001, qui a provoqué 31 morts, plus de 4 000 blessés, plus de 10 MdsF 2001 de dégâts, 34 500 foyers et 3 500 entreprises sinistrés (Sauvage, 2002).

1.2 La prévention des catastrophes naturelles et technologiques

La prévention est menée par l'acteur qui supporte le coût des catastrophes, i.e. l'Etat pour les risques naturels et l'industriel pour les risques technologiques. Cependant, comme la gestion des catastrophes représente un enjeu en matière de sécurité civile, il revient également en partie à l'Etat d'organiser la prévention des risques industriels. Pour réduire le risque, il est possible d'agir soit sur l'aléa (probabilité d'occurrence d'un événement et intensité de cet événement), soit sur les enjeux (nombre et vulnérabilité des populations, logements et installations) soumis à cet aléa.

[4]Voir `http://www.azf.fr/l-usine-azf-de-toulouse/historique-800233.html`. Le développement de l'agglomération autour de l'usine y est illustré par des photographies de l'usine et de ses environs dans les années 1930 et en 2001.

[5]Pour les risques industriels en France, voir le Code de l'environnement (article L. 514-19), les règles de responsabilité civile (Code civil, article 1382 et suivants) et la jurisprudence. Une unique exception peut être invoquée : les pollutions chroniques qui induiraient des nuisances mais sans dommage corporel ni matériel (Code de la construction et de l'habitation, article L. 112-16).

1.2.1 Réduction de l'aléa

Les politiques publiques d'aménagement du territoire et les actions des industriels peuvent permettre de réduire l'aléa, notamment par des travaux d'ingénierie. Dans le cas des inondations par exemple, les digues, les barrages, les bassins de rétention ou les systèmes d'assainissement urbains[6] permettent de diminuer l'aléa. De même, l'industriel peut réduire le risque à la source, par exemple en augmentant la sécurité sur le site ou en modifiant le système de production.

1.2.2 Réduction de la vulnérabilité

Pour réduire la vulnérabilité, l'Etat peut prescrire des travaux de renforcement aux constructions exposées : batardeaux contre les inondations, filmage des vitres pour éviter les bris de verre en cas d'explosion sur un site industriel. Dans les zones exposées à un fort aléa, l'Etat peut également réduire l'urbanisation existante, en préemptant les terrains exposés ou expropriant leurs occupants, et l'urbanisation future, en interdisant les nouvelles constructions. Suite aux grandes inondations de 1993 aux Etats-Unis, plus de 9 000 ménages ont vendu leurs propriétés (FEMA, 2008) ; des villes entières, comme Valmeyer dans l'Illinois ont décidé de déménager vers des zones plus en amont (Bagstad et al., 2007). Au sein de l'Union Européenne, les Etats membres ont mis en place des politiques d'aménagement du territoire et ont notamment défini des zones interdites de toute construction autour des usines dangereuses[7]. Ce type de mesures existait au niveau national, bien avant la création de l'Union Européenne. En France, par exemple, suite à l'explosion de la poudrerie de Grenelle en 1794, le décret impérial du 15 octobre 1810 relatif aux manufactures et ateliers insalubres, incommodes ou dangereux avait déjà introduit le principe d'une implantation réglementée de ces activités et obligeait les activités les plus dangereuses à s'éloigner des habitations.

[6] Les systèmes d'assainissement urbains permettent d'améliorer l'évacuation des eaux en cas d'inondation.

[7] L'article 12 de la directive Seveso II (directive 96/82/CE du Conseil du 9 décembre 1996 concernant la maîtrise des dangers liés aux accidents majeurs impliquant des substances dangereuses) impose aux Etats membres de prendre en compte dans leur politiques d'aménagement du territoire la nécessité de maintenir des distances de sécurité entre les industries dangereuses et leur environnement humain et naturel. Basta (2009) fournit une comparaison exhaustive des implémentations nationales de ces politiques dans les différents Etats membres.

Les industriels peuvent également de leur propre chef acheter ou louer des terrains autour de leurs usines. En Louisiane (Etats-Unis), en 1991, la compagnie Dow Chemical a par exemple financé la relocalisation d'un village de 300 habitants initialement situé tout près de ses usines chimiques (Sauvage, 1997).

La prévention comprend également l'information préventive. En France, par exemple, les dispositifs locaux d'information comportent la diffusion de plaquettes d'information, la mise en place du plan particulier d'intervention (plan d'urgence en cas d'accident industriel) et d'un comité local d'information et de concertation[8]. Par ailleurs, l'information acquéreur locataire[9] oblige le vendeur ou le bailleur à informer par écrit l'acquéreur ou le locataire de l'inclusion du logement dans le périmètre d'un plan de prévention des risques naturels ou technologiques et, si tel est le cas, de catastrophes naturelles ou technologiques passées. La prévention consiste enfin à organiser le suivi et surveillance des risques, à préparer à la gestion de crise et effectuer le retour d'expérience en cas de sinistre.

1.2.3 Le rôle des communes

Ces actions de prévention sont par nature essentiellement locales. Les collectivités territoriales jouent donc un rôle déterminant dans la mise en place des politiques publiques de prévention. Les différents niveaux de l'Etat sont soumis au même arbitrage entre, d'une part, la prévention des personnes et des biens et, d'autre part, le développement économique (limitation de la pression foncière, implantation de nouvelles activités créatrices d'emplois). Mais les maires peuvent prendre des décisions biaisées. Ils peuvent sous-estimer l'exposition aux risques de leur commune (ou au contraire la surestimer suite à des catastrophes) ou surestimer les gains liés au développement économique, car ils les évaluent à court terme dans une optique électorale. Dans le cas des inondations, Burby (2006) nomme ce phénomène "paradoxe du gouvernement local" et l'illustre par de nombreux exemples aux Etats-Unis. Ce phénomène est aussi constaté le cas des risques industriels, et ce depuis plusieurs

[8] La mission de cette instance est de donner un cadre d'échanges et d'information entre l'administration, les collectivités territoriales, les exploitants, les riverains et les salariés des établissements concernés.

[9] L'information acquéreur locataire est imposée par la loi n°2003-699 du 30 juillet 2003 relative à la prévention des risques technologiques et naturels et à la réparation des dommages. Elle est entrée en vigueur le 1er juin 2006.

siècles. Ainsi, le décret impérial français de 1810 qui réglementait l'installation des établissements dangereux précisait que l'autorisation d'installation ne devait pas relever des maires mais des préfets.

1.2.4 L'exemple français

En France, une grande partie des mesures de prévention sont regroupées dans un unique outil réglementaire, le plan de prévention des risques, qui se décline pour les risques naturels et technologiques[10]. Un plan de prévention des risques fait connaître les zones exposées et définit les mesures pour réduire les risques encourus. Le plan est prescrit, c'est-à-dire lancé, par le préfet qui détermine le périmètre et la nature des risques étudiés. Le projet de plan, basé sur une évaluation du risque, est ensuite soumis à consultation via une enquête publique. Après d'éventuelles modifications, le projet est enfin approuvé par le préfet et annexé au plan local d'urbanisme. D'après le Ministère de l'Ecologie, les plans de prévention des risques naturels s'appliquent à un quart des communes françaises (8 801 sur 36 682 au 1er septembre 2011) et les 420 plans de prévention des risques technologiques concernent plus de 600 établissements sur plus de 900 communes.

1.3 La couverture des catastrophes naturelles et technologiques

La gestion des risques majeurs ne se limite pas à la prévention de ces risques mais comprend aussi l'indemnisation des sinistres.

1.3.1 L'organisation du partage des risques extrêmes

Les catastrophes naturelles et technologiques impliquent des dommages potentiels de grande ampleur et fortement corrélés. Ces dommages peuvent ainsi être considérés comme inassurables du fait de la difficulté des assureurs à trouver des capacités suffisantes sur le marché de la réassurance. Kleindorfer et Kunreuther (1999) montrent les difficultés du secteur privé à assurer les risques majeurs ;

[10]Les plans de prévention des risques naturels sont définis par la loi n^{o}95-101 du 2 février 1995 relative au renforcement de la protection de l'environnement. Les plans de prévention des risques technologiques sont définis par la loi n^{o}2003-699 du 30 juillet 2003 relative à la prévention des risques technologiques et naturels et à la réparation des dommages.

Charpentier (2008) analyse spécifiquement l'assurabilité des risques climatiques.

L'Etat peut alors aider au développement de l'assurance de certains risques majeurs, qu'ils relèvent ou non d'une responsabilité collective, par exemple en encadrant certaines ententes entre assureurs. La Commission Européenne permet en effet le regroupement de différents assureurs et réassureurs au sein de "pools" et autorise ainsi la mise en commun de calculs, tables, études, modèles et couverture de certains "risques nouveaux"[11]. Par exemple, le pool d'assurance et de réassurance Assurpol offre une assurance couvrant les dommages de pollution causés aux tiers ainsi qu'aux espèces et habitats protégés[12]. De même, le pool de coréassurance Assuratome offre une assurance responsabilité civile aux exploitants des installations nucléaires. Cette assurance se réfère au régime de responsabilité des exploitants[13] ; cette responsabilité est objective, i.e. sans faute, mais financièrement limitée. Au-delà de ce plafond, l'Etat sur le territoire duquel s'est déroulé l'accident est responsable jusqu'à un deuxième plafond ; l'ensemble des Etats parties prenantes à la convention assurent solidairement une troisième tranche[14].

L'exemple du risque nucléaire est tout à fait exceptionnel, puisque les Etats s'impliquent financièrement dans l'assurance des risques nucléaires du fait de leur forte volonté politique de soutenir cette activité. En règle générale, puisque les

[11] Règlement (UE) n^{O}267/2010 de la Commission du 24 mars 2010 concernant l'application de l'article 101, paragraphe 3, du traité sur le fonctionnement de l'Union Européenne à certaines catégories d'accords, de décisions et de pratiques concertées dans le secteur des assurances.

[12] En effet, la directive européenne 2004/35/CE sur la responsabilité environnementale en ce qui concerne la prévention et la réparation des dommages environnementaux a introduit la notion de dommage environnemental. Il ne s'agit pas d'un régime de responsabilité mais de police administrative. Le contrat d'assurance responsabilité environnementale proposé par Assurpol comprend ainsi deux volets : le premier volet "assurance responsabilité civile atteinte à l'environnement" couvre la responsabilité civile et le second "assurance responsabilité environnementale" la responsabilité environnementale. Voir Boyer et Porrini (2008) pour une analyse de la régulation de l'assurance des dommages environnementaux.

[13] Ce régime a été instauré par les Conventions de Paris de 1960 et de Bruxelles de 1963 ratifiées par la France. En France, ces conventions ont été transposées par la loi n^{O}68-943 du 30 octobre 1968 relative à la responsabilité civile dans le domaine de l'énergie nucléaire et modifiée depuis par la loi n^{O}90-488 du 16 juin 1990.

[14] Actuellement, en France, la responsabilité des exploitants est de 91 M€ par accident, "la limite la plus basse en Europe" [ma traduction] (Faure et Fiore, 2008) ; le deuxième plafond est de 231 M€ et le troisième de 381 M€. Les derniers protocoles des conventions de Paris et Bruxelles sur la responsabilité civile nucléaire de 2004 augmentent ces montants respectifs à 700 M€, 1,2 Mds€ et 1,5 Mds€. Ces protocoles ne sont pas encore ratifiés par la France. L'impact de ces nouveaux textes sur l'organisation du marché est analysé par Faure et Fiore (2008).

risques industriels impliquent la responsabilité d'un tiers, l'implication financière de l'Etat dans l'indemnisation des sinistres est très limitée, afin de responsabiliser l'industriel et d'éviter de faire payer l'ensemble des contribuables en cas de dommage[15]. Par exemple, en vertu du principe pollueur-payeur, l'Etat n'est pas impliqué dans l'assurance pollution.

1.3.2 Risques industriels

Organiser la solvabilité de l'industriel responsable. L'Etat peut cependant inciter à la couverture des responsables potentiels afin de limiter leur risque d'insolvabilité. Cependant, il peut être en pratique difficile de définir le champ de l'obligation (exonérations, plafonds). Une obligation restreinte peut permettre aux industriels de ne s'assurer jusqu'à la limite de leurs actifs et ainsi être sans effet sur leur solvabilité. Mais une obligation étendue peut être difficilement applicable si l'offre du secteur de l'assurance est limitée. Faure (2006) expose les arguments économiques pour et contre l'obligation d'assurance des industriels ; Demougin et Fluet (2007) réalisent une étude approfondie de l'impact des règles de responsabilité et de l'assurance sur les incitations des entreprises à la prévention.

Organiser la couverture des victimes des risques industriels. L'Etat peut également organiser la couverture des victimes, comme en France dans le cas des catastrophes technologiques. Ce système, créé en 2003 suite à l'explosion d'AZF, s'inspire clairement du fonctionnement du régime d'indemnisation des catastrophes naturelles déjà mis en place mais en diffère de par la présence d'un tiers responsable (voir tableau 1.1 pour une comparaison de ces deux régimes). Il a pour seuls buts d'éviter de longues procédures juridiques aux victimes (en avançant les remboursements) et de couvrir les risques de non identification et d'insolvabilité du responsable. Ce dispositif ne couvre que les dommages aux biens. Les dommages corporels subis par les personnes sont partiellement indemnisés par la sécurité sociale et par des mutuelles complémentaires ou par des contrats d'assurance additionnels, tels que le contrat garantie des accidents de la vie[16]. Les victimes peuvent également recevoir

[15] Voir Sanseverino-Godfrin (1996) pour une analyse approfondie du cadre juridique de l'assurance des risques majeurs et de l'intervention de l'Etat dans la gestion de ces risques.

[16] Le contrat garantie des accidents de la vie, créé en 2003, couvre tous les dommages corporels hors automobile et notamment les dommages causés par les catastrophes. En juin 2010, 6 millions de personnes sont assurées à ce titre, ce qui représente un encaissement de 480 M€ de primes

des dommages et intérêts dans le cadre d'un procès.

1.3.3 Risques naturels

Organiser la mutualisation des risques naturels. Si au contraire les dommages n'engagent aucune responsabilité privée, cette responsabilité devient collective et c'est à l'Etat d'indemniser, au moins partiellement, les victimes et donc d'organiser la mutualisation de ces risques collectifs. C'est le cas des catastrophes naturelles ou du terrorisme. Le degré de l'implication publique dépend en pratique de l'histoire politique et culturelle du pays et du développement du marché privé de l'assurance. La nature de cette implication est également très variable. La mutualisation de ces risques peut prendre la forme d'aides financées ex post par des crédits budgétaires ; elle peut être organisée par un fonds ou un système d'assurance avec un encaissement ex ante de cotisations.

En Europe et plus généralement dans le monde, il n'existe pas de modèle d'indemnisation des catastrophes naturelles qui rassemblerait une majorité de pays. Nous pouvons cependant identifier différents modèles qui correspondent à différentes conceptions de l'implication de l'Etat dans l'économie. Cette classification s'inspire largement de celle de Dumas et al. (2005) et a été mise à jour et complétée à l'aide notamment de références récentes (Botzen et al. (2009), Bouwer et al. (2007)).

Trois grands profils peuvent être retenus. Tout d'abord, le système peut reposer entièrement sur l'assurance et la réassurance privées au sein d'un marché libre et concurrentiel, où les pouvoirs publics n'interviennent que peu ou pas du tout. Parmi ces pays se trouvent notamment le Royaume-Uni, l'Irlande et la Pologne. Au contraire, le système peut reposer sur une forte intervention de l'Etat plus ou moins organisée. Certains pays ont mis en place un dispositif public obligatoire et monopolistique (de droit ou de fait) d'assurance qu'ils complètent souvent par certaines aides publiques directes, comme par exemple l'Espagne[17] et la Turquie (à

annuelles. En cas de catastrophe avec un tiers responsable identifié et solvable, la réparation des dommages corporels est à la charge du responsable. En effet, contrairement à l'assurance des dommages aux biens contre les catastrophes technologiques, l'assurance garantie des accidents de la vie n'avance pas les frais et ne se retourne pas contre l'industriel responsable (Pénet, 2010).

[17]En Espagne, l'assurance contre les catastrophes naturelles est une garantie obligatoire des contrats d'assurance habitation ; elle est offerte par le Consorcio de Compensaciòn de Seguros.

terme). D'autres pays ne présentent pas un marché d'assurance des catastrophes naturelles développé et se limitent à des interventions publiques ponctuelles, soit au cas par cas, soit dans le cadre d'un mécanisme permanent. C'est le cas de la Corée, l'Italie, la Suède, ainsi que de nombreux pays en développement.

Il existe également des systèmes hybrides parmi lesquels se distinguent deux principaux modèles. Un premier modèle hybride combine à la fois un système assurantiel concurrentiel et des aides publiques. Suivant les cas, ces aides peuvent être définies ex ante ou bien ex post. Dans le cas des aides institutionnalisées et donc décidées ex ante, il existe des mécanismes complémentaires d'aide publique souvent limités à un seul risque ayant un impact important dans ces pays. C'est le cas par exemple du Danemark (Fonds Inondation Tempête), des Etats-Unis au niveau fédéral ("National Flood Insurance Program"). Les aides définies ex post peuvent correspondre à des interventions publiques ponctuelles, plus ou moins massives selon les circonstances. C'est le cas de l'Allemagne, de l'Australie, du Canada et du Mexique. Au Canada (Dumas et al., 2005) ou pour l'assurance inondations en Allemagne (Bouwer et al., 2007), une assurance privée peu souscrite coexiste avec ces mécanismes d'aides publiques. Il est difficile de déterminer si les mécanismes d'assistance pallient une offre d'assurance privée limitée ou bien si la demande pour l'assurance est faible précisément à cause des aides publiques, substituts à l'assurance formelle.

Un second modèle hybride consiste en un système assurantiel mixte, privé et public. Il peut s'agir d'un système assurantiel privé, encadré par les pouvoirs publics avec des mécanismes de réassurance publics ou parapublics. Ces mécanismes peuvent ne concerner que certains risques bien déterminés. C'est le cas au Japon pour le risque sismique et dans certains Etats fédérés américains (par exemple la Californie pour le risque sismique et la Floride pour les tempêtes, les cyclones et les "sinkholes"[18]). Une variante de ce système existe également en Suisse. Le système assurantiel mixte peut également se traduire par une réassurance publique étendue à plusieurs risques avec une réglementation des contrats d'assurance privés. C'est le cas de la France,

[18]Les "sinkholes" ou dolines sont des dépressions du terrain dues à la dissolution de la roche mère, le plus souvent calcaire ou argileuse.

de la Belgique[19] et peut-être à terme des Pays-Bas[20].

L'exemple français. La France appartient à la catégorie des modèles hybrides du second type mais est assez proche de la deuxième grande famille de profils. En France, l'assurance des dommages aux biens des particuliers et des entreprises contre les risques naturels (hors risques agricoles[21]) est régie par deux systèmes complémentaires : d'une part, un dispositif assurantiel contractuel classique couvre les risques considérés comme assurables (par exemple les tempêtes) ; d'autre part, le régime d'indemnisation des catastrophes naturelles (tableau 1.1) concerne les risques non assurables. Le régime d'assurance des catastrophes naturelles a été créé suite à une multiplication des aides et compensations définies ex post[22]. Ce régime implique la garantie illimitée de l'Etat via la Caisse Centrale de Réassurance (CCR)[23]. Cette garantie a d'ailleurs joué suite aux événements de 1999 et la CCR a failli devoir à nouveau y faire appel suite aux événements de 2003[24].

[19]La Belgique a, comme la France, adopté une limitation du dispositif public en matière de catastrophes naturelles à la fonction de réassurance. La récente réforme (loi du 17 juin 2009) a étendu la couverture obligatoire inondations à toutes les catastrophes naturelles, et ce pour l'ensemble des agents assurés contre l'incendie.

[20]Les Pays-Bas tentent de transférer une part de leur exposition au risque de catastrophes naturelles au marché. Actuellement, le gouvernement indemnise les victimes de catastrophes naturelles par le "Calamities Compensation Act" depuis 1998.

[21]La protection de l'agriculture contre les risques climatiques relève du secteur privé pour les risques assurables et de l'indemnisation publique par le fonds national de garantie des calamités agricoles pour les risques non assurables. Jusqu'en 2006, l'assurance privée ne couvrait que les effets de la grêle et de la tempête sur les récoltes non engrangées. Depuis 2006, les assureurs proposent des produits d'assurance multirisques climatiques, couramment appelés "assurance récolte" destinés aux agriculteurs couvrant les pertes de revenus liées aux autres risques. Cependant, la prime d'assurance correspondante reste subventionnée à hauteur de 35% par l'Etat (décret n^{O}2008-270 du 18 mars 2008 fixant pour l'année 2008 les modalités d'application de l'article L. 361-8 du Code rural en vue de favoriser le développement de l'assurance contre certains risques agricoles).

[22]L'idée remonte à la Révolution française : "[a]u XVIII^{eme} siècle, dans un moment de libéralisme émergent, les méthodes qui régissaient la distribution des aides d'Etat commençaient à faire l'objet de débats et à évoluer du principe de charité vers de nouveaux systèmes dans lesquels l'importance des pertes endurées pouvait prévaloir sur la nécessaire assistance envers les plus démunis, jusqu'à ce que, pour la première fois pendant la Révolution française, un projet de loi considère la possibilité - pas encore d'un droit à l'indemnisation - mais au moins d'une sorte de devoir de solidarité" [ma traduction] (Favier et Pfister, 2007). Voir Bidan (2000) pour l'histoire du régime français depuis sa création en 1982 jusqu'en 2000.

[23]L'Etat peut être appelé en garantie par la CCR, lorsque 90% des provisions d'égalisation et réserves spéciales de la CCR constituées au titre des catastrophes naturelles sont nécessaires pour indemniser les sinistres dus à des catastrophes naturelles au cours d'une année.

[24]Suite aux événements de 1999 (intempéries de décembre 1999, retraits et gonflements des argiles, inondations du sud de la France de novembre 1999), la CCR a fait jouer la garantie de l'Etat en septembre 2000 pour un montant de 263 M€. Suite aux retraits et gonflements des argiles de 2003, si toutes les demandes d'indemnisation avaient été acceptées, le risque financier global aurait pu atteindre près de 3,5 Mds€, d'après la CCR. La CCR aurait alors été amenée à faire

Ces dispositifs ne concernent que les dommages aux biens. Les garanties correspondantes sont incluses dans les contrats d'assurance habitation, entreprise ou automobile, qui sont souscrits par une très large majorité de ménages et d'entreprises en France métropolitaine (Grislain-Letrémy et Peinturier (2010) et chapitre 4) - mais pas en Outre-mer. En effet, seulement la moitié des ménages français dans les départements d'Outre-mer (DOM) ont assuré en 2006 leur résidence principale contre les catastrophes naturelles (chapitre 4). Les dommages corporels sont exclus de ces dispositifs. Par ailleurs, de nombreux biens publics ne sont pas assurés, car l'Etat[25] et les collectivités territoriales peuvent être leur propre assureur. Différents mécanismes d'aide aux niveaux européen et national existent pour ces biens publics non assurés[26].

Inciter à la prévention. Pour diminuer le coût des catastrophes naturelles, plusieurs pays ont essayé de lier couverture et prévention. Tout d'abord, les assureurs peuvent refuser d'assurer les ménages et entreprises qui se sont installés dans des zones d'exclusion après la mise en place de cette interdiction, comme c'est le cas en France (Code des assurances, article L. 125-6), mais dans les faits très peu de bâtiments sont concernés. Aux Etats-Unis, il n'y a pas d'interdiction stricte de construction mais l'Etat fédéral n'offre pas l'assurance inondations aux ménages vivant dans les zones fortement exposées (FEMA, 2007).

La tarification de la couverture offerte par les pouvoirs publics (assurance, taxation, fonds) peut refléter l'exposition aux risques naturels dans la limite de l'information disponible. Aux Etats-Unis, l'assurance inondations est actuarielle, du moins dans la limite de l'information fournie par les cartes d'aléa (Hayes et Neal, 2009) ; il en est de même au Japon, mais les cartes ne définissent que quatre zones d'aléa de

appel à la garantie de l'Etat pour des sommes évaluées entre 500 M€ et 1 Md€ (Dumas et al., 2005).

[25] Le principe selon lequel "l'Etat est son propre assureur" date de 1889. Cette décision "relève d'une pure opportunité financière et elle s'analyse comme une mesure d'ordre inférieur à laquelle l'Etat peut déroger lorsqu'il l'estime nécessaire" (Valluet, 1978). Depuis, divers textes ont confirmé cette pratique au cas par cas.

[26] Voir Grislain-Letrémy et Peinturier (2012) pour une présentation détaillée l'indemnisation des risques naturels (hors risques agricoles) en France et une illustration des nombreux dispositifs de compensation avec le retour d'expérience de la tempête Xynthia de février 2011.

tremblements de terre (Tsubokawa, 2004)[27]. En France, l'assurance catastrophes naturelles est basée sur une prime uniforme. Plus précisément, l'Etat impose que la prime catastrophes naturelles soit égale à un pourcentage fixe des primes dommages du contrat assurance habitation, entreprise ou automobile (tableau 1.1). Cependant, depuis septembre 2000, les franchises sont modulées à la hausse pour les sinistres situés dans des communes non dotées d'un plan prescrit alors qu'elles ont déjà fait l'objet de plusieurs catastrophes naturelles[28].

1.4 Eléments d'évaluation de ces politiques publiques

L'objet de cette thèse est d'apporter des éléments d'évaluation des politiques publiques de prévention et de couverture des risques naturels et technologiques, en France comme à l'étranger. Chacun des quatre chapitres propose des éléments d'évaluation de ces politiques en analysant notamment les liens entre politiques d'assurance et d'urbanisme (chapitre 2), entre politiques d'assurance et de prévention collective (chapitre 3), entre politiques d'assurance et d'aides publiques (chapitre 4), entre politiques de prévention et immobilier (chapitre 5). Les différents chapitres prennent également en compte les liens entre les politiques publiques nationales et locales.

1.4.1 Assurance et urbanisme

Le chapitre coécrit avec Bertrand Villeneuve analyse le lien entre l'assurance et la prévention individuelle des risques naturels et industriels, prévention qui se traduit essentiellement par le choix du lieu d'habitation. L'urbanisation dans les zones exposées augmente le coût des catastrophes. Dans le cas des risques industriels, les victimes potentielles, en s'installant à proximité des usines, augmentent la responsabilité des industriels en cas de dommage. Dans le cas des risques naturels, la surexposition de certains ménages sape les efforts de mutualisation. Les politiques

[27] La prime d'assurance dépend également du type de construction (bois ou renforcé).

[28] Par exemple, dans une commune non dotée d'un PPRN inondation, et frappée par une troisième inondation, les franchises de tous les habitants et entreprises sont doublées. Il a été reproché à cette règle de ne pas inciter à la mise en place effective des plans (approbation), qui rend obligatoires les mesures de prévention décidées. En effet, le lancement de la procédure (prescription du plan) neutralise les augmentations de franchise pendant une durée pouvant aller jusqu'à 5 ans (Letrémy, 2009). Le délai a été ramené de 5 à 4 ans par un arrêté du 4 août 2003, ce qui a partiellement corrigé l'effet de "sur-prescription" induit par le système.

d'urbanisme et d'assurance peuvent inciter les ménages à s'installer dans des zones moins exposées. Les politiques d'urbanisme peuvent correspondre à des zones d'exclusion comme en France, à un refus d'assurance dans les zones fortement exposées comme aux Etats-Unis ou bien à des rachats de terrain par l'entreprise autour de ses usines. Les politiques d'assurance peuvent correspondre à des primes d'assurance croissantes avec l'exposition au risque naturel, comme l'assurance inondations aux Etats-Unis, l'assurance tremblements de terre au Japon ou bien à des taxes dépendant de la localisation autour des sites industriels, comme en France où les plans de prévention des risques technologiques prévoient des mesures de prévention assez coûteuses pour les ménages très exposés.

Mais ces politiques d'urbanisme et d'assurance ne peuvent être plus précises que les cartes d'aléa sur lesquelles elles sont basées. La différenciation des tarifs d'assurance en fonction de ces cartes est un sujet sensible politiquement : une redéfinition plus précise des cartes permet une tarification plus discriminante, ce qui génère des gains en termes d'efficacité mais implique une inégalité de traitement entre les ménages. Ce chapitre identifie une opération de redéfinition des cartes qui augmente le bien-être de tous les habitants.

Enfin, le changement climatique et la croissance démographique augmentent le risque. Ce chapitre montre des cas réalistes où les zones d'exclusion se réduisent à mesure que le risque augmente. Les différents effets en jeu sont identifiés et précisément analysés. Tous ces résultats sont établis en considérant plusieurs scénarios qui diffèrent quant à la répartition du pouvoir de négociation entre les ménages, le maire et l'industriel.

1.4.2 Assurance et prévention collective

Le chapitre coécrit avec Sabine Lemoyne de Forges étudie l'exemple des inondations et l'impact de l'assurance individuelle sur la prévention collective réalisée par les communes. Ces mesures de prévention (digues, barrages, bassins de rétention) génèrent d'importantes externalités sur les communes voisines. La couverture des habitants contre les inondations peut correspondre à une tarification actuar-

ielle, comme aux Etats-Unis, ou uniforme, comme en France ou en Espagne[29]. L'assurance uniforme est cependant comprise dans une acception large qui inclut les mécanismes d'aides publiques. D'autres pays (Italie, Corée) ont en effet organisé des fonds alimentés par des taxes forfaitaires pour couvrir les ménages contre les inondations.

Pour analyser l'exposition aux inondations, ce chapitre présente un modèle adapté à cette question : il suppose des externalités asymétriques de prévention et des risques corrélés au sein de chaque commune et s'intéresse spécifiquement à l'assurance uniforme répandue dans de nombreux pays. Les spécifications d'autres papiers théoriques étant adaptées à des questions génériques ou à d'autres risques, cette structure théorique n'a pas d'équivalent dans la littérature de l'assurance ou du fédéralisme fiscal.

Comme l'assurance uniforme dépend des risques de tous les assurés, elle permet d'intégrer partiellement ces externalités. Le premier résultat de ce chapitre illustre la théorie générale du second best de Lipsey et Lancaster (1956-1957) : il montre qu'en présence de faibles externalités, l'assurance actuarielle Pareto domine l'assurance uniforme ; au contraire, en présence de fortes externalités, il peut être préférable de mettre en place une assurance uniforme.

Sous assurance uniforme et en information symétrique, ce chapitre précise ensuite dans quelle mesure le gouvernement central peut coordonner les mesures de prévention collective à l'aide d'une modulation de prime ou d'une limitation de la couverture assurantielle. Sous assurance complète, une modulation de primes est équivalente à un système fiscal incitatif et peut donc correspondre à une taxe Pigouvienne qui permettrait d'intégrer les externalités et d'implémenter les niveaux de prévention optimaux. L'impact de l'introduction d'une franchise dépend du type de prévention réalisée : si la prévention diminue le montant de la perte sans en

[29]En France comme en Espagne, l'assurance contre les catastrophes naturelles est une garantie obligatoire des contrats d'assurance habitation. En France, l'Etat apporte sa garantie illimitée à la Caisse Centrale de Réassurance et régule le prix de la garantie catastrophes naturelles. En Espagne, l'assurance contre les catastrophes naturelles est offerte par le Consorcio de Compensaciòn de Seguros.

changer la probabilité (*self-insurance* au sens de Ehrlich et Becker (1972)), alors cette politique est sans effet sur les niveaux de prévention et de bien-être ; si au contraire la prévention diminue la probabilité de la perte sans changer le montant de la perte (*self-protection*), alors l'introduction d'une franchise augmente les niveaux de prévention et peut augmenter le bien-être des habitants.

1.4.3 Assurance et aides publiques

Les deux chapitres théoriques considèrent l'assurance contre les catastrophes naturelles dans une acception large qui inclut les mécanismes d'aides publiques. Ce chapitre complète cette analyse en étudiant la substitution entre assurance formelle et assistance dans les DOM. En effet, les DOM sont bien plus exposés aux catastrophes naturelles que ne le sont les ménages métropolitains. Pourtant, la moitié des ménages vivant dans les DOM n'ont pas souscrit d'assurance habitation, qui inclut la couverture contre les catastrophes naturelles, alors que la quasi-totalité des ménages métropolitains sont assurés. La sous-assurance des ménages ultramarins est un enjeu en matière de politique publique du fait des aides versées par les pouvoirs publics aux ménages non assurés et de l'implication financière de l'Etat dans le régime d'assurance contre les catastrophes naturelles.

Jusqu'à présent, les causes de la sous-assurance dans les DOM n'ont pas été étudiées. Plusieurs explications peuvent être envisagées. Tout d'abord, il se peut que les primes d'assurance soient trop chères pour ces ménages. Certains rapports locaux de l'Association Française de Génie Parasismique mentionnent des primes d'assurance très élevées. Le niveau de vie dans les DOM étant par ailleurs inférieur à celui de la France métropolitaine, il se peut que les ménages ultramarins ne puissent tout simplement pas s'assurer au vu de leurs capacités budgétaires. De plus, le risque de catastrophes naturelles est peut-être sous-estimé par les ménages, car les biais de perception sont fréquents dans le cas des risques extrêmes. Une autre explication possible repose sur l'anticipation d'aides en cas de catastrophe naturelle. Les ménages d'Outre-mer reçoivent en effet des aides importantes de la part de l'Etat, des autorités locales et de leurs proches (voisins, famille). Enfin, le faible taux de souscription pourrait être dû à l'habitat traditionnel individuel, répandu en Outre-mer : de nombreux ménages construisent eux-mêmes leurs

maisons, parfois sans respecter les normes de construction ou sans permis de construire. Ces logements peuvent ne pas être assurables.

Ce chapitre spécifie et estime un modèle structurel d'offre et de demande d'assurance. Une équation d'offre permet d'estimer la prime d'assurance habitation proposée par les assureurs ; une équation de demande explique la probabilité de souscrire une assurance de la part des ménages, en tenant compte du fait que la décision d'assurance dépend de la prime d'assurance proposée. Ce modèle est très classique, mais il n'a pas encore été estimé faute de données adéquates. L'estimation de ce modèle requiert en effet des données microéconomiques fines sur les assurés et les non assurés. Pour cette étude, une base de données inédite a été constituée en croisant la base Budget de famille 2006 de l'Insee avec des données relatives à l'exposition aux risques naturels fournies par le Ministère de l'Ecologie.

L'estimation de ce modèle structurel permet ainsi d'identifier les différents déterminants de l'offre et la demande d'assurance. Les explications classiques sont écartées ; le faible taux de souscription dans les DOM est principalement dû à l'anticipation d'une assistance financière et à l'habitat individuel traditionnel. Les implications en matière de politique publique sont discutées, ainsi que la portée de ces résultats pour les autres pays où coexistent assurance et assistance contre les catastrophes naturelles.

1.4.4 Prévention et immobilier

La présence de l'industrie responsable du risque complique l'acceptabilité des politiques de prévention. Comme le montre le chapitre 2, le pouvoir de négociation entre le maire et l'industriel détermine la répartition des coûts et bénéfices des mesures de prévention et donc l'importance des efforts consentis par les populations et les communes.

En pratique, la perspective de devoir supporter certains coûts, même indirects, peut rendre les ménages et les communes très réticents à la mise en place des politiques de prévention. En France, par exemple, de nombreux acteurs locaux

redoutent la mise en place des plans de prévention des risques technologiques car ils craignent que ces plans ne révèlent le risque industriel et diminuent ainsi le prix des logements situés dans les zones exposées. Cet impact est difficile à estimer, car les plans mis en œuvre en zones urbanisées sont récents. Cependant, l'analyse d'autres évènements révélant le risque industriel permet d'apporter des premiers éléments.

Le dernier chapitre coécrit avec Arthur Katossky évalue l'impact de certaines politiques publiques de prévention, notamment d'information, et d'assurance des risques industriels sur les prix des logements existants à proximité des usines dangereuses en France. Ce chapitre étudie trois zones urbaines situées à proximité d'installations industrielles appartenant aux agglomérations françaises de Bordeaux, Dunkerque et Rouen. Ces trois sites industriels correspondent à des perceptions du risque très différentes. La poudrerie de Bordeaux n'est pas forcément vécue comme dangereuse par les riverains. En effet, il s'agit d'une ancienne installation militaire dont seuls les barbelés qui l'entourent sont visibles depuis certains endroits du périmètre d'étude. Par ailleurs, l'installation est particulièrement étendue (650 bâtiments répartis dans 350 hectares) ; le risque est ainsi perçu comme contenu à l'intérieur du complexe industriel. Au contraire, les industries chimiques présentes à Dunkerque et Rouen sont identifiées par les populations comme des industries dangereuses. Les bâtiments, les cheminées ou tout du moins les panaches de fumée sont visibles depuis l'ensemble du périmètre d'étude à Dunkerque. A Rouen par contre, sur certaines zones du périmètre d'étude, les cheminées et silos sont cachés du fait du relief.

Ce chapitre a nécessité un travail important de recueil de données, notamment quant aux caractéristiques extrinsèques des logements (distance aux commerces et services publics, exposition au risque industriel, à d'autres risques et nuisances). Les données relatives au prix et aux caractéristiques intrinsèques des logements ont été fournies par les Notaires de France. L'application de la méthode des prix hédoniques permet d'estimer l'effet de la proximité des usines sur les prix des logements. Ce chapitre montre que les prix sont plus bas à proximité des usines sur les sites de Dunkerque et de Rouen. Les écarts de prix ne sont pas significativement modifiés par les incidents locaux, la catastrophe d'AZF, les dispositifs d'information ni par la mise en place du régime d'assurance catastrophes technologiques.

Table 1.1: Fonctionnement comparé de l'assurance des catastrophes naturelles et technologiques

Régime d'indemnisation	Catastrophes naturelles	Catastrophes technologiques
Loi	Ce régime est institué en France métropolitaine par la loi n^{O}82-600 du 13 juillet 1982 relative à l'indemnisation des victimes de catastrophes naturelles. Cette loi s'applique depuis le 1er août 1990 aux départements d'outre-mer, à Mayotte et à Saint-Pierre-et-Miquelon et partiellement à Wallis-et-Futuna.	Ce régime est mis en place en France par la loi n^{O}2003-699 du 30 juillet 2003 relative à la prévention des risques technologiques et naturels et à la réparation des dommages.
Définition des catastrophes	Ce régime est dit "à péril non dénommé" : il n'existe pas de liste exhaustive des aléas qu'il couvre. Les effets des catastrophes naturelles sont définis légalement en France comme les "dommages matériels directs non assurables ayant eu pour cause déterminante l'intensité anormale d'un agent naturel, lorsque les mesures habituelles à prendre pour prévenir ces dommages n'ont pu empêcher leur survenance ou n'ont pu être prises" (article L. 125-1 du Code des assurances).	Une catastrophe technologique est définie par la loi comme un accident (non nucléaire) endommageant un grand nombre de biens immobiliers (au moins 500 logements rendus inhabitables) et survenant soit dans une installation classée[a], soit dans un stockage souterrain de produits dangereux, soit à l'occasion d'un transport de matières dangereuses (article L. 128-1 et R. 128 du Code des assurances).
Déclenchement de la garantie	L'Etat de catastrophe naturelle est constaté par un arrêté interministériel. Si un arrêté est publié, seules les personnes assurées peuvent bénéficier de la garantie catastrophes naturelles.	L'Etat de catastrophe technologique est constaté par un arrêté interministériel. Si un arrêté est publié, les personnes assurées peuvent bénéficier de la garantie catastrophes technologiques et les personnes non assurées peuvent être indemnisées par le Fonds de Garantie des Assurances Obligatoires dans la limite de 100 000€. La présence de ce plafond traduit la volonté de l'Etat d'inciter les ménages à s'assurer.
Obligation légale d'assurance et champ de la couverture	Un contrat d'assurance de dommages aux biens, pour les particuliers comme pour les entreprises, comporte obligatoirement la couverture des catastrophes naturelles. Les biens concernés sont les bâtiments à usage d'habitation ou professionnel et leur mobilier, les véhicules terrestres à moteur, le matériel, y compris le bétail en étable et les récoltes engrangées.	Un contrat d'assurance de dommages aux biens pour les particuliers comporte obligatoirement la couverture des catastrophes technologiques. Cette garantie, exclusivement offerte aux particuliers, ne couvre que l'immobilier de la résidence principale.
Rôle de l'Etat dans l'indemnisation : tarification	La prime catastrophes naturelles est incluse dans la prime d'assurance habitation, entreprise ou automobile. L'Etat impose qu'elle soit égale à un pourcentage fixe des primes dommages du contrat d'assurance habitation (12%), entreprise (12%) ou automobile (6%)[b].	La prime catastrophes technologiques est incluse dans la prime d'assurance habitation mais n'est pas encadrée par l'Etat[c]. Cependant, les assureurs n'ont pas le droit d'établir une franchise.
et garantie de l'Etat	L'Etat apporte sa garantie à la Caisse Centrale de Réassurance pour la réassurance des risques de catastrophes naturelles.	La garantie de l'Etat n'est pas engagée.

[a] Installation soumise à déclaration ou à autorisation incluant les sites Seveso. Les sites Seveso sont des sites à haut risque définis par la nomenclature de la directive européenne Seveso II (directive du Conseil du 9 décembre 1996 concernant la maîtrise des dangers liés aux accidents majeurs impliquant des substances dangereuses).

[b] La prime annuelle moyenne de la garantie catastrophes naturelles sur la période 1995-2005 est de 17€ pour les particuliers et de 138€ pour les entreprises (Grislain-Letrémy et Peinturier, 2010).

[c] La prime catastrophes technologiques correspond à quelques euros par an.

Chapter 2

Natural and Industrial Disasters: Land Use and Insurance

This chapter is cowritten with Bertrand Villeneuve (Université Paris-Dauphine and CREST).

Abstract

Urbanization in exposed areas increases the cost of disasters. For industrial risks, potential victims raise firms' liabilities. For natural risks, overexposure by some undermines mutualization. Land use policy (particularly exclusion zones) and insurance shape urbanization, but their efficiency is limited by hazard-map precision. Map-based discrimination being politically sensitive, we identify an operation of map redrawing that increases the welfare of all. Climate change and population growth increase risk. We exhibit realistic cases where exclusion zones shrink as risk rises. We disentangle the competing effects at play. Results are established for alternative distributions of bargaining power between households, mayor and firm.

Keywords: natural disasters, industrial disasters, insurance, land use regulation, hazard maps

JEL classification: H23, G22, R52, Q54

Résumé long

Ce chapitre analyse le lien entre l'assurance et la prévention individuelle des risques naturels et industriels, prévention qui se traduit essentiellement par le choix du lieu d'habitation. L'urbanisation dans les zones exposées augmente le coût des catastrophes. Dans le cas des risques industriels, les victimes potentielles, en s'installant à proximité des usines, augmentent la responsabilité des industriels en cas de dommage. Dans le cas des risques naturels, la surexposition de certains ménages sape les efforts de mutualisation. Les politiques d'urbanisme et d'assurance peuvent inciter les ménages à s'installer dans des zones moins exposées. Les politiques d'urbanisme peuvent correspondre à des zones d'exclusion comme en France, à un refus d'assurance dans les zones fortement exposées comme aux Etats-Unis ou bien à des rachats de terrain par l'entreprise autour de ses usines. Les politiques d'assurance peuvent correspondre à des primes d'assurance croissantes avec l'exposition au risque naturel, comme l'assurance inondations aux Etats-Unis, l'assurance tremblements de terre au Japon ou bien à des taxes dépendant de la localisation autour des sites industriels, comme en France où les plans de prévention des risques technologiques prévoient des mesures de prévention assez coûteuses pour les ménages très exposés.

Mais ces politiques d'urbanisme et d'assurance ne peuvent être plus précises que les cartes d'aléa sur lesquelles elles sont basées. La différenciation des tarifs d'assurance en fonction de ces cartes est un sujet sensible politiquement : une redéfinition plus précise des cartes permet une tarification plus discriminante, ce qui génère des gains en termes d'efficacité mais implique une inégalité de traitement entre les ménages. Ce chapitre identifie une opération de redéfinition des cartes qui augmente le bien-être de tous les habitants.

Enfin, le changement climatique et la croissance démographique augmentent le risque. Ce chapitre montre des cas réalistes où les zones d'exclusion se réduisent à mesure que le risque augmente. Les différents effets en jeu sont identifiés et précisément analysés. Tous ces résultats sont établis en considérant plusieurs scénarios qui diffèrent quant à la répartition du pouvoir de négociation entre les ménages, le maire et l'industriel.

2.1 Introduction

Many areas exposed to catastrophic risks are inhabited and used for economic activities. According to Zhang (2004), in China, "about 8% of the land area located in the mid- and down stream parts of the seven major rivers of the country [is] prone to floods". However, 50% of the country's total population lives in these areas, and "they contribute over 2/3 of total agricultural and industrial product value". According to Doherty et al. (2008), "in 2004, [...] the modeling firm AIR Worldwide estimated that nearly 80 percent of insured assets in Florida are located near the coasts, the high-risk area in the state. This represents $1.9 trillion of insured exposure located in coastal areas (commercial and residential exposure)".

The magnitude of the disaster which occurred in 1984 at the Union Carbide India Limited pesticide plant in Bhopal (India) is partly explained by uncontrolled urbanization in the vicinity of the plant. "The population of Bhopal stood at 102,000 in 1966. After Union Carbide and other industries settled there in the 1960s, the population grew to 385,000 in 1971, 670,000 in 1981, and 800,000 in 1984" (Ferrante, 2011). Creeping urbanization is exemplified by neighborhoods near to the AZF plant in Toulouse (France), which exploded in 2001. The AZF website mentions that "initially [in 1924] far from the dwelling areas, the plant has been progressively bordered by the Toulouse agglomeration"; pictures of the plant and its neighborhoods in the 1930s and in 2001 illustrate the agglomeration's expansion.[1]

Indeed, populations are drawn to risky locations by associated amenities such as river views, by jobs in industrial areas, or because they are fleeing expensive centers. The intertwined histories of risk and urban development can be complex but the law is quite simple: there is no right of "initial land use" by which the community or the industrialist can renege on its responsibility for any disaster compensation to the newcomers.[2]

[1] See `http://www.azf.fr/l-usine-azf-de-toulouse/historique-800233.html`.

[2] For industrial disasters in France, see the Environment Code (section L. 514-19), the rules of civil liability (Civil Code, section 1382 and the following ones) and legal precedents. A unique exception can be invoked: constant and chronic pollution that would induce nuisances but neither material nor health damages (Code of Building and Living, section L. 112-16).

The cost of natural and industrial risks is strongly determined by the number of people and businesses located in exposed areas and the value of their assets. "Changes in population, inflation and per capita real wealth are the main factors contributing to the increase of the original raw losses" due to floods in Europe between 1970 and 2006; "[a]fter filtering their influence there remains no evident signal suggesting any influence of anthropogenic climate change on the trend of flood losses in Europe during the assessed period" (Barredo, 2009). Similarly, "insured losses from earthquakes are rising because population growth and higher population density, especially in urban areas, expose more people to a single damaging earthquake [...] the seismic threat itself remains unchanged" (Bevere et al., 2011).

White and Haas (1975) deplore that research on natural disasters has mainly focused on physics and engineering while overlooking the economic, social and political dimensions of these events. Mileti (1999), in his book *Disasters by Design*, confirms the underinvestment in these important fields but observes that in the 1990s policies have evolved in this respect. Risk is the combination of hazard, i.e. the probability that a loss occurs, and vulnerability, i.e. the value that could be lost. Here, we leave aside hazard reduction (dams, levees or safety-oriented industrial design) and building standards (antiseismic systems or improved air tightness in protection against toxic fumes). We assume that all technical risk reduction measures have already been taken. As the topic has been neglected, our analysis focuses on vulnerability, inasmuch as it reflects urbanization choices at the individual and collective levels.

Land use externalities, namely the fact that urbanization in risky localities increases the cost of potential disasters, are the focus of this chapter. In the case of industrial risks, the externality is directly exerted on the firm. In the case of natural risks, the externality takes the form of free-riding when the mutualization of risk (via insurance or other solidarity mechanisms, namely tax-funded aid) provides no incentive to households to locate efficiently. Morgan (2007) explains that in Santa Rosa County (Florida), "subsidized insurance premia create a [real estate] market imbalance by reducing expected flood losses [...] in floodplain areas". Clearly, several vulnerability decreasing policies based on land use or insurance regulations

can internalize land use externalities: density restrictions, adjusted insurance premiums, and location-dependent taxes all contribute to shaping equilibrium risk exposure. We provide examples of these policies.

The community or industrialists can limit urbanization in exposed areas. The State can appropriate land, prohibit new building or limit population density to reduce exposure to natural risks. After the Great Flood of 1993 in the United States, "across nine states in the Midwest, more than 9,000 homeowners sold their properties" (FEMA, 2008); "entire towns, such as Valmeyer, Illinois, decided to move from the floodplain to higher ground, breaking an ongoing cycle of flood damage and government relief spending" (Bagstad et al., 2007). Similarly, an industrial firm can purchase or rent land, establishing a red zone in the vicinity of its plants. In the United States, "for example, in 1991 the company Dow Chemical paid to relocate a village of 300 inhabitants, which was situated very close to one of its chemical plants in Louisiana" (Sauvage (1997), our translation). In practice, when land is purchased by the firm, the conditions are negotiated between the firm and the mayor.

Insurance premiums for households and businesses can also provide incentives to locate in less exposed areas and therefore internalize (at least partly) land use externalities. Empirical works confirm that insurance tariffs are reflected in housing markets, real estate prices and density. Real estate prices respond even more to insurance premiums than to some other risk revelations: in Houston (Texas) in the 1980s, real estate prices did not immediately decline after a flood, but "when flood insurance premiums r[o]se dramatically approximately one year after the [1979] flood, these higher rates [were] capitalized into home values and prices [did] decline" (Skantz and Strickland, 1987). As the cost of industrial disasters is borne by firms, households and businesses do not need to purchase insurance against these risks, except perhaps via legal assistance insurance.[3] However, location-dependent taxes (or equivalently obligations with differentiated financial incidence) can play an incentive role similar to that played by insurance. For example, after the 2001

[3]For example, the aim of the French insurance system is only to manage the basic coverage for victims by avoiding long litigation and by covering the residual risk of no responsible identification. In many other countries, households directly lodge a complaint against the firm and no such insurance system is organized.

AZF accident in France, a series of costly construction works were imposed in the vicinity of hazardous plants. The extent to which the community is compensated by the firm for this extra burden is the most relevant political issue.

In this chapter, we analyze households' equilibrium location choices and risk exposure given the insurance tariffs and organization of the real estate market. When households do not pay fully for the risk they take, they exert land use externalities on society; these are key to our analysis. For natural disasters, free-riding is an unintended consequence of solidarity mechanisms. For industrial disasters, ex post compensation by the industrialist hardly encourages preventive measures from households.

Our approach deliberately leaves aside the issue of imperfect compensation (delays, defaults, deductibles). Therefore risk influences location choices only through the insurance premium, which makes cognitive biases on risk perception irrelevant.[4] This is not to deny the practical importance of these phenomena, but rather to propose a basic and pure analysis of the common types of real world institutions.

Picard (2008) proposes a model in which households' locations are fixed but differ with respect to their exposure to natural disasters. Actuarial insurance would be efficient, since it would induce consumers to invest optimally in prevention and mitigation. However, inequalities would be inevitably attached to the individualized tariffs. For that reason, transfers could be promoted. Here, we focus instead on competitive location choices and thus adopt the long-term perspective.

In a model derived from classical urban economics literature (see Fujita and Thisse (2002) for a review), Frame (1998) takes into account a second spatial dimension: locations not only vary in terms of distance to the center, but also in terms of risk. The paper proposes comparative statics on the equilibrium variables for each of two cases: where households have to absorb losses by themselves and where actuarial insurance (with loadings) is available. We focus instead on the degree of insurance

[4]Tatano et al. (2004) recall that correcting imperfect risk perception could enhance market efficiency.

price discrimination between locations and its equilibrium consequences.

Frame (2001) shows that starting from a situation without insurance or with imperfect insurance (for example because of loadings), a small dose of uniform coverage increases welfare. The intuition is that making exposed areas less daunting benefits everyone via an alleviation of urban congestion. In fact, his result is only local: complete uniform insurance would unleash land use externalities and may not Pareto dominate the absence of insurance. Our objective is precisely to analyze the complementary policies that counteract these undesirable effects.

The first contribution of this chapter is to analyze the hazard maps used by regulators and insurers to differentiate land use restrictions and insurance tariffs. The precision of the maps depends on scientific and technical limitations, as it requires historical data, engineering and prospective analysis (climate change for example, or reliability analysis for industry). Map refining is likely to trigger political disputes, since a more accurate map opens the way to more discriminating land use policies and insurance tariffs. We identify an operation of map redrawing that increases the welfare of all.

The second contribution concerns the impact of the parameters on the equilibrium policy. Although currently the increasing cost of natural disasters is largely explained by the growing urbanization of risky areas, in the future climate change could have a major impact. We examine both factors. Intuitively, an increase of risk should extend the exclusion zone (red zone in this chapter) as a way to contain the burden of disasters. However, the net impact of an increase of population is particularly ambiguous, as it combines an increased demand for space with a need for a reinforced protection of areas with higher densities of potential victims. A far less intuitive source of ambiguity is that an increase of risk can benefit to households and make them richer and so more difficult to squeeze. We disentangle three pure effects that can be signed and quantified. In particular but not only, we exhibit several realistic cases in which the red zone is reduced as risk increases.

The third contribution of this chapter is to offer a spectrum of alternative games.

We analyze the similarities and differences between the management of natural and industrial risks. We also consider different distributions of bargaining power between households, the mayor (representing the collective interest of households) and the firm (when there is one). The design of a red zone is an intrinsically political choice, as it depends on the distribution of bargaining power.

Section 3.2 sets up the model. Section 2.3 presents the case of natural disasters. After the treatment of the polar pricings (actuarial insurance and uniform insurance with a red zone), the central role of hazard maps is shown. Section 2.4 investigates industrial disasters. Typical organizations of real estate markets are studied: bargaining power lying with the firm, with the mayor, and more competitive forms. Section 2.5 explicates the comparative statics with respect to risk and between games. Section 2.6 concludes.

2.2 The model

Space and risk. $[0;\bar{x}]$ is the set of inhabitable locations (Figure 2.1). The risk source (e.g. the river bed or the plant) is located at 0. The distance x between the source and a location determines risk exposure. The safest place $\bar{x}$ can be seen as a crest.

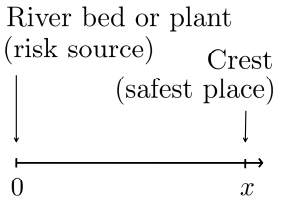


Figure 2.1: Space and risk

A household lives at a given location, say x, in $[0;\bar{x}]$; its dwelling occupies a surface $s(x)$ and the density of households at location x is $n(x)$. $[0;\bar{x}]$ may have uninhabited intervals. We have

$$\int_0^{\bar{x}} n(x)dx = N, \qquad \text{(POP)}$$

where N is the total population (POP). There is surface limitation at every location:

$$\forall x,\ n(x)\ s(x) \leq 1.$$

A dwelling located at x will be damaged only once with probability $p(x)$ with

$$\forall x,\ p(x) = \rho\ f(x), \tag{2.1}$$

where function $f(\cdot)$ is positive, decreasing along the space line and piecewise continuous. $\rho > 0$ is a magnitude index that will be used for comparative statics. The damage per dwelling has two parts, one fixed $\lambda_F \geq 0$ and the other proportional to the housing surface $\lambda_S\ s$ with $\lambda_S \geq 0$. The damage corresponds to (re)building cost and does not depend on land value. There is no damage in empty places.

Risk is a combination of hazard and vulnerability. Here, hazard is measured by $p(\cdot)$ and vulnerability associated with building techniques is measured by λ_F and λ_S. We assume that all technical risk reduction measures have already been taken. *Endogenous* vulnerability due to location choices (household density and housing surface) is the main focus of the study.

Insurance. Within a given community, risks are by nature highly correlated. The large number of communities on a much larger scale makes global risk tolerance high, so that we can assume risk neutrality of the insurance sector. We also assume that insurers have sufficient reserves to absorb any loss so that there is no risk for households not to be fully compensated.

Insurance policies offered to cover a dwelling of surface s located at x consist of a premium $\pi(x, s)$ and a complete reimbursement $\lambda_F + \lambda_S\ s$. Delays and associated costs are supposed to be fully compensated. Therefore risk influences location choices only through $\pi(x, s)$. We consider premium functions (PF) with two components, one fixed and the other proportional to surface:

$$\pi(x, s) = \pi_F(x) + \pi_S(x)\ s. \tag{PF}$$

This conforms well with the structure of risk and it allows us to study and compare actuarial and uniform premiums.

In all games, all households are insured: voluntarily for natural disasters when insurance is actuarial, compulsorily when it is uniform (to avoid adverse selection), and by a third party for industrial disasters.

We assume that natural disasters (ND) compensation takes the form of a pure insurance system without administrative costs:

$$\int_0^{\bar{x}} \pi(x, s(x)) n(x) dx = \int_0^{\bar{x}} p(x) \left(\lambda_F + \lambda_S \, s(x)\right) n(x) dx. \tag{ND}$$

It could be implemented by a perfectly competitive private sector or by an efficient administration.

For industrial disasters (ID), the firm is liable for all damages. There is no need for households to take out insurance:

$$\forall x, \ \forall s, \ \pi(x, s) = 0. \tag{ID}$$

The firm itself is assumed to be risk-neutral or equivalently fully insured by risk-neutral insurers.

Rent. Buying or perpetually renting a surface is equivalent; so we speak of rents henceforth. The rent $r(x)$ is the price per unit of surface at x. The opportunity cost of land is assumed to be nil so that rent is nil in empty places. If $r(x) = 0$, supply is in $[0; 1]$; if $r(x) > 0$, supply is 1. In equilibrium demand equals supply in each location.

$$n(x)s(x) = \begin{cases} 1 & \text{in inhabited locations,} \\ 0 & \text{otherwise.} \end{cases} \tag{LOC}$$

We assume that the whole land area is owned by a fund of which households have equal shares; this structure makes sure that all reforms have a homogenous effect on households. Households each receive

$$\bar{r} = \frac{1}{N} \int_0^{\bar{x}} r(x) s(x) n(x) dx, \tag{2.2}$$

which they take as given. The income effects are worth analyzing; this is why we do not make the "absentee landlord" hypothesis, often encountered in the literature. If one wants to neutralize the income effects, one can take a quasilinear utility function as a special case, as the flexibility of our model allows (see next paragraph).

Households. We assume that households are identical and have no intrinsic preference for one location over another. Their utility $U(z, s)$ depends on their consumption z of the composite good (henceforth money) and on their housing surface s. U is twice differentiable, strictly increasing and strictly quasiconcave with respect to z and s. Households are price takers; they have an income ω and they maximize their expected utility under their budget constraint. Since insurance is complete, the expected utility EU is no more than the utility U. Households' (HH) choice (x, z, s) is optimal if it solves

$$\max_{x,z,s} U(z, s) \quad \text{s.t. } \omega + \bar{r} \geq z + sr(x) + \pi(x, s). \tag{HH}$$

We say that x is inhabited if it is part of a solution of (HH). In the following, $(z(x), s(x))$ denotes the optimal consumption associated with location x (inhabited or not).

We denote MRS_{sz} the marginal rate of substitution of s with respect to z, that is

$$\mathrm{MRS}_{sz} = \frac{\partial U/\partial s}{\partial U/\partial z}. \tag{2.3}$$

We use a similar convention for MRS_{zs}.

The equilibrium. As households are free to move, equilibrium is defined by the fact that no household has an incentive to change its location or its housing surface and that local and general constraints are satisfied.

Definition 1 (Equilibrium)**.** *Let $\pi(\cdot, \cdot)$ be an insurance pricing allowed by (PF). An equilibrium is a set of functions $n(\cdot), z(\cdot), s(\cdot), r(\cdot)$ such that the following four conditions are satisfied: (i) (POP), (ii) (ND) for natural disasters or (ID) for industrial disasters, (iii) (HH) and (iv) (LOC).*

In equilibrium, population density, housing surface, location choice and therefore

individual and total risk exposures are endogenous and depend on the insurance pricing (e.g. actuarial or uniform). Appendix 2.7.1 determines useful necessary conditions characterizing the equilibrium. The existence of a solution and its essential uniqueness will be proved in the games we will now study.

2.3 Natural disasters

Regulators and insurers use maps delineating location-based risk segments to differentiate land use restrictions and insurance tariffs. In France, natural disasters insurance is based on uniform premiums;[5] in Japan, the Probabilistic Seismic Hazard Maps delineate the four earthquake premium zones (Tsubokawa, 2004); in the United States the Flood Insurance Rate Maps delimit the flood premium zones (Hayes and Neal, 2009) and flood insurance is actuarial with respect to these maps.

Defining the precision of hazard maps is a political choice, since a more accurate map opens the way to more discriminating land use or insurance regulations. But it also depends on scientific and technical limitations, as it requires historical data, engineering and prospective analysis (climate change for example, or reliability analysis for industry). The precision of hazard maps varies between hazard types. The maps of seismic activity in France exhibit five zones.[6] The ones relative to shrinking and swelling of clay soils are more precise but not reliable at the dwelling scale.[7] Flood maps in the United States are reliable at the street scale.[8] The precision and even the availability of hazard maps also vary from one area to the next due to a lack of standardization. The precision of floods maps in France depends on the implementation stage of a natural risk prevention plan;[9] flood maps in the United States are not provided in all jurisdictions.

Maps shape the real estate market and insurance and have a durable effect on total

[5] The guarantee against natural disasters is mandatorily included in home, business building or car insurance policies. The natural disasters premium is a fixed share of the premium for other damages covered by the insurance policy.

[6] See `http://www.planseisme.fr/spip.php?article19`.

[7] See `http://www.argiles.fr/`.

[8] See `https://msc.fema.gov/webapp/wcs/stores/servlet/FemaWelcomeView?storeId=10001&catalogId=10001&langId=-1`.

[9] See `http://cartorisque.prim.net/`.

risk exposure. We first analyze two polar examples: actuarial insurance and uniform insurance with a red zone, i.e., an area where settlement is prohibited. Actuarial insurance corresponds to pricing in compliance with the hazard map reflecting the hazard function $p(\cdot)$. On the contrary, uniform insurance with a red zone relies on the simplest maps with two zones: one where land use is prohibited and one where a single insurance tariff is applied. We then describe the efficiency gains of refining hazard categories, keeping in mind that they should be balanced with assessment costs.

2.3.1 Actuarial insurance

With actuarially fair pricing, all households purchase insurance. When households choose location x and surface $s(x)$, they consider the "total" rent $r(x) + \lambda_S p(x)$ and the fixed part $\lambda_F p(x)$. Two locations are equally attractive only if the total rent is smaller where the fixed part is higher. In riskier areas, the fixed part is clearly more expensive, therefore the total rent is necessarily smaller (Equation 2.23 in Appendix 2.7.1).[10] Along the isoutility curve where all optimal choices are located, smaller total rent is necessarily associated with more demand for space: compensated demand increases as the price decreases. Consequently, in riskier areas, households demand more space and are thus more dispersed. Therefore $n(\cdot)$ and $z(\cdot)$ increase with respect to x, while $s(\cdot)$ decreases. At the limit, the riskiest areas are deserted. As $r(\cdot)$ is increasing, either $r(0) = 0$ and we denote x^* the highest location defined by

$$r(x^*) = 0, \tag{2.4}$$

or $r(0) > 0$ and the whole space is inhabited and then $x^* = 0$. Therefore x^* is the leftmost (i.e. riskiest) inhabited location in equilibrium.

Proposition 1. *Actuarial insurance pricing implements a Pareto optimum.*

Proof. See Appendix 2.7.2. Note that this proof only uses $p(\cdot)$ decreasing. □

Indeed, actuarial insurance makes households pay the price of risk. Similar effects can be produced with location-dependent limitation of population density instead

[10] Several empirical studies based on the hedonic prices method confirm that housing markets value the capitalized flow of natural risks insurance premiums (Bin et al. (2008), MacDonald et al. (1990), Harrison et al. (2001)).

of location-dependent insurance pricing. Density limitation can be implemented via auctions of occupancy rights.

2.3.2 Red zone under uniform pricing

We will now consider the polar case of uniform insurance. Uniform insurance opens the way to adverse selection and difficulties of mutualization on a large scale. In France and in Spain, uniform insurance is organized by the government and comes automatically with basic property insurance policies (Dumas et al., 2005). The notion of uniform insurance should not be taken too literally: State assistance funded by taxes has equivalent effects, taxes being similar to insurance premiums.[11] In many countries the insurance market is not developed and the State organizes public aid after disasters (Dumas et al., 2005). We consider here that all households benefit from compensation after natural disasters at a uniform price.

Clearly, uniform insurance exacerbates land use externalities: households do not pay for the risk they generate by locating in exposed areas. All permitted locations have the same value for households and the building zone is fully and uniformly used. Combining uniform insurance with building restrictions partially corrects imperfect internalization of risk and increases efficiency. The State understands this and prohibits the most exposed areas, thus defining a block that we will henceforth call a *red zone*. In equilibrium, x^* denotes both the size of the red zone and the leftmost inhabited location (Figure 2.2). The red zone is the only variable that policy can change to reach an optimum: increasing x^* reduces the cost of risk and available space at the same time.

When land use is uniform over the inhabited area $[x^*, \bar{x}]$, the total expected cost of risk CR amounts to

$$\mathrm{CR}(x^*) = \left(\frac{N\lambda_F}{\bar{x} - x^*} + \lambda_S \right) \int_{x^*}^{\bar{x}} p(t)dt. \tag{2.5}$$

[11] Coate (1995) claims with reason that the equivalence is less than perfect. First, ex post assistance by the State is less efficient because there is no reason to expect that people who provide assistance will choose the optimal level of assistance: assistance may rely on approximate loss assessments or discretionary decisions. Second, natural disasters assistance is provided by various actors (non-profit organizations, States); the uninsured can free-ride. In this respect, the assistance providers themselves can consider that the level of assistance is not optimal. We leave these issues aside.

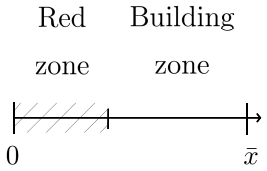


Figure 2.2: Red zone

Remark that increasing x^* decreases the cost of risk (people occupy less risky zones): it leads to a positive marginal risk reduction MRR.

$$\mathrm{MRR}(x^*) = -\frac{d\mathrm{CR}}{dx} \geq 0. \tag{2.6}$$

We assume that the marginal benefit of reducing the cost of risk decreases.[12]

$$\forall x,\ \frac{d\mathrm{MRR}}{dx} \leq 0. \tag{CVX}$$

Definition 2 (Constrained optimality)**.** *A red zone is said to be* constrained optimal *if it is Pareto optimal under the constraint that authorized land is uniformly used by households.*

The constrained-optimal red zone is the solution of the program maximizing utility under the budget constraint:

$$\left\{\begin{array}{ll} \max\limits_{(z,x)} & U\left(z, \frac{\bar{x}-x}{N}\right), \\ \text{s.t.} & \omega + \bar{r} \geq z + \frac{\bar{x}-x}{N} r(x) + \frac{\mathrm{CR}(x)}{N}, \\ & 0 \leq x \leq \bar{x}. \end{array}\right. \Leftrightarrow \left\{\begin{array}{ll} \max\limits_{(T,x)} & U\left(\omega + \frac{T}{N}, \frac{\bar{x}-x}{N}\right), \\ \text{s.t.} & -T \geq \mathrm{CR}(x), \\ & 0 \leq x \leq \bar{x}. \end{array}\right. \tag{2.7}$$

The uniform premium shares the total expected cost of risk equally between households.

Proposition 2. *The following two conditions are equivalent.*

(A) x^* is the constrained-optimal red zone.

[12] In other words, the cost of risk $\mathrm{CR}(\cdot)$ is convex. Note that $p(\cdot)$ convex is a sufficient condition to get $\mathrm{CR}(\cdot)$ convex.

(B) x^* is the unique *solution of*

$$\begin{cases} x^* = 0 & \textit{and } \mathrm{MRR}(0) \leq \mathrm{MRS}_{sz}\left(\omega - \frac{\mathrm{CR}(0)}{N}, \frac{\bar{x}}{N}\right), \\ x^* \in (0, \bar{x}) & \textit{and } \mathrm{MRR}(x^*) = \mathrm{MRS}_{sz}\left(\omega - \frac{\mathrm{CR}(x^*)}{N}, \frac{\bar{x}-x^*}{N}\right), \\ x^* = \bar{x} & \textit{and } \mathrm{MRR}(\bar{x}) \geq \mathrm{MRS}_{sz}\left(\omega - \frac{\mathrm{CR}(\bar{x})}{N}, 0\right), \end{cases} \tag{2.8}$$

where MRR is the marginal risk reduction and MRS_{sz} the marginal rate of substitution of households.

Proof. The constraint in (2.7) is convex in T and in x (it is linear in T and $\mathrm{CR}(\cdot)$ is convex (CVX)). As additionally the objective is strictly quasiconcave, the Kuhn-Tucker conditions can be easily rearranged to give the necessary and sufficient condition (B) defining the unique constrained optimum (A). Note that corner solutions are not excluded. □

We denote by x^*_{Nat} the constrained-optimal red zone. The utility of all is $U\left(\omega - \frac{\mathrm{CR}(x^*_{\mathrm{Nat}})}{N}, \frac{\bar{x}-x^*_{\mathrm{Nat}}}{N}\right)$. The utility increases with respect to the income ω, and decreases with respect to the loss parameters λ_F, λ_S and ρ. The impact of an increase of population N on the utility is ambiguous. Indeed, increasing the number of households reduces the surface occupied by each of them but also dilutes the land use externalities.

In France, where insurance is uniform, the 1995 law created natural risk prevention plans that define red zones where new building is prohibited.[13] In practice, these plans applied to one fourth of the municipalities in September 2011 (8,801 out of 36,682 according to the Ministry of Ecology) and are included in the local land-use plans. Furthermore, insurers can refuse to insure households who have built their dwelling in prohibited areas after the implementation of the plan (Insurance Code, section L. 125-6), but few houses are concerned. In the United States, there is no strict prohibition but flood insurance coverage is not offered to households living in high flood risk areas (FEMA, 2007).

[13] See law n°95-101 of February 2, 1995 relative to the strengthening of environment protection. This law modified the law n°87-565 of July 22, 1987 relative to the organization of civil security, forest protection against fire and prevention of major risks.

Mayors play a primary role in the implementation of these policies. If each jurisdiction bore the cost of its natural disasters (in particular by paying adjusted premiums to insurers), then a result à la Tiebout (1956) applies: each mayor designs the optimal red zone in his or her jurisdiction to make it most attractive. However, in practice, mayors may prioritize short-term economic and demographic development over risk prevention and may therefore minimize red zones. This phenomenon is named the *local government paradox* by Burby (2006), who provides several illustrations of it in the United States. This is one of the reasons why French and American public insurance directly link the contributions paid by households to the prevention measures taken by mayors.[14] Nevertheless, in France, it would appear that some local authorities exploit loopholes to delay natural risk prevention plans, as became apparent following the Xynthia Storm in 2010 (AFP, 2011).

2.3.3 Refining maps

Gross pricing opens the way to adverse selection within each tariff zone: the less exposed do not purchase insurance, so undermining mutualization. We assume here that all households purchase insurance, either because risk aversion makes the zone-based tariff remain attractive for all (even for an imprecise map) or because insurance is compulsory. In reality, in many European countries, a majority of households are not insured against floods (Bouwer et al., 2007). In the United States, flood insurance is purchased by half of households living in flood prone areas,[15] and by only 1% of households living outside these areas (Dixon et al., 2006). Important events confirm these low penetration rates for flood and earthquake insurance: "only 10% of damages were insured after the summer 2002 floods in central Europe, 3% after the 1995 Kobe earthquake, 4% after the 1999 Istanbul earthquake, 24% after the 1993 Mississippi floods, and 0.75% after the 1998 China floods" (Tallon and Vergnaud (2007), our translation).

The optimal positioning of n risk segments would be the generalization of the problem we solved above. In the following, we privilege the analysis of the fineness of

[14] These public policies also take into account the externalities exerted by collective prevention measures (e.g. dams, levees) on neighboring jurisdictions (see Chapter 3).

[15] I.e. where the flood probability is at least equal to one percent.

zoning and we expose a remarkably simple and powerful result.

Definition 3. *Zoning is the partition of space into subintervals (zones) such that building is either prohibited or authorized on each zone; the premium is uniform within each zone and actuarially balanced by zone.*

Uniform insurance with a red zone and actuarial insurance correspond to two polar examples (the latter with potentially a potentially infinite number of zones).

Definition 4. *Zoning Z_2 is finer than zoning Z_1 if every zone of Z_2 is a subset of a zone of Z_1 and is authorized if it belongs to an authorized zone of Z_1.*

In other words, Z_2 is a further fragmentation of Z_1 and building prohibition is (weakly) less restricted.

Proposition 3. *Refining the zoning is Pareto improving.*

Proof. Consider two zonings Z_1 and Z_2, Z_2 being finer than Z_1. $\hat{p}(\cdot)$ is the unique function such that, for every zone Z of the partition Z_2, $\hat{p}(\cdot)$ is constant over Z and equals the mean of $p(\cdot)$ over Z. Let $\hat{p}(\cdot)$ take the role taken by $p(\cdot)$ in the previous analysis. Proposition 1 can be applied to $\hat{p}(\cdot)$, since it is decreasing: the unconstrained actuarial equilibrium for $\hat{p}(\cdot)$ implements the optimum allocation. Clearly, this equilibrium can be implemented even if we impose zoning Z_2. Zoning Z_1 being grosser than Z_2, it imposes additional constraints and thus can only lead to a Pareto inferior allocation. □

Finer zoning is more efficient in principle but is likely to be costly in terms of risk assessment. The optimal fineness is a tradeoff.

However, short-term costs and benefits are very likely to dominate the public debate and to determine the acceptance of the reform. In the short term, as people do not move or change their dwellings, they only see their insurance premium increase or decrease. In zones unchanged by the reform, inhabitants are indifferent. In refined zones, some inhabitants lose (win) because their premium increases (decreases). The State can choose the sizes of the new zones to get the reform accepted.

The State may compensate the minority losers, as the American Federal State did. Flood insurance is provided by the Federal State in the framework of the National Flood Insurance Program. The Congress established this program in 1968 and combined zone-dependent premiums with subsidies for exposed houses that were built before risk maps. This program has been more costly than expected: "at the end of 2007, [the NFIP] had borrowed $17 billion, largely as a result of the 2004 and 2005 hurricane seasons" (Kousky and Michel-Kerjan, 2010).

> "Grand Isle, Louisiana's only inhabited barrier island, [...] has been hit by 50 major storms in the past 130 years. According to Tulane University's Oliver Houck (Burdeau, 2004), the total federal spending in Grand Isle amounted to $439,000 per home. Subtracting the many vacation homes increases the subsidy to $1.28 million for each of its 622 year round residents" (Bagstad et al., 2007).

Transition from one zoning to another certainly requires a long process of destructions and reconstructions, but in view of the economic burden of repetitive losses, Bagstad et al. (2007) conclude that "when evaluated from a long-term cost perspective, a one-time relocation is clearly cheaper than an ongoing cycle of damage and rebuilding".

2.4 Industrial disasters

We will now reinterpret the model to underline the similarities and differences between natural and industrial risks. The potential losses due to households' choices (location, surface) and the probabilities have the same structure and notation. The difference is that the firm is liable for all damages. To accentuate the contrast, we assume that households are neither employees nor owners of the firm. Note that if the firm were entirely the property of the households, the issues addressed in the previous section could be readily transposed. Limited liability of the firm would certainly produce interesting effects: excessive risk-taking by the firm and, in turn, less risky location choices by imperfectly protected households.[16] We focus here on

[16] Several empirical works based on the hedonic prices method show that perception of industrial risks can decrease property values (Gawande and Jenkins-Smith (2001), Kiel and McClain (1995), Chapter 5).

the "curse of unlimited liability": fully compensated households pay no insurance premium and rent is constant across locations; households carelessly occupy the available land and, in doing so, they exert maximum land use externalities on the firm. The mayor can be seen as the head of the fund, who acts as a proxy for households and defends their interests.

First we show that location-dependent taxes set up by the mayor can play an incentive role similar to that of insurance in the previous section. Then, to complete the analysis presented for natural risks, we explore alternative games about the firm's participation in the real estate market. In the simple case of red zones, we compare the maps between games.

2.4.1 Location-dependent taxes

In exchange for compensation paid by the firm, the mayor could set up location-dependent taxes to harness the land use externalities. Like insurance, the tax would have a fixed part and another proportional to surface, both dependent on location. Taxes based on the hazard map reflecting the hazard function $p(\cdot)$ implement a first-best allocation. The optimal zoning results from a tradeoff between efficiency benefits and assessment costs, the argument being similar to the one presented for natural risks.

To improve security after the AZF accident in 2001, technological risk prevention plans were created in 2003.[17] These plans establish red zones and zone-dependent prevention measures such as changing windows, improved air tightness in protection against toxic fumes, and thermal insulation of roofs. These renovations are mandatory up to 10% of the dwelling's market value; they typically cost €10,000 to €15,000. These measures combine technical risk reduction according to location and, in the long run, incentives for efficient land use. In their financial dimension, these measures are similar in effect to the zone-dependent taxes mentioned above, except that the community is only partially compensated by the firm for this extra

[17] See law n°2003-699 of July 30, 2003 relative to prevention of technological and natural risks and to damages repair. See also Environment Code, section R. 562-5.

burden.[18] This State assistance is explained by the fear that regulatory constraints and their associated cost cause firms to relocate. The European Commission decided in 2007 that this State assistance to firms did not cause a significant competition distortion.[19]

2.4.2 Red zones

The firm does not need land per se; it participates in the land market only to prevent the riskiest locations being occupied by potential victims. The purchasing of land by firms has been studied, but not in the framework of risk exposure. The analysis of takeover bids as in Grossman and Hart (1980) is certainly more advanced and it is a valid source of inspiration for solutions. Blume et al. (1984) and Nosal (2001) study the efficiency of paying compensation; Miceli and Segerson (2006) and Strange (1995) analyze the problem of holdout faced by a developer, when each individual landowner knows that each of his parcels of land is necessary for project completion and can postpone or even block the overall project.

Here the mayor represents the collective interest of households. The fact that households are landowners make them likely to benefit from exchanges, but the way competition distributes the benefits of risk reduction between stakeholders depends on market organization. In practice, land purchase can be decided principally by the firm or by the mayor.[20] In Moselle (France), "on the Carling petrochemical platform, one operator developed a stealth policy of buying zone 1 [the most exposed area] land and houses for sale, in order to guarantee land control in the vicinity of its installations. The dwellings are destroyed by the

[18] The State and mayors decided to subsidize industrialists by partly funding the purchase of the red zone and the mitigation measures required from households (order on May 3, 2007 relative to the methods of funding, follow-up and control of the implementation of land and supplementary measures foreseen by the technological risk prevention plans). These mitigation measures are currently partially subsidized by the State via a tax credit, without any transfer paid by the firm for the time being (2011 law of finance n^{O}2010-1657 of December 29, 2010).

[19] See note on April 25, 2007 from the European Commission to the French authorities relative to State assistance N 508/2006.

[20] Industrialists cannot define a zone-dependent land use limitation. Rare exceptions can be found when industrial risks are managed by the State. For example, French law defines a zone-dependent limitation of population density by isolation polygons and areas in the very close vicinity of military pyrotechnic storage areas (law n^{O}1929-08-08 of August 8, 1929 relative to relative to urban constraints around stores and facilities used to store, handle or produce gunpowder, ammunition, fireworks or explosives).

industrialist and the land is kept for its own use or without any determined use, guaranteeing a "buffer" function with the close neighborhoods" (Sauvage (1997), our translation). Mayors or the State can encourage the firm to buy or rent land exposed to industrial risks. In Waziers (France), at the end of the 1980s, "the local authority owned most of the unplowed land [...]. It obtained the industrialist's agreement to buy [...] the land included in the future protection area within a 240 meter radius around the hydrogen storage." (Sauvage (1997), our translation).

We consider three different organizations of the market offering a wide spectrum of games in the distribution of bargaining power; all determine an equilibrium allocation generically denoted by (T^*, x^*) where T^* is (by convention) the net transfer from the firm to households; subscripts will refer to the particular game.

Firm game. The firm holds the bargaining power and captures all the surplus. Acceptance by the mayor depends on households doing at least as well as without the red zone. More precisely, the firm offers a two-part tariff: it chooses the rent per unit of land and the lump-sum transfer to the community.

Market game. Households and the firm are both price takers. The red zone is determined by the equilibrium in the land market. The surplus is partly captured by the firm via access to the land and partly recovered by households via rents.

Mayor game. The mayor holds the bargaining power and redistributes to households the benefits of risk reduction extracted from the firm. The no-red-zone situation is the firm's reference for acceptance. More precisely, the mayor offers two different rents (one for households and another for the firm) and requires a lump-sum transfer from the firm to households.

The three red zones are denoted x^*_{Firm}, x^*_{Market} and x^*_{Mayor}. We prove that all games yield a constrained optimal allocation.

The constrained optimal allocations (T, x) (Definition 2) can all be given by the

maximization of the utility of households given a minimum profit of the firm $\overline{\Pi}$:

$$\left\{\begin{array}{ll}\max\limits_{(z,x)} & U\left(z, \frac{\bar{x}-x}{N}\right), \\ \text{s.t.} & \omega + \bar{r} + \frac{T}{N} \geq z + \frac{\bar{x}-x}{N} r(x), \\ & \Pi_i - T - \mathrm{CR}(x) \geq \overline{\Pi}, \\ & 0 \leq x \leq \bar{x}. \end{array}\right. \Leftrightarrow \left\{\begin{array}{ll}\max\limits_{(T,x)} & U\left(\omega + \frac{T}{N}, \frac{\bar{x}-x}{N}\right), \\ \text{s.t.} & \Pi_i - T - \mathrm{CR}(x) \geq \overline{\Pi}, \\ & 0 \leq x \leq \bar{x}. \end{array}\right. \tag{2.9}$$

where Π_i is the unmodeled profit generated by the firm's primary activity. Existence and uniqueness of the solution for a given $\overline{\Pi}$ are directly established by the argument used in the proof of Proposition 2.

We check that the equilibrium of each game corresponds to one such program.

In the mayor game, we recognize that $\overline{\Pi} = \Pi_i - \mathrm{CR}(0)$. Indeed, the households capture all the benefits from risk reduction and the corresponding transfer from the firm to households is $T^*_{\text{Mayor}} = \mathrm{CR}(0) - \mathrm{CR}(x^*_{\text{Mayor}})$.

In the firm game, the firm solves a dual program where minimum utility $U\left(\omega, \frac{\bar{x}}{N}\right)$ is guaranteed to the households. T^*_{Firm} is such that $U\left(\omega + \frac{T^*_{\text{Firm}}}{N}, \frac{\bar{x}-x^*_{\text{Firm}}}{N}\right) = U\left(\omega, \frac{\bar{x}}{N}\right)$.

In the market game, the program cannot be directly interpreted as the equilibrium program. Existence of the equilibrium allocation is proved in Appendix 2.7.3. Let r be the equilibrium rent in the market game. Assume for example that the market allocation is interior. We have

$$\mathrm{MRR}(x^*_{\text{Market}}) = r, \tag{2.10}$$

$$\mathrm{MRS}_{sz}\left(\omega + \frac{r x^*_{\text{Market}}}{N}, \frac{\bar{x} - x^*_{\text{Market}}}{N}\right) = r. \tag{2.11}$$

We take $\overline{\Pi} = \Pi_i - r x^*_{\text{Market}} - \mathrm{CR}(x^*_{\text{Market}})$ in program 2.9. After eliminating T using the binding constraint, the first-order condition of program 2.9 becomes:

$$\mathrm{MRR}(x) = \mathrm{MRS}_{sz}\left(\omega + \frac{r x^*_{\text{Market}} + \mathrm{CR}(x^*_{\text{Market}}) - \mathrm{CR}(x)}{N}, \frac{\bar{x} - x}{N}\right). \tag{2.12}$$

By inspection of (2.10) and (2.11), we see that $x = x^*_{\text{Market}}$ is a solution of (2.12). As the optimum is unique, we conclude that the market game is efficient. The line

of reasoning is similar when the market yields a corner solution.

Proposition 4. *For the three games, the equilibrium allocation* (T^*, x^*) *is constrained optimal and is the solution of*

$$\begin{cases} x^* = 0 & \text{and } \mathrm{MRR}(0) \leq \mathrm{MRS}_{sz}\left(\omega + \frac{T^*}{N}, \frac{\bar{x}}{N}\right), \\ x^* \in (0, \bar{x}) & \text{and } \mathrm{MRR}(x^*) = \mathrm{MRS}_{sz}\left(\omega + \frac{T^*}{N}, \frac{\bar{x}-x^*}{N}\right), \\ x^* = \bar{x} & \text{and } \mathrm{MRR}(\bar{x}) \geq \mathrm{MRS}_{sz}\left(\omega + \frac{T^*}{N}, 0\right), \end{cases} \tag{2.13}$$

where the net transfer T^* *from the firm to households is*

$$T^*_{\text{Firm}} \text{ such that } U\left(\omega + \frac{T^*_{\text{Firm}}}{N}, \frac{\bar{x}-x^*}{N}\right) = U\left(\omega, \frac{\bar{x}}{N}\right) \tag{2.14}$$

$$T^*_{\text{Market}} = rx^* \text{ where } r = \mathrm{MRS}_{sz}\left(\omega + \frac{rx^*}{N}, \frac{\bar{x}-x^*}{N}\right), \tag{2.15}$$

$$T^*_{\text{Mayor}} = \mathrm{CR}(0) - \mathrm{CR}(x^*). \tag{2.16}$$

For the firm game and the mayor game, the equilibrium allocation is unique.

Comparing the $\overline{\Pi}$ between games amounts to comparing the bargaining position of the mayor in each game. With $\overline{\Pi}_{\text{Nat}} = \Pi_i$, program 2.9 gives the constrained-optimal solution for natural risks. This is the worst case for the community. Then come the firm game, the market game and the mayor game. Thus: $\overline{\Pi}_{\text{Nat}} \geq \overline{\Pi}_{\text{Firm}} \geq \overline{\Pi}_{\text{Market}} \geq \overline{\Pi}_{\text{Mayor}}$.

This suggests a strategy for comparing the red zones. As we can compare the $\overline{\Pi}$ between games, if the Engel curves of the consumers are increasing, the red zones can be readily ordered.

Simple ordinal sufficient conditions to have increasing Engel curves are:

$$\begin{aligned} &\forall (z,s),\ \frac{\partial \mathrm{MRS}_{zs}}{\partial z} \equiv \frac{\partial}{\partial z}\left(\frac{\partial U/\partial z}{\partial U/\partial s}\right) \leq 0, \\ &\forall (z,s),\ \frac{\partial \mathrm{MRS}_{sz}}{\partial s} \equiv \frac{\partial}{\partial s}\left(\frac{\partial U/\partial s}{\partial U/\partial z}\right) \leq 0. \end{aligned} \tag{ENG}$$

These assumptions simply say that the relative value of the commodity becoming more abundant decreases. They are maintained hereafter. Proposition 5 compares the red zones.

Proposition 5. *The four red zones are ordered as follows:*

$$x^*_{\text{Nat}} \geq x^*_{\text{Firm}} \geq x^*_{\text{Market}} \geq x^*_{\text{Mayor}}. \tag{2.17}$$

Proof. From (2.9),

$$\left(\frac{d\text{MRR}}{dx} + \frac{1}{N}\frac{\partial \text{MRS}_{sz}}{\partial s} - \frac{\text{MRR}}{N}\right)\frac{dx^*}{d\overline{\Pi}} = -\frac{1}{N}\left(\frac{\partial \text{MRS}_{sz}}{\partial z}\right). \tag{2.18}$$

(CVX) and (ENG) are sufficient for the red zone x^* to increase with respect to $\overline{\Pi}$. Note that (ENG) would be sufficient with a linear constraint in program 2.9. As the constraint is not linear in x, we need the assumption that $\text{CR}(\cdot)$ is convex (CVX). □

This confirms the intuition that households have more space when their situation is more favorable. The design of a red zone is an intrinsically political choice, as it depends on the distribution of the bargaining power between parties.

2.5 Delimiting red zones: comparative statics

Red zones aptly summarize the tradeoffs encountered by decision-makers: extending the regions where building is forbidden certainly reduces the total cost of risk but squeezes households at the same time. An increase of population has a particularly ambiguous impact on this tradeoff, as this risk factor comes with an increased demand for land. Furthermore an increase of risk can make households richer (e.g. via rent increase) and so more difficult to squeeze. We determine the impact of climatic or technological change, summarized by ρ, and demographic evolution, summarized by N, on red zones in all games. We exhibit several realistic cases with the counterintuitive effect of a smaller red zone with higher risk.

Inasmuch as expected loss can be assimilated formally to transportation costs, similar comparative statics for the empty zone have been established by Pines and Sadka (1986): the empty space increases with respect to ρ and can increase or decrease with respect to N. We show here that these findings remain valid for the red zone with natural risks in the second-best situation, but that they cannot be extrapolated to the games with industrial disasters, because of the introduction of the firm as a

third party. Another critical difference justifying an original approach is that the expected loss depends on the surface occupied by the household.

Method. *We determine the impact of ρ or N on the equilibrium red zone x^* in three steps.*

> **First step.** *We disentangle and explicate the three basic effects at play.*
>
> **Second step.** *We give the signs of the three effects depending on the game and the nature of risk increase.*
>
> **Third step.** *We identify clear cases and resolve remaining ambiguities with specific additional assumptions.*

First step. Let a stand for either ρ or N. Under assumptions (CVX) on risk and (ENG) on preferences, the sign of dx^*/da is the sign of

$$\underbrace{\left.\frac{\partial \mathrm{MRR}}{\partial a}\right|_{x^*=cst}}_{\text{Risk avoidance effect } \geq 0} \quad \underbrace{-\frac{\partial \mathrm{MRS}_{sz}}{\partial s}\left.\frac{\partial s}{\partial a}\right|_{x^*=cst}}_{\text{Land sharing effect } \leq 0} \quad \underbrace{-\frac{\partial \mathrm{MRS}_{sz}}{\partial z}\left.\frac{\partial z}{\partial a}\right|_{x^*=cst}}_{\text{Income effect } \gtrless 0}, \tag{2.19}$$

as proved in Appendix 2.7.4. If ρ or N increases, the MRR increases: the agents that bear the growing cost of risk want to extend the red zone (risk avoidance effect). An increase of ρ or N modifies the MRS_{sz} through two components: an increase of N reduces the available space per head and so increases the households' demand for space (land sharing effect); it makes households richer or poorer, which changes their demand for land (income effect).

Second step. The risk avoidance effect depends on the nature of risk increase. $\partial \mathrm{MRR}/\partial \rho$ depends on λ_F (per head part of damage) and λ_S (per surface-unit part of damage). $\partial \mathrm{MRR}/\partial N$ is proportional to λ_F; therefore, if λ_F is negligible, the firm or the State is not willing to increase its bid on land.

The land sharing effect operates only as N increases and is straightforward.

The income effect varies between games. With natural risks, an increase of ρ makes households poorer, since they bear the cost of risk, and it reduces their demand for

land. On the contrary, an increase of N makes households more numerous to share the cost of risk. With industrial risks, households can benefit from an increase of risk because they extract rent from the firm: as renters, they certainly see higher rents but, as landowners, they become richer. In the market game, the net income effect is ambiguous.

Table 2.1 synthesizes the results.

Table 2.1: Comparative statics of x^* with respect to ρ and N

	Risk avoidance effect	Land sharing effect	Income effect	**Net impact on x^***
$a = \rho$				
Nat	+	0	+	↗
Firm	+	0	0	↗
Market	+	0	+ or −	↗ or ↘
Mayor	+	0	−	↗ or ↘
$a = N$				
Nat	+	−	−	↗ or ↘
Firm	+	−	+	↗ or ↘
Market	+	−	+ or −	↗ or ↘
Mayor	+	−	+	↗ or ↘

Proof: See Appendix 2.7.4.

Third step. An increase of ρ extends the red zone in the games where the agents that pay the cost of risk control the red zone, namely with natural risks or in the firm game. This is why, in these two games, the size of the red zone increases, as illustrated by the first two lines of Table 2.1. In the market game, if $\partial \text{MRS}_{sz}/\partial z$ is negligible, that is U is almost quasilinear (linear in z), the risk avoidance effect dominates the income effect. The firm's point of view prevails and the red zone extends as ρ increases. In the mayor game, if $\partial \text{MRR}/\partial \rho$ is negligible, the income effect dominates the risk avoidance effect. The households' point of view prevails and the red zone narrows down as ρ increases.

Let's consider an increase of N. With natural risks, if λ_F is negligible, the risk avoidance effect is dominated by the land sharing and income effects and the red

zone shrinks. In the market game, if λ_F and $\partial \mathrm{MRS}_{sz}/\partial z$ are negligible, then the land sharing effect dominates and the red zone is also reduced as N increases. In the firm game and in the mayor game, if $\partial \mathrm{MRS}_{sz}/\partial s$ is negligible, that is if U is almost quasilinear (linear in s), the red zone extends as N increases.

A calculable case. We consider a log-log utility function and linear loss probability, i.e.

$$U(z,s) = \log(z) + \alpha \log(s) \quad \text{and} \quad p(x) = \rho \cdot (\bar{x} - x). \tag{2.20}$$

The variations of the red zone with respect to ρ and N and their limits as these parameters tend to infinity are presented in Table 2.2 and proved in Appendix 2.7.5.

As ρ increases, the red zone extends in all games. Proposition 5 says that red zones are smaller when households are in a better position. This order is preserved as ρ tends to infinity. With natural risks and in the firm game, households are forced onto the crest as ρ tends to infinity. In the market and mayor games, households have more bargaining power and the inhabited zone narrows down to a "city sanctuary". See Figure 2.3.

As N increases, the red zone narrows down with natural risks, in the firm and market games. In the mayor game, the red zone is monotonic with respect to N, either increasing or decreasing. If λ_F is negligible, the firm is not willing to increase its bid on land and the red zone decreases in the mayor game; if λ_F is large, the red zone increases. In all games, if λ_F negligible, the red zone completely disappears as N tends to infinity; if λ_F is large, it tends to an ultimate "risk sanctuary". See Figure 2.3.

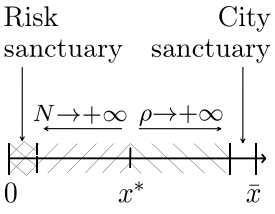


Figure 2.3: City and risk sanctuaries

Table 2.2: Comparative statics with respect to risk in the case of a log-log utility function and a linear loss probability

	Variations w.r.t. ρ	City sanctuary $\lim x^*$ as $\rho \to +\infty$	Variations w.r.t. N	Risk sanctuary $\lim x^*$ as $N \to +\infty$
x^*_{Nat}	$\nearrow$	$\bar{x}$	$\searrow$	$\max\left\{\bar{x} - \frac{2\alpha}{1+\alpha}\frac{\omega}{\rho\lambda_F}; 0\right\}$
x^*_{Firm}	$\nearrow$	$\bar{x}$	$\searrow$	$\max\left\{\bar{x} - \left(\frac{2\alpha\omega\bar{x}^\alpha}{\rho\lambda_F}\right)^{\frac{1}{1+\alpha}}; 0\right\}$
x^*_{Market}	$\nearrow$	$\frac{1}{1+\alpha}\bar{x}$	$\searrow$	$\max\left\{\frac{1}{1+\alpha}\bar{x} - \frac{2\alpha}{1+\alpha}\frac{\omega}{\rho\lambda_F}; 0\right\}$
x^*_{Mayor}	$\nearrow$	$\lim_{\rho\to+\infty} x^*_{\text{Mayor}} < \bar{x}$ (†)	monotonic ($\searrow$ or $\nearrow$)	$\max\left\{\frac{1}{1+\alpha}\bar{x} - \frac{2\alpha}{1+\alpha}\frac{\omega}{\rho\lambda_F}; 0\right\}$ or $\bar{x}\left(1 - \sqrt{\frac{\alpha}{2+\alpha}}\right)$ (‡)

(†) More precisely, $\lim_{\rho\to+\infty} x^*_{\text{Mayor}} = \bar{x} - \frac{(1+\alpha)}{2(2+\alpha)}\frac{\lambda_F N}{\lambda_S}\left(\sqrt{1 + 4\frac{\alpha(2+\alpha)}{(1+\alpha)^2}\frac{\lambda_S\bar{x}}{\lambda_F N}\left(\frac{\lambda_S\bar{x}}{\lambda_F N} + 1\right)} - 1\right)$.
(‡) If the size of the red zone increases with respect to N, the lower bound is not $\lim_{N\to+\infty} x^*_{\text{Mayor}} = \max\left\{\frac{1}{1+\alpha}\bar{x} - \frac{2\alpha}{1+\alpha}\frac{\omega}{\rho\lambda_F}; 0\right\}$ but $\lim_{N\to 0} x^*_{\text{Mayor}} = \bar{x}\left(1 - \sqrt{\frac{\alpha}{2+\alpha}}\right)$.
Proof: see Appendix 2.7.5.

2.6 Conclusion

For now, the increasing cost of natural disasters is largely explained by the growing urbanization of risky areas (see Introduction). However, in the future, it is presumed that climate change will increase the intensity and the frequency of natural hazards, as reiterated by the European Parliament (Anderson, 2006) and the Intergovernmental Panel of Climate Change (Schneider et al., 2007). For example, the Netherlands are particularly vulnerable to a rise in sea level since about 70% of properties lie below either the current sea level or the river water level (Kok et al., 2002). In 2008, anticipation of climate change effects led the Delta Committee to recommend several advances in water management, including land purchase along the major river areas.

Industrial hazards also evolve, not only because of technological advances, but also because of evolving natural hazards. Indeed, natural disasters can cause industrial ones. For example, in March 2011 an earthquake in Japan triggered a 33ft tsunami, which caused nuclear accidents in Fukushima. Other disasters are a combination of natural and industrial hazards, like the toxic mud floods caused by a tank failure in an aluminum plant in Hungary in October 2010. Natural and industrial

hazards can also mutually aggravate each other. For example, the increase of seismic activity due to the Three Gorges Dam in China, which was a subject of debate among scientists (Naik and Oster, 2009), is now officially recognized by Chinese authorities (Garric, 2011). Even past industrial accidents can worsen the consequences of natural disasters. In 2010, forest fires in Russia burned areas that were polluted after the 1986 Tchernobyl accident, recontaminating agricultural crops and local populations in 2010.

Our parallel analysis of natural and industrial disasters enables us to focus on the essential difference between natural and industrial disasters: implied liability. In practice, determining to what extent the liability of an industrialist is involved is an increasingly critical question for legislators, regulators and insurers. The case of Fukushima illustrates the importance of analysis on this question (Uranaka, 2011).

2.7 Appendices

2.7.1 Necessary conditions characterizing the equilibrium

All households are identical in terms of preferences and income and they are free to move. In equilibrium, U^* is the (unique) maximum utility that can be reached given the insurance tariff.

$$\forall x \in [x^*, \bar{x}], U^* = U\Big(\omega + \bar{r} - \pi_F(x) - s(x)[r(x) + \pi_S(x)], s(x)\Big). \tag{2.21}$$

Program (HH) leads to

$$\frac{\partial U/\partial s}{\partial U/\partial z} = r(x) + \pi_S(x). \tag{2.22}$$

We assume here that $p(\cdot)$ is differentiable to apply differential calculus. Let's apply the envelope theorem to the indirect utility function $V(x)$ where x is any optimal location choice:

$$\frac{dV}{dx} = 0 = -\frac{\partial U}{\partial z}\left[\frac{ds}{dx}\Big(r(x) + \pi_S(x)\Big) + s(x)\Big(\frac{dr}{dx} + \frac{\partial \pi_S}{\partial x}\Big) + \frac{\partial \pi_F}{\partial x}\right] + \frac{\partial U}{\partial s}\frac{ds}{dx}.$$

Thanks to (2.22) and since $\partial U/\partial z \neq 0$, we finally get

$$s(x)\Big(\frac{dr}{dx} + \frac{\partial \pi_S}{\partial x}\Big) + \frac{\partial \pi_F}{\partial x} = 0. \tag{2.23}$$

In equilibrium, a marginal reduction in rent is balanced by the marginal increase of insurance price. This expresses the tradeoff between land consumption and insurance expenditures.

Therefore an equilibrium satisfies the following necessary conditions: (2.21), (2.22), (2.23), (LOC), (ND or ID) and (POP).

2.7.2 Proof of Proposition 1: efficiency of actuarial insurance

Let U_A^* denote the utility attained in the actuarial-insurance equilibrium. Following Fujita and Thisse (2002), we prove that the actuarial-insurance equilibrium is efficient by showing that it minimizes the social cost of achieving U_A^*.

For any allocation achieving utility U_A^*, $(n(x), z(x), s(x); x' \leq x \leq \bar{x})$ where x' delimits the inhabited area, the social cost for a household at x to enjoy utility U_A^* is the sum of the quantity of money $Z(s(x), U_A^*)$ such that $U(Z(s(x), U_A^*), s(x)) = U_A^*$ and of the cost of risk $p(x)(\lambda_F + \lambda_S\ s(x))$. Thus, we want to show that the actuarial insurance equilibrium allocation is a solution of the following program:

$$\min_{x', n(\cdot), s(\cdot)} \int_{x'}^{\bar{x}} [Z(s(x), U_A^*) + p(x)\ (\lambda_F + \lambda_S\ s(x))] n(x) dx \tag{2.24}$$

$$\text{s.t.} \begin{cases} \int_{x'}^{\bar{x}} n(x) dx = N, \\ \forall x \in [x'; \bar{x}],\ n(x)s(x) = 1. \end{cases} \tag{2.25}$$

Basic rearrangement gives the equivalent maximization program

$$\max_{x', s(\cdot)} \int_{x'}^{\bar{x}} \frac{\omega + \bar{r}_A - Z(s(x), U_A^*) - p(x)\ (\lambda_F + \lambda_S\ s(x))}{s(x)} dx, \tag{2.26}$$

$$\text{s.t.} \int_{x'}^{\bar{x}} \frac{1}{s(x)} dx = N, \tag{2.27}$$

where $\bar{r}_A$ is the redistributed rent in the actuarial insurance equilibrium.

We first neglect the constraint 2.27. We denote

$$\psi(x, s, U_A^*) = \frac{\omega + \bar{r}_A - Z(s, U_A^*) - p(x)\ (\lambda_F + \lambda_S\ s)}{s}, \tag{2.28}$$

$$\Psi(x, U_A^*) = \max_s \psi(x, s, U_A^*). \tag{2.29}$$

The program 2.26 corresponds to

$$\max_{x',s(\cdot)} \int_{x'}^{\bar{x}} \psi(x,s,U_A^*)dx = \max_{x'} \int_{x'}^{\bar{x}} \Psi(x,U_A^*)dx. \tag{2.30}$$

As the maximum operator and $\psi(\cdot,s,U_A^*)$ increase (as $p(\cdot)$ decreases), by composition $\Psi(\cdot,U_A^*)$ increases as well. We denote x^* the highest value such that $\Psi(x^*,U_A^*)=0$ if it exists in $[0;\bar{x}]$ and $x^*=0$ otherwise. Once the objective is maximized with respect to s, one efficient value of x' is x^*.

It is straightforward that the actuarial-insurance equilibrium allocation is a solution of this rearranged program: at each $x \geq x'$, $\Psi(x,U_A^*)$ can be interpreted as the bid rent given the proposition to settle at x with a surface s and to pay the actuarial premium $p(x)\,(\lambda_F+\lambda_S\,s)$; x^* can be interpreted as the most exposed inhabited area in the actuarial insurance equilibrium.

Finally, we know that the actuarial-insurance equilibrium allocation satisfies the constraint 2.27. Consequently, the actuarial-insurance equilibrium is efficient.

2.7.3 Part of proof of Proposition 4: existence of the market equilibrium

The proof of the existence of a market equilibrium is quite easy. The demand for land of the firm $x(r)$ only depends on the rent. The demand of a household is $s_d\left(w+\frac{rx(r)}{N},r\right)$ where the first argument is the income and the second is the price.

Finding an equilibrium amounts to finding a root r to the equation

$$Ns_d\left(w+\frac{rx(r)}{N},r\right)+x(r)=\bar{x}.$$

The LHS will be denoted $D(r)$ henceforth.

Remark that $D(\cdot)$ is continuous over $\mathbb{R}$: $x(r)$ is continuous because $\mathrm{CR}(\cdot)$ is convex, which implies in turn that the households experience continuous variations of their income and of the price as r increases. Their total demand for land is therefore

also continuous with respect to r.

For r very close to 0, the households have an unbounded demand for land, meaning that $D(0^+)$ overtakes $\bar{x}$. For very high r, the rent paid by the firm is bounded, as it would never pay more than CR(0). This proves that households keep a bounded income when the price of land explodes: their demand goes to 0 and $D(r)$ is below $\bar{x}$.

We now use the intermediate value theorem: the previous two paragraphs establish that there is a finite $r > 0$ such that $D(r) = \bar{x}$, which implies in turn that a market equilibrium exists. Note that uniqueness is not warranted.

2.7.4 Proof of Equation 2.19 and Table 2.1: comparative statics

We compute the comparative statics of x^*. In the equations below, a stands for ρ or N to economize typing.

For a given red zone x, $\hat{s}(x,a) = \frac{\bar{x}-x}{N}$, and $\hat{z}(x,a) = \omega + \frac{T(x,a)}{N}$ where

$$T(x,a) = \begin{cases} -\mathrm{CR}(x) & \text{(Nat)} \quad (2.31) \\ T & \text{(Firm) } T \text{ s.t. } U\left(\omega + \frac{T}{N}, \frac{\bar{x}-x}{N}\right) = U\left(\omega, \frac{\bar{x}}{N}\right) \quad (2.32) \\ rx & \text{(Market) } r = \mathrm{MRS}_{sz}\left(\omega + \frac{rx}{N}, \frac{\bar{x}-x}{N}\right), \quad (2.33) \\ \mathrm{CR}(0) - \mathrm{CR}(x) & \text{(Mayor).} \quad (2.34) \end{cases}$$

As stated by (2.8) and (2.13) for interior solutions, the red zones $x^* \in (0, \bar{x})$ are characterized by the equality between the marginal risk reduction (MRR) and the marginal rate of substitution (MRS_{sz}) of households.

$$\hat{\mathrm{MRR}}(x^*, a) = \mathrm{MRS}_{sz}\left(\hat{z}(x^*, a), \hat{s}(x^*, a)\right). \quad (2.35)$$

By derivation of (2.35) with respect to a, we get

$$\left(\frac{\partial \hat{\mathrm{MRR}}}{\partial x}\frac{dx^*}{da} + \frac{\partial \hat{\mathrm{MRR}}}{\partial a}\right) = \frac{\partial \mathrm{MRS}_{sz}}{\partial z}\frac{d\hat{z}}{da} + \frac{\partial \mathrm{MRS}_{sz}}{\partial s}\frac{d\hat{s}}{da}. \quad (2.36)$$

As

$$\frac{d\hat{z}}{da} = \frac{\partial \hat{z}}{\partial a} + \frac{\partial \hat{z}}{\partial x}\frac{dx^*}{da}, \tag{2.37}$$

$$\frac{d\hat{s}}{da} = \frac{\partial \hat{s}}{\partial a} + \frac{\partial \hat{s}}{\partial x}\frac{dx^*}{da}, \tag{2.38}$$

we get

$$\frac{dx^*}{da}\left(\frac{\partial \hat{\mathrm{MRR}}}{\partial x} - \frac{\partial \mathrm{MRS}_{sz}}{\partial z}\frac{\partial \hat{z}}{\partial x} - \frac{\partial \mathrm{MRS}_{sz}}{\partial s}\frac{\partial \hat{s}}{\partial x}\right) = -\frac{\partial \hat{\mathrm{MRR}}}{\partial a} + \frac{\partial \mathrm{MRS}_{sz}}{\partial z}\frac{\partial \hat{z}}{\partial a} + \frac{\partial \mathrm{MRS}_{sz}}{\partial s}\frac{\partial \hat{s}}{\partial a}. \tag{2.39}$$

With natural risks, in the firm and mayor games. Remark that $\partial \hat{z}/\partial x > 0$. As $\partial \hat{s}/\partial x = -1/N < 0$ and thanks to technical assumptions (CVX) and (ENG), the factor of dx^*/da in (2.39) above is negative. Therefore the sign of dx^*/da is the sign of

$$\frac{\partial \hat{\mathrm{MRR}}}{\partial a} - \underbrace{\frac{\partial \mathrm{MRS}_{sz}}{\partial z}}_{\geq 0}\frac{\partial \hat{z}}{\partial a} - \underbrace{\frac{\partial \mathrm{MRS}_{sz}}{\partial s}}_{\leq 0}\frac{\partial \hat{s}}{\partial a}.$$

The signs of $\partial \hat{\mathrm{MRR}}/\partial a$, $\partial \hat{z}/\partial a$ and $\partial \hat{s}/\partial a$ are given in Table 2.3. Note that $\partial \hat{z}/\partial a$ depends on the game considered.

Table 2.3: Derivatives of $\hat{\mathrm{MRR}}$, $\hat{z}$ and $\hat{s}$ with respect to ρ and N

All games	$\frac{\partial \hat{\mathrm{MRR}}}{\partial \rho} = \frac{\hat{\mathrm{MRR}}}{\rho}$	> 0	$\frac{\partial \hat{\mathrm{MRR}}}{\partial N} = \frac{\lambda_F}{\bar{x}-x^*}\left(p(x^*) - \frac{\int_{x^*}^{\bar{x}} p(t)dt}{\bar{x}-x^*}\right)$	≥ 0
All games	$\frac{\partial \hat{s}}{\partial \rho} = 0$	$= 0$	$\frac{\partial \hat{s}}{\partial N} = -\frac{\bar{x}-x^*}{N^2}$	< 0
Nat	$\frac{\partial \hat{z}}{\partial \rho} = -\frac{\mathrm{CR}(x^*)}{N\rho}$	< 0	$\frac{\partial \hat{z}}{\partial N} = \frac{\lambda_S}{N^2}\rho\int_{x^*}^{\bar{x}} f(t)dt$	> 0
Firm	$\frac{\partial \hat{z}}{\partial \rho} = 0$	$= 0$	$\frac{\partial \hat{z}}{\partial N} = -\frac{x^*}{N^2}\frac{U_s}{U_z}$	< 0
Mayor	$\frac{\partial \hat{z}}{\partial \rho} = \frac{\mathrm{CR}(0)-\mathrm{CR}(x^*)}{N\rho}$	> 0	$\frac{\partial \hat{z}}{\partial N} = -\frac{\lambda_S}{N^2}\rho\int_0^{x^*} f(t)dt$	< 0

In the market game. (2.39) cannot be directly used: the sign of $\partial \hat{z}/\partial x$ cannot be straightforwardly computed, as the rent r is endogenous.

By derivation of $\hat{\mathrm{MRR}} = r$ and $\mathrm{MRS}_{sz} = r$ with respect to ρ or N, we get

ambiguous expressions (available upon request).

2.7.5 Proof of Table 2.2

In the case of a log-log utility function and a linear loss probability, i.e.

$$U(z,s) = \log(z) + \alpha \log(s) \quad \text{and} \quad p(x) = \rho \cdot (\bar{x} - x), \tag{2.40}$$

we can compute some of the red zones, their variations with respect to ρ and N and their limits (the sanctuaries) as these parameters tend to infinity.

Lemma 1 (Comparative statics of the size of the red zone)**.** *Let us consider the LHS and RHS of an equation defining x^*. We assume that LHS decreases with respect to x^* and that RHS increases with respect to x^*. LHS and RHS both depend on a parameter k.*

$$LHS(x^*, k) = RHS(x^*, k). \tag{2.41}$$

(i) If LHS increases or is constant with respect to k and RHS decreases or is constant with respect to k, then x^* increases with respect to k.

(ii) If LHS decreases or is constant with respect to k and RHS increases or is constant with respect to k, then x^* decreases with respect to k.

With natural risks, the first order condition characterizing the interior solution

$$\mathrm{MRR}(x^*) = \mathrm{MRS}_{s/z}\left(\omega - \frac{\mathrm{CR}(x^*)}{N}, \frac{\bar{x} - x^*}{N}\right), \tag{2.42}$$

becomes

$$\frac{\rho\lambda_F N}{2} + \rho\lambda_S(\bar{x} - x^*_{\mathrm{Nat}}) = \frac{\alpha N}{\bar{x} - x^*_{\mathrm{Nat}}}\left(\omega - \frac{\rho\lambda_F}{2}(\bar{x} - x^*_{\mathrm{Nat}}) - \frac{\rho\lambda_S}{2N}(\bar{x} - x^*_{\mathrm{Nat}})^2\right). \tag{2.43}$$

Case (i) of Lemma 1 applies and x^*_{Nat} increases with respect to ρ. Dividing (2.43) by N enables to apply case (ii) of Lemma 1 and to conclude that x^*_{Nat} decreases with respect to N. The red zone is

$$x^*_{\mathrm{Nat}} = \bar{x} - \frac{(1+\alpha)}{2(2+\alpha)}\frac{\lambda_F N}{\lambda_S}\left(\sqrt{1 + 8\frac{(2+\alpha)}{(1+\alpha)^2}\frac{\lambda_S \alpha\omega}{\lambda_F^2 N\rho}} - 1\right). \tag{2.44}$$

There is no city sanctuary and a non trivial risk sanctuary.

$$\lim_{\rho \to +\infty} x^*_{\text{Nat}} = \bar{x}, \tag{2.45}$$

$$\lim_{N \to +\infty} x^*_{\text{Nat}} = \max \left\{ \bar{x} - \frac{2\alpha}{1+\alpha} \frac{\omega}{\rho \lambda_F}; 0 \right\}. \tag{2.46}$$

In the firm game, the first order condition characterizing the interior solution

$$\text{MRR}(x^*) = \text{MRS}_{s/z} \left(\omega + \frac{Nt}{N}, \frac{\bar{x} - x^*}{N} \right), \tag{2.47}$$

where t is defined by

$$\log \left(\omega + t, \frac{\bar{x} - x^*}{N} \right) = \log \left(\omega, \frac{\bar{x}}{N} \right), \tag{2.48}$$

becomes

$$\frac{\rho \lambda_F N}{2} + \rho \lambda_S (\bar{x} - x^*_{\text{Firm}}) = \frac{\alpha \omega N \bar{x}^\alpha}{(\bar{x} - x^*_{\text{Firm}})^{1+\alpha}}. \tag{2.49}$$

Case (i) of Lemma 1 applies and x^*_{Firm} increases with respect to ρ. Dividing (2.49) by N enables to apply case (ii) of Lemma 1 and to conclude that x^*_{Firm} decreases with respect to N. There is no city sanctuary and a non trivial risk sanctuary.

$$\lim_{\rho \to +\infty} x^*_{\text{Firm}} = \bar{x}, \tag{2.50}$$

$$\lim_{N \to +\infty} x^*_{\text{Firm}} = \max \left\{ \bar{x} - \left(\frac{2\alpha\omega\bar{x}^\alpha}{\rho \lambda_F} \right)^{\frac{1}{1+\alpha}}; 0 \right\}. \tag{2.51}$$

In the market game, the first order condition characterizing the interior solution

$$\text{MRR}(x^*) = \text{MRS}_{s/z} \left(\omega + \frac{rx^*}{N}, \frac{\bar{x} - x^*}{N} \right), \tag{2.52}$$

becomes

$$\frac{\rho \lambda_F N}{2} + \rho \lambda_S (\bar{x} - x^*_{\text{Market}}) = \frac{\alpha \omega N}{\bar{x} - (1+\alpha) x^*_{\text{Market}}}. \tag{2.53}$$

Households being the owners of the land, the price of land partly defines their

income ($z = \omega + \frac{rx^*}{N}$) and their expenditures. Here, the rent increases with respect to the size of the red zone. Given that the rent increases with respect to the size of the red zone, the MRS increases with respect to x^*. Using case (i) of Lemma 1, we conclude that x^*_{Market} increases with respect to ρ. Dividing (2.53) by N enables to apply case (ii) of Lemma 1: x^*_{Market} decreases so with respect to N.

The red zone is

$$x^*_{\text{Market}} = \frac{1}{1+\alpha}\frac{\bar{x}}{2}\left[2+\alpha-\alpha\sqrt{1+\frac{\alpha}{1+\alpha}\frac{\omega N}{\rho\lambda_S(\frac{\alpha}{1+\alpha}\frac{\bar{x}}{2}+\frac{\lambda_F}{\lambda_S}\frac{N}{4})^2}}\right] + \frac{\lambda_F}{\lambda_S}\frac{N}{4}\left[1-\sqrt{1+\frac{\alpha}{1+\alpha}\frac{\omega N}{\rho\lambda_S(\frac{\alpha}{1+\alpha}\frac{\bar{x}}{2}+\frac{\lambda_F}{\lambda_S}\frac{N}{4})^2}}\right]. \tag{2.54}$$

The city and risk sanctuaries are

$$\lim_{\rho\to+\infty} x^*_{\text{Market}} = \frac{1}{1+\alpha}\bar{x}, \tag{2.55}$$

$$\lim_{N\to+\infty} x^*_{\text{Market}} \max\left\{\frac{1}{1+\alpha}\bar{x} - \frac{\alpha}{1+\alpha}\frac{2\omega}{\rho\lambda_F}; 0\right\}. \tag{2.56}$$

In the mayor game, the first order condition characterizing the interior solution

$$\text{MRR}(x^*) = \text{MRS}_{s/z}\left(\omega + \frac{\text{CR}(0)-\text{CR}(x^*)}{N}, \frac{\bar{x}-x^*}{N}\right), \tag{2.57}$$

becomes

$$\frac{\rho\lambda_F N}{2} + \rho\lambda_S(\bar{x}-x^*_{\text{Mayor}}) = \frac{\alpha N}{\bar{x}-x^*_{\text{Mayor}}}\left(\omega + \frac{\rho\lambda_F}{2}x^*_{\text{Mayor}} + \frac{\rho\lambda_S}{2N}x^*_{\text{Mayor}}(2\bar{x}-x^*_{\text{Mayor}})\right). \tag{2.58}$$

Dividing (2.58) by ρ enables to apply case (i) of Lemma 1 and to conclude that x^*_{Mayor} increases with respect to ρ. The red zone is

$$x^*_{\text{Mayor}} = \bar{x} - \frac{(1+\alpha)}{2(2+\alpha)}\frac{\lambda_F N}{\lambda_S}\left(\sqrt{1+8\frac{(2+\alpha)}{(1+\alpha)^2}\frac{\lambda_S\alpha}{\lambda_F^2 N\rho}\left(\omega+\frac{\rho\lambda_S}{2N}\bar{x}^2+\frac{\rho\lambda_F}{2}\bar{x}\right)}-1\right). \tag{2.59}$$

x^*_{Mayor} is monotonic with respect to N. Let us denote

$$C(\underbrace{\alpha}_{+},\underbrace{\omega}_{+},\underbrace{\rho\lambda_F}_{-}) = \frac{(2+\alpha)\alpha}{(1+\alpha)^2}\left(\frac{2\omega}{\rho\lambda_F}+\bar{x}\right)^2. \tag{2.60}$$

If $C(\alpha,\omega,\rho\lambda_F) \geq 1$, then the size of the red zone decreases with respect to N; if $C(\alpha,\omega,\rho\lambda_F) < 1$, then the red zone strictly increases with respect to N.

There is a city sanctuary. The risk sanctuary can be either $\lim\limits_{N\to+\infty} x^*_{\text{Mayor}}$ or $\lim\limits_{N\to 0} x^*_{\text{Mayor}}$.

$$\lim_{\rho\to+\infty} x^*_{\text{Mayor}} = \bar{x} - \frac{(1+\alpha)}{2(2+\alpha)}\frac{\lambda_F N}{\lambda_S}\left(\sqrt{1+4\frac{\alpha(2+\alpha)}{(1+\alpha)^2}\frac{\lambda_S\bar{x}}{\lambda_F N}\left(\frac{\lambda_S\bar{x}}{\lambda_F N}+1\right)}-1\right), \tag{2.61}$$

$$\lim_{N\to+\infty} x^*_{\text{Mayor}} = \max\left\{\frac{1}{1+\alpha}\bar{x} - \frac{\alpha}{1+\alpha}\frac{2\omega}{\rho\lambda_F}; 0\right\}, \tag{2.62}$$

$$\lim_{N\to 0} x^*_{\text{Mayor}} = \bar{x}\left(1-\sqrt{\frac{\alpha}{2+\alpha}}\right). \tag{2.63}$$

Chapter 3

The Flood Issue: Uniform Insurance and Collective Prevention with Risk Externalities

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This chapter is cowritten with Sabine Lemoyne de Forges (Ecole Polytechnique and AgroParisTech).

Abstract

Prevention policies against flood, such as dams or levees, are commonly designed by local jurisdictions. They exert externalities on neighboring jurisdictions. The choice of collective prevention measures depends on the insurance system that covers individuals. As uniform insurance depends on all insureds' risk, it enables a partial integration of prevention externalities by jurisdictions. We determine under which conditions uniform insurance Pareto dominates actuarial insurance. Central government can use tools based on household insurance to coordinate local collective prevention measures. Under uniform insurance, we show that limiting insurance coverage creates incentives for self-protection but none for self-insurance.

Keywords: insurance, prevention, externalities, flood

JEL classification: D62, H23, Q54

Résumé long

Ce chapitre étudie l'exemple des inondations et l'impact de l'assurance individuelle sur la prévention collective réalisée par les communes. Ces mesures de prévention (digues, barrages, bassins de rétention) génèrent d'importantes externalités sur les communes voisines. La couverture des habitants contre les inondations peut correspondre à une tarification actuarielle, comme aux Etats-Unis, ou uniforme, comme en France ou en Espagne. L'assurance uniforme est cependant comprise dans une acception large qui inclut les mécanismes d'aides publiques. D'autres pays (Italie, Corée) ont en effet organisé des fonds alimentés par des taxes forfaitaires pour couvrir les ménages contre les inondations.

Pour analyser l'exposition aux inondations, ce chapitre présente un modèle adapté à cette question : il suppose des externalités asymétriques de prévention et des risques corrélés au sein de chaque commune et s'intéresse spécifiquement à l'assurance uniforme répandue dans de nombreux pays. Les spécifications d'autres papiers théoriques étant adaptées à des questions génériques ou à d'autres risques, cette structure théorique n'a pas d'équivalent dans la littérature de l'assurance ou du fédéralisme fiscal.

Comme l'assurance uniforme dépend des risques de tous les assurés, elle permet d'intégrer partiellement ces externalités. Le premier résultat de ce chapitre illustre la théorie générale du second best de Lipsey et Lancaster (1956-1957) : il montre qu'en présence de faibles externalités, l'assurance actuarielle Pareto domine l'assurance uniforme ; au contraire, en présence de fortes externalités, il peut être préférable de mettre en place une assurance uniforme.

Sous assurance uniforme et en information symétrique, ce chapitre précise ensuite dans quelle mesure le gouvernement central peut coordonner les mesures de prévention collective à l'aide d'une modulation de prime ou d'une limitation de la couverture assurantielle. Sous assurance complète, une modulation de primes est équivalente à un système fiscal incitatif et peut donc correspondre à une taxe Pigouvienne qui permettrait d'intégrer les externalités et d'implémenter les niveaux de prévention optimaux. L'impact de l'introduction d'une franchise dépend du type de prévention réalisée : si la prévention diminue le montant de la perte sans en changer la probabilité (*self-insurance* au sens de Ehrlich et Becker (1972)), alors cette politique est sans effet sur les niveaux de prévention et de bien-être ; si au contraire la prévention diminue la probabilité de la perte sans changer le montant de la perte (*self-protection*), alors l'introduction d'une franchise augmente les niveaux de prévention et peut augmenter le bien-être des habitants.

3.1 Introduction

Risk management embraces multiple dimensions from engineering to public policy. From an economic perspective, two important aspects interact: the prevention that defines risk exposure and the financial coverage of homeowners and assets. This chapter analyzes flood prevention choices by jurisdictions when these prevention measures exert externalities on neighboring jurisdictions and when household insurance is available, especially uniform insurance. Indeed, such assumptions are adapted to flood coverage study as most flood collective prevention measures (dams, levees, retention basins) exert positive or negative externalities on neighboring jurisdictions (Lünenbürger, 2006), and as, in many countries, flood coverage is based on uniform contributions via insurance or other redistributive systems. Thus studying flood exposure leads to an original theoretical structure.

Our model is based on a simple framework of two jurisdictions, one upstream and one downstream. The upstream jurisdiction, when protecting itself, may exert positive or negative externalities on the downstream one. Each jurisdiction is composed of identical agents exposed to the same completely correlated risk and can realize prevention measures to reduce the risk exposure of all its inhabitants. Information is symmetric and the timing is the following one. Household insurance scheme is initially fixed: it is either a competitive insurance market or a uniform state insurance. Then, the two jurisdictions choose their prevention levels.

Intuitively, prevention choices by jurisdictions depend on the insurance system that covers their inhabitants. As uniform insurance depends on all insureds' risk, it enables a partial integration of prevention externalities by jurisdictions. On the contrary, actuarial insurance reflects inhabitants' own risk. We show that, when the burden of prevention externalities is important, uniform insurance Pareto dominates a competitive insurance market. Note that the burden of prevention externalities results not only from the physical magnitude of prevention externalities but also from the size of the downstream population subject to this physical phenomenon. This illustrates the general theory of second best formalized by Lipsey and Lancaster (1956-1957): "it is not true that a situation in which more,

but not all, of the optimum conditions are fulfilled is necessarily, or is even likely to be, superior to a situation in which fewer are fulfilled". Actuarial insurance corresponds to the first best policy in the absence of externalities (as in Chapter 2), but can be Pareto dominated by uniform insurance in the presence of externalities.

We then determine how central government can use tools based on household insurance to coordinate local collective prevention measures. Under full insurance, incentives through household insurance premium are equivalent to tax incentives for jurisdictions; thus, a Pigouvian premium can lead to the optimal prevention levels. All the precedent results are valid whether prevention decreases either the flood probability or the potential loss, because under full insurance only the expected value of loss matters. When considering the introduction of a deductible in the case of uniform insurance, the impact of this policy depends on the prevention technology. We show that limiting insurance coverage creates incentives for collective prevention if the prevention technology decreases the flood probability (self-protection in the sense of Ehrlich and Becker (1972)), but not if it decreases the damages caused by a flood (self-insurance in the sense of Ehrlich and Becker (1972)).

We know detail and illustrate the specificities of flood risk and why the set of assumptions used by other papers studying prevention are not suited to flood risk analysis.

The flood issue. This chapter contributes to analyzing a practical problem that is flood exposure. Floodplains, deltas, and coastal areas development has historically been driven by the hydraulic works as observed on the Mississippi, Rhine, Nile or Mekong rivers. Dams, levees, elevations or polders were either designed to expand the territories available for development, to get water storage for dry seasons, or to simply protect from floods or submersion (Fanchette, 2006). On rivers and deltas, flood protection works that are built can have important impacts on the flood exposure of other areas alongside the water. Indeed, dams and levees built by a jurisdiction create positive or negative externalities on its neighbors, upstream or downstream, during the normal course of their operations (Tobin, 2007). A dam built by an upstream jurisdiction protects the downstream ones from

flooding. On the contrary, an upstream levee increases the downstream flow. In the event of dam or levee failures, negative externalities are exerted downstream as a failure causes a large increase in velocity and flow rate. The Three-Gorges Dam in China is a typical example: it changed the whole hydraulic of the Yangtse river in its regular regime downstream as well as upstream, and in case of flood it provides a regulation of flows very different from what was in place beforehand (Zhu and Rong, 2010). More generally, land use choices are an important part of floodplain management and may change the exposure of areas along the river. For instance, waterproofing with no proper dimensioning of water evacuation can create negative externalities, as recalled by the 2010 flash floods and mudslides in Madeira. The existence of such externalities pleads for the coordination of prevention policies.

Risk managers, and particularly engineers, have known for a long time the importance of integrating collective prevention externalities when designing flood control systems. Some examples reveal strong efforts by central government to coordinate local prevention policies and reduce negative prevention externalities this way. In the Netherlands, construction and maintenance of "polders" have been performed by the "waterschappen" (local water communities) since the 18th century. Because of the numerous legal disagreements between polders due to their induced negative externalities - typically soil removed to strengthen levees -, the "waterstaat" (central water administration) was created in 1798 to coordinate all these local activities. Other examples illustrate efforts by central government to compensate neighboring inhabitants for suffering negative prevention externalities. In France, some projects include initial compensation to neighboring inhabitants for disturbance, loss of real estate value and also the determination of ex post compensation for flooding.[1]

However, in most cases, central government faces important difficulties in coordinating local prevention measures. In the case of the 1993 Missouri floods, some landowners had built higher levees than authorized to protect their crops. Therefore they put other developed land nearby at risk (Rasmussen, 1999). Indeed, in practice central government can rarely enforce prevention constraints

[1] An example is the dynamic reduction in flooding of the Meuse at Mouzon in France (Chambre d'Agriculture des Ardennes, 2006).

on jurisdictions. Even if legal sanctions exist, these may not have the desired preventive effect on jurisdictions. For example, in the United States, states can be sued if protection measures are not implemented: "the Legislature approved $500 million in settlements of claims in 2005 for failed levees in the 1986 and 1997 floods" against the state of California (California Hearing, 2005).

Central government is concerned by collective prevention not only because of civil security but also because it takes in charge the compensation in case of natural disasters for individuals and jurisdictions (via insurance coverage, financial aids, conditional loans and/or urgency disaster rescue). In many countries, flood coverage is based on uniform contribution. Some countries such as France or Spain have set up bundled uniform insurance for natural disasters.[2] Many other countries have designed redistributive systems that are similar to uniform insurance. In Italy or Korea, compensation for floods is based on public assistance; in Australia, Canada, Germany or in the Netherlands, public funds coexist with private flood insurance and provide important compensation because insurance penetration rate is low (Dumas et al., 2005).[3]

During the last decades, some countries have set up public policies linking collective prevention and individual insurance to give higher incentives for flood collective prevention(Kunreuther, 2000). For example, in the United States, in the framework of the National Flood Insurance Program, insured households receive a rebate on their premium depending on prevention measures taken by their jurisdiction (Burby, 2001).[4] In France, if a jurisdiction has been touched by several floods and if no risk prevention plan has been undertaken by the jurisdiction, inhabitants' insurance deductibles are significantly increased (Dumas et al., 2005).

[2]In France and Spain, insurance against natural disasters is a mandatory guarantee of classical home insurance. In France, the State provides its unlimited guarantee to the natural disasters insurance system via the Caisse Centrale de Réassurance and regulates the price of natural disasters insurance. In Spain, insurance against natural disasters is provided by the Consorcio de Compensación de Seguros.

[3]In Germany, for example, less than 10% of households have purchased flood insurance (Bouwer et al., 2007) and public aid to households and businesses reached Bn€ 1.7 following the Elbe floods in 2002 (Dumas et al., 2005).

[4]In the United States, flood insurance is actuarial with subvention of specific risks.

For all these reasons, we focus on collective prevention with risk externalities and uniform insurance to study flood exposure.

Related literature. To better understand theoretically the link between flood prevention and coverage policies at the jurisdictional level, we were naturally driven to consider specific assumptions: asymmetric prevention externalities, risk correlation within one jurisdiction. We were especially interested in scrutinizing the uniform insurance case given the policies in place in many countries. As underlined by Lipsey and Lancaster (1956-1957), an adequate and specific model is required to assess and compare second best policies. The specifications of other papers that study prevention are adapted to generic issues or to other risks; they cannot be transposed to the analysis of our subject: flood prevention and coverage.

Some generic models study incentive tools for individual prevention with risk externalities and consider actuarial insurance. Hofmann (2007) analyzes agents with interdependent risks and investigates the case of a benevolent monopolist insurer. She shows that under actuarial insurance with imperfect information, the insurer can reach the social optimum by engaging in price discrimination as it reduces the cost of risk selection. Muermann and Kunreuther (2008) consider actuarial insurance and positive externalities; they show the under-investment in self-protection in the absence of coordination among the individuals. They point out that limited insurance coverage either through deductible or "at-fault" insurance can improve welfare.

The study of specific risks has lead to different assumptions that also consider actuarial insurance. Lakdawalla and Zanjani (2005) address the specific case of terrorism, where self-protection induces negative externalities as risk terrorists will switch to more vulnerable targets. The authors consider actuarial insurance with a loading factor and asymmetric information. They show that government subsidies for terror insurance limit self-protection. Lohse et al. (2010) analyze local public goods providing self-protection or self-insurance and targeting uncorrelated risks. They consider actuarial insurance and show that the availability of market insurance reduces the provision level of the public good for both public

and private provision. In the fiscal federalism literature, Persson and Tabellini (1996) analyze the tradeoff between federal risk sharing and moral hazard under asymmetric information; they do not consider risk correlation between local entities.

Most natural disasters do not imply prevention externalities. Picard (2008) compares actuarial and uniform insurance against natural disasters in the absence of externalities. He illustrates the equity-efficiency tradeoff for the coverage of natural disasters: incentives to individual prevention through insurance create strong inequalities between individuals with different risk types and prevention costs, but actuarial insurance combined with tax-transfers overcomes this tradeoff. Latruffe and Picard (2005) had considered limiting coverage as an incentive for prevention. Under uniform insurance, in the absence of risk externalities and while considering self-protection, they show that if the proportion of high risks is sufficiently large, there exists a level of deductible such that introducing a deductible for high risk inhabitants Pareto dominates full uniform insurance.

Flood coverage has been specifically studied by Lünenbürger (2006). The author considers flood collective prevention as public goods with unidirectional spillovers. He assumes that each jurisdiction bears its expected loss, due to its own flood exposure and to externalities exerted by its neighbors: in other words, he considers actuarial insurance. His focus is the supply of flood prevention as the outcome of voting procedure and he compares different federal settings.

This chapter is organized as follows. Section 3.2 lays out the model assumptions. Section 3.3 derives the comparison between actuarial and uniform insurance systems. Section 3.4 analyzes insurance incentives tools for prevention. Section 3.5 concludes.

3.2 The model

Jurisdictions. We consider a watershed composed of two jurisdictions 1 and 2 located next to a river and a central government. Jurisdiction 1 is upstream; jurisdiction 2 is downstream. The jurisdictions respectively consist of a population of

N_1 individuals and of N_2 individuals. All individuals are identical. We denote

$$N_2 = \eta N_1. \tag{3.1}$$

We denote W_j the total wealth in jurisdiction j, $j \in \{1, 2\}$, and w_j the individual wealth of an inhabitant of jurisdiction j:

$$W_j = N_j w_j. \tag{3.2}$$

Each jurisdiction can organize wealth redistribution between its inhabitants. Similarly, central government can organize wealth redistribution between jurisdictions and implement it via transfers $(T_j)_{j\in\{1,2\}}$. Therefore, here, we do analyze inequalities or redistribution effects neither inside jurisdictions nor between them.

Individual preferences. Preferences of the inhabitants in jurisdiction j are described by a common utility function $u(x_j)$ where x_j is the private good consumption. We assume that individuals are risk averse and therefore that $u(\cdot)$ is increasing and concave.

Flood risk. Each individual has an income I and is exposed to a loss L.[5] We assume that flood risks are perfectly correlated within a jurisdiction: one flood may damage all inhabitants in a jurisdiction or nobody. However, when a flood occurs next to the river, each jurisdiction may be flooded or not depending on its prevention level. We assume that the initial loss probability is the same for both jurisdictions and we denote this common probability by p^0.

Flood collective prevention. Each jurisdiction can reduce its expected loss by implementing preventive or protective measures, henceforth called prevention, to reduce the risk exposure for all its inhabitants. Flood collective prevention is so a local public good, since it modifies risk exposure of neighboring inhabitants in a nonrival and nonexcludable way.

We denote a_j as the prevention level, $0 \leq a_j \leq 1$. It has a cost denoted by $C_j(a_j)$

[5] Considering different losses among individuals within a jurisdiction and allowing transfers between them would only change the results under partial insurance.

which is assumed to be quadratic:

$$C_1(a_1) = \frac{c_1}{2}a_1^2, \quad c_1 > 0, \tag{3.3}$$

$$C_2(a_2) = \frac{c_2}{2}a_2^2, \quad c_2 > 0. \tag{3.4}$$

Prevention is funded at the jurisdictional level by lump sum local taxes: collective prevention benefits to all inhabitants of the jurisdiction and is equally funded by each of them.[6]

We abstract from consideration of voting procedure to choose prevention within a jurisdiction, as it is the case in Lünenbürger (2006). We simply consider that the local prevention choice maximizes the total wealth of the inhabitants.

Flood prevention externalities. Jurisdiction 1's final expected loss depends on its own prevention level. Jurisdiction 2 can also decrease its expected loss by its own prevention measures. However, it is subject to loss externalities originating from the prevention measures implemented upstream by jurisdiction 1. Therefore the expected losses of all inhabitants are correlated. We use e to denote the externalities coefficient. For the sake of simplicity, we assume that the expected losses at the jurisdictional scale are[7]

$$EL_1(a_1) = N_1 p^0 L(1 - a_1), \tag{3.5}$$

$$EL_2(a_1, a_2) = N_2 p^0 L(1 - a_2 - e a_1). \tag{3.6}$$

If $e > 0$, the prevention measures that may be implemented by jurisdiction 1 reduce jurisdiction 2's expected loss. Thus, $e > 0$ corresponds to positive externalities and $e < 0$ to negative ones. Note that the form chosen for externalities implies that jurisdiction 2 cannot reduce the impact of the externalities generated by jurisdiction 1 using its own prevention measures. Besides, this specification allows to consider prevention measures as decreasing the loss probability (self-protection) or as decreasing the potential loss (self-insurance). Therefore, under full insurance,

[6] Note that taxes providing prevention incentives to individuals would not make sense, as individuals cannot decide the collective prevention level on their own.

[7] This expression is different from the one used by Hofmann (2007) and Muermann and Kunreuther (2008). Both papers assume that a loss directly caused by an agent and a loss indirectly caused via others are independent.

these two interpretations are equivalent.

We assume that $-1 \leq e \leq 1$ as we suppose that jurisdiction 2's prevention has a higher impact on its own risk level than the jurisdiction 1's prevention. To guarantee expected losses to be positive, we assume that[8]

$$0 \leq a_1 \leq 1, \tag{3.7}$$

$$0 \leq a_2 \leq 1, \tag{3.8}$$

$$a_2 + ea_1 \leq 1. \tag{3.9}$$

Household insurance. This model represents a region with two connected jurisdictions among which risks are correlated. However, at the national level, the number of regions enables risk tolerance by the insurer to be increased as well as risk to be diversified. Household insurance can be provided by a competitive market or an efficient administration. For the sake of simplicity, there are no administrative costs (no loading factor). We assume that all individuals purchase insurance for reasons exposed thereafter.

We consider two different insurance schemes: uniform or actuarial insurance.

Uniform insurance. We consider compulsory uniform insurance as implemented in several countries. Uniform insurance has to be understood here in a broad meaning; it includes other solidarity mechanisms than insurance itself, and especially public aid: State assistance is funded by taxes which are similar to insurance premiums. We consider that all individuals benefit from a compensation after natural disasters at a uniform price organized by the State.

Note that Coate (1995) explains that the equivalence between *ex post* taxation and uniform insurance is imperfect. Ex post assistance by the State is less efficient because assistance may rely on approximate loss assessments or discretionary decisions. Besides, as natural disasters assistance is provided by various actors (non-profit organizations, States), the uninsured can free-ride. We leave these

[8] These conditions of validity are derived in Appendix 3.6.1 in each of the cases that we study.

issues aside.

The uniform premium Π^u depends on the prevention levels in the two jurisdictions.

$$\begin{aligned}\Pi^u(a_1, a_2) &= \frac{N_1 p^0 L(1-a_1) + N_2 p^0 L(1-a_2-ea_1)}{N_1+N_2}, \\ &= p^0 L\left(1 - \frac{1+\eta e}{1+\eta}a_1 - \frac{\eta}{1+\eta}a_2\right). \end{aligned} \tag{3.10}$$

The burden of externalities burden is measured by ηe. Consistently, it depends on the externality coefficient e and on the relative size of the population that is subject to these externalities η. The uniform premium shares the total cost of risk and externalities between the two jurisdictions. The two factors $1/(1+\eta)$ and $\eta/(1+\eta)$ that appear in the expression traduce this *loss sharing effect*, respectively for jurisdiction 1 and for jurisdiction 2.

Actuarial insurance. Competition implies that insurance makes individuals pay for their own risk. It does not make individuals living in jurisdiction 1 pay for the externalities their collective prevention exert on jurisdiction 2.[9] Therefore, under actuarial insurance, the premiums are

$$\Pi_1^a = p^0 L(1-a_1), \tag{3.11}$$

$$\Pi_2^a = p^0 L(1-a_2-ea_1). \tag{3.12}$$

All individuals purchase flood insurance.

Timing. Central government and jurisdictions have symmetric information. The timing of the model is as follows.

Stage 1: Insurance scheme is fixed. Central government chooses the form of the prevention incentives, if any, and the transfers policy between jurisdictions.

Stage 2: Jurisdictions determine their prevention levels.

[9]Indeed, if externalities are negative, individuals will not purchase a more expensive insurance that internalizes the externalities they create. If externalities are positive, an insurer is able to offer a reduced premium only if he insures all the individuals living in jurisdiction 2; this condition is not compatible with competition.

Stage 3: The state of nature is realized: losses are revealed and each individual knows its final wealth.

As in Hofmann (2007) and Muermann and Kunreuther (2008), in Stage 2 we consider the Nash equilibrium. Here however, due to our specification (Equations 3.5 and 3.6), the prevention choice of one jurisdiction does not depend on the prevention level set up by its neighbor. Indeed, jurisdiction 2 cannot use its own prevention measures to reduce the impact of the externalities exerted by jurisdiction 1. Besides, jurisdiction 1 is not impacted by the prevention measures implemented by jurisdiction 2.

First best. We consider full insurance. We analyze here the first best situation, where central government decides the prevention levels and simultaneously designs a transfers policy between the two jurisdictions. Under full insurance - uniform ($s = u$) or actuarial ($s = a$) - and in the presence of transfers, the central government program is to maximize the total wealth of the individuals:

$$\max_{a_j^s} W_1 + W_2 = N_1 \left(I - \Pi_1^s - \tfrac{c_1}{2N_1}(a_1^s)^2 \right) + N_2 \left(I - \Pi_2^s - \tfrac{c_2}{2N_2}(a_2^s)^2 \right). \tag{3.13}$$

This leads to the following prevention levels:

$$a_1^{**} = \frac{p^0 L N_1}{c_1}(1 + \eta e), \tag{3.14}$$

$$a_2^{**} = \frac{p^0 L N_2}{c_2}. \tag{3.15}$$

The prevention level in jurisdiction 1 internalizes externalities exerted on jurisdiction 2.

Note that under full insurance, the prevention levels do not depend on the given insurance system whether uniform or actuarial. Indeed, the sum of expected losses supported by the jurisdictions does not depend on the way the financial burden for flood losses is shared between jurisdictions. However, even if the jurisdictions have the same population size and the same cost function, the two insurance systems do not lead to the same wealth in each jurisdiction because of the geographic heterogeneity between both jurisdictions.

If there was a benevolent monopolist insurer and if insurance was mandatory, these prevention levels could be implemented by the following insurance mechanism: the unique insurer would make inhabitants pay for the overall consequences of their prevention actions, that is for their own risk and for the prevention externalities they exert on the neighboring jurisdiction.[10]

$$\Pi_1^i = p^0 L(1 - (1 + \eta e)a_1), \tag{3.16}$$

$$\Pi_2^i = p^0 L(1 - a_2). \tag{3.17}$$

3.3 Comparing uniform and actuarial insurance

In a second best world, that is without policy incentives to coordinate local prevention policies, we consider uniform insurance that depends on all insureds' risk and partially integrates prevention externalities; we also consider actuarial insurance that makes individuals pay for their own risk but not for the prevention externalities they exert on the neighboring jurisdiction.

Each jurisdiction maximizes the wealth of its inhabitants either under uniform insurance ($s = u$) or under actuarial insurance ($s = a$).

$$\forall j \in \{1;2\}, \max_{a_j^s} W_j^s = N_j \left(I - \Pi_j^s - \frac{c_j}{2N_j}(a_j^s)^2 \right). \tag{3.18}$$

Uniform insurance. The uniform premium provides a price signal on the direct impact of prevention as well as on the externalities created for the upstream jurisdiction. However, the signal on these impacts is diluted since the uniform premium shares the total cost of risk and externalities between the two jurisdictions. The factors $1/(1+\eta)$ and $\eta/(1+\eta)$ that respectively appear in the expression for the

[10] Assuming mandatory insurance is required in the case of negative externalities with a downstream jurisdiction more populated than the upstream one. In that case, the term $\eta e a_1$ in Equation 3.16 strongly increases the premium offered to upstream households; despite of their risk aversion, these households could so prefer not to purchase insurance.

prevention level by jurisdiction 1 and by jurisdiction 2 reflect this loss sharing effect:

$$a_1^{u*} = \frac{p^0 L N_1}{c_1} \frac{1+\eta e}{1+\eta} < a_1^{**}, \tag{3.19}$$

$$a_2^{u*} = \frac{p^0 L N_2}{c_2} \frac{\eta}{1+\eta} < a_2^{**}. \tag{3.20}$$

Because of the loss sharing effect, prevention levels are lower than those that would be implemented by central government under centralization.

Actuarial insurance. Under actuarial insurance, the prevention level in jurisdiction 1 does not internalize externalities exerted on the downstream jurisdiction 2, since actuarial insurance does not give any price signal on these.

$$a_1^{a*} = \frac{p^0 L N_1}{c_1} < a_1^{**} \Leftrightarrow e > 0, \tag{3.21}$$

$$a_2^{a*} = \frac{p^0 L N_2}{c_2} = a_2^{**}. \tag{3.22}$$

This is why centralization leads to higher prevention levels than in the absence of prevention policy coordination if and only if externalities are positive. Note that, in the absence of prevention policy coordination, if there are no externalities, actuarial insurance leads to optimum prevention levels.

In the absence of prevention policy coordination, the prevention levels are not optimum. However, modifying them would reduce the welfare of jurisdictions. To avoid this, central government can organize transfers between jurisdictions. As centralization corresponds to the first best and includes a transfers policy, it Pareto dominates the absence of prevention policy coordination. For example, under uniform insurance, the social welfare in centralization is higher than the social welfare in the absence of prevention policy coordination:

$$W_1^{u**} + W_2^{u**} - W_1^{u*} - W_2^{u*} = \frac{(p^0 L N_1)^2}{2} \left(\frac{\eta}{1+\eta}\right)^2 \left(\frac{(1+\eta e)^2}{c_1} + \frac{1}{c_2}\right) > 0. \tag{3.23}$$

This social welfare difference increases with respect to η, that is the difference in population size between the two jurisdictions. Indeed, the loss sharing effect, which explains why prevention levels in the absence of prevention policy coordination are

not optimum, is expressed by $(\eta/(1+\eta))^2$ and increases with respect to η.

Comparing uniform and actuarial insurance. In the absence of prevention policy coordination, the prevention levels are lower under uniform insurance than under actuarial insurance. Indeed, prevention is of more benefit under actuarial insurance: a marginal increase in jurisdictional prevention decreases the actuarial premium by 1, whereas it decreases the uniform premium by $(1+\eta e)/(1+\eta) < 1$ for jurisdiction 1 and by $\eta/(1+\eta) < 1$ for jurisdiction 2.

$$a_1^{u*} < a_1^{a*}, \tag{3.24}$$

$$a_2^{u*} < a_2^{a*}. \tag{3.25}$$

However, the difference between uniform and actuarial premiums is ambiguous. On the one hand, uniform insurance leads to lower one's own prevention level (OwnP), which tends to make uniform premium larger than actuarial one. On the other hand, uniform insurance depends on the prevention levels in the two jurisdictions. Therefore, it enables inhabitants of one jurisdiction to benefit from the prevention realized in the other jurisdiction (OtherP), which tends to make the uniform premium lower than the actuarial one.

$$\begin{aligned}\Delta\Pi_1^{u-a} &= \Pi^u(a_1^{u*}, a_2^{u*}) - \Pi_1^a(a_1^{a*}),\\ &= \underbrace{\frac{(p^0LN_1)^2}{c_1}\left(1-\left(\frac{1+\eta e}{1+\eta}\right)^2\right)}_{\text{OwnP}\geq 0}\underbrace{-(p^0L)^2\frac{N_1N_2}{c_2}\left(\frac{\eta}{1+\eta}\right)^2}_{\text{OtherP}\leq 0},\end{aligned} \tag{3.26}$$

$$\begin{aligned}\Delta\Pi_2^{u-a} &= \Pi^u(a_1^{u*}, a_2^{u*}) - \Pi_2^a(a_1^{a*}, a_2^{a*}),\\ &= \underbrace{\frac{(p^0LN_2)^2}{c_2}\left(1-\left(\frac{\eta}{1+\eta}\right)^2\right)}_{\text{OwnP}\geq 0}+\underbrace{(p^0L)^2\frac{N_1N_2}{c_1}\left(e-\left(\frac{1+\eta e}{1+\eta}\right)^2\right)}_{\text{OtherP}\leq 0}.\end{aligned} \tag{3.27}$$

In addition, as uniform insurance leads to less prevention than actuarial insurance, the prevention costs are lower under uniform insurance.

$$\Delta C_1^{u-a} = C_1(a_1^{u*}) - C_1(a_1^{a*}) \leq 0, \tag{3.28}$$

$$\Delta C_2^{u-a} = C_2(a_2^{u*}) - C_2(a_2^{a*}) \leq 0. \tag{3.29}$$

Therefore, uniform insurance may lead to a higher wealth for inhabitants than actuarial insurance.

$$W_1^{u*} - W_1^{a*} = \underbrace{-N_1 \Delta\Pi_1^{u-a}}_{\gtrless 0} \underbrace{-\Delta C_1^{u-a}}_{\geq 0}, \tag{3.30}$$

$$W_2^{u*} - W_2^{a*} = \underbrace{-N_2 \Delta\Pi_2^{u-a}}_{\gtrless 0} \underbrace{-\Delta C_2^{u-a}}_{\geq 0}. \tag{3.31}$$

Finally, uniform insurance leads to a higher social welfare than actuarial insurance if and only if

$$\begin{aligned} SW^u - SW^a &= W_1^{u*} + W_2^{u*} - W_1^{a*} - W_2^{a*}, \\ &= -N_1 \Delta\Pi_1^{u-a} - N_2 \Delta\Pi_2^{u-a} - \Delta C_1^{u-a} - \Delta C_2^{u-a} \geq 0. \end{aligned} \tag{3.32}$$

Note that, as there are only two jurisdictions, social welfare increase is equivalent to Pareto dominance. Indeed, a higher social welfare implies that the potential wealth loss in one jurisdiction is lower than the wealth gain in the other. Therefore the potential wealth decrease in one jurisdiction can be compensated by a transfer from the other jurisdiction.

We can now express condition 3.32 under our specification. This leads to the following proposition.

Proposition 1. *In the absence of prevention policy coordination and under full coverage, there exists a transfers policy such that uniform insurance Pareto dominates actuarial insurance if and only if*

$$SW^u - SW^a = -\frac{(p^0 L N_1)^2}{c_1} \frac{1}{(1+\eta)^2} \left(e + e\eta + \eta^2 \left(\frac{1}{2} - e - \frac{1}{2}e^2 + \frac{1}{2}\frac{c_1}{c_2} \right) - e^2\eta^3 \right) \geq 0. \tag{3.33}$$

Proof. See Appendix 3.6.2. □

This result illustrates the general theory of second best formalized by Lipsey and Lancaster (1956-1957): in the absence of externalities, actuarial insurance corresponds to the first best policy; however, when the burden of externalities is important, there exists a transfers policy such that uniform insurance Pareto

dominates actuarial insurance.

To better understand the implication of Proposition 1, we focus on one particular case: equal cost coefficients ($c_1 = c_2$) and $p^0 LN_1/c_1 = 0.01$. Figure 3.1 provides a graphical illustration of the comparison between the social welfare under uniform insurance SW^u and the social welfare under actuarial insurance SW^a. As the burden of externalities ηe results from the physical magnitude of prevention externalities e and from the relative size of the downstream population subject to this physical phenomenon η, we compare the social welfare under uniform and actuarial insurance for a whole set of points (η, e).

The two curves on Figure 3.1 correspond to the set of points (η, e) where the social welfare is the same under uniform and actuarial insurance.[11] Between these two curves, that is with a little burden of externalities, actuarial insurance leads to a higher social welfare than uniform insurance ($SW^a > SW^u$): therefore there exists a transfers policy such that actuarial insurance Pareto dominates uniform insurance. Above and below, that is with an important burden of externalities, uniform insurance leads to a higher social welfare than actuarial insurance ($SW^u > SW^a$): therefore there exists a transfers policy such that uniform insurance Pareto dominates actuarial insurance.

We can now compare the wealth in each jurisdiction between uniform and actuarial insurance. We consider here that central government does not organize transfers between the two jurisdictions. For jurisdiction 1, the intuition to explain the wealth difference under uniform or actuarial insurance is straightforward: as η increases, under uniform insurance, the share of the expected losses that is borne by jurisdiction 1 decreases, whereas its cost of risk is unchanged under actuarial insurance. This is why jurisdiction 1 is better off under uniform insurance for high values of η.

The situation for jurisdiction 2 is not as simple because of borne externalities:

[11] The whole set of points (η, e) considered on Figure 3.1 verify the conditions of validity under uniform and actuarial insurance (see Appendix 3.6.1).

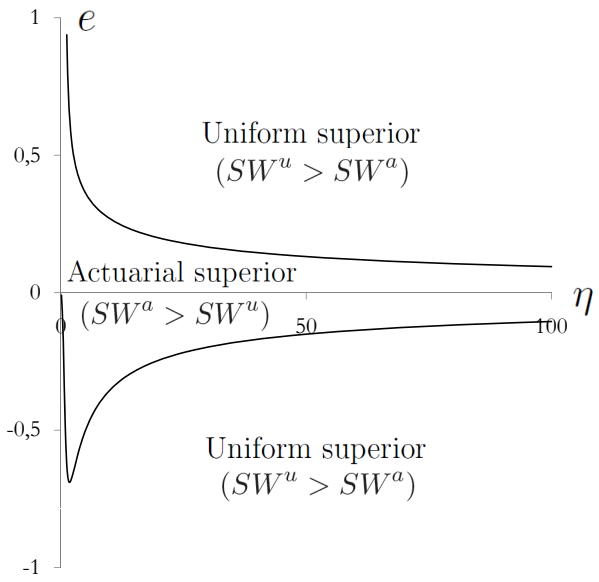


Figure 3.1: Social welfare under uniform and actuarial insurance ($c_1 = c_2$, $p^0 LN_1/c_1 = 0.01$)

- If externalities are strongly negative for all (or most) values of η, jurisdiction 2 is better off under uniform insurance (see Appendix 3.6.3). The loss sharing under uniform insurance is certainly not in favor of jurisdiction 2 for high values of η. But this is counterbalanced by the fact that uniform insurance leads to a lower prevention level in jurisdiction 1, which is desirable as externalities are strongly negative.
- On the contrary, if externalities are positive or not too negative, for high values of η, jurisdiction 2 is better off under actuarial insurance: not only the loss sharing effect under uniform insurance is not in its favor, but uniform insurance leads to lower prevention levels in jurisdiction 1, whereas a higher prevention level in jurisdiction 1 is here desirable.

Therefore, if externalities are strongly negative, for high values of η, both jurisdictions are better off under uniform insurance, whereas if externalities are positive or not too negative, the two jurisdictions have opposite interests. This leads to the following corollary.

Corollary 1. *In the absence of transfers, if* $e(1-e) \leq -\frac{c_1}{c_2}$, *for* $\eta \geq \max\{\eta_1, \eta_2^+\}$,

both jurisdictions are better off under uniform insurance where

$$\eta_1 = \frac{(1-e^2)}{4}\frac{c_2}{c_1}\left(1+\sqrt{1+\frac{16}{(1-e)(1+e)^2}\frac{c_1}{c_2}}\right) \tag{3.34}$$

$$\eta_2^+ = -\frac{c_1}{4(c_1+c_2e(1-e))}\left(1+\sqrt{1+16(1-e)\left(\frac{c_2}{c_1}+\left(\frac{c_2}{c_1}\right)^2 e(1-e)\right)}\right), \tag{3.35}$$

Proof. See Appendix 3.6.3. □

Note that the question of size effect can be thought not only in terms of population size but also in terms of number of jurisdictions alongside the river. Grislain-Letrémy and Lemoyne de Forges (2011) consider a watershed with numerous jurisdictions exposed to unidirectional prevention externalities. They consider N jurisdictions of equal size, N being large, and with the same prevention cost. They also find an illustration of the general theory of second best. As jurisdictions are of equal size, the cost of risk and externalities is equally shared between all the jurisdictions. Therefore, the interpretation only relies on externalities: if externalities are positive or not too negative, actuarial insurance, which leads to higher prevention levels, leads all jurisdictions to a higher wealth; on the contrary, if negative externalities are strongly negative, actuarial insurance is not desirable, except for the upstream jurisdiction 1 which is not subject to externalities.

3.4 Incentives for prevention under uniform insurance

We now focus on uniform insurance. In a situation where prevention policies are decentralized at the jurisdictional level, central government has to consider tools to coordinate local prevention choices. We study two types of insurance policies: incentives through household insurance premium and introduction of deductibles.

3.4.1 Premium incentives

We consider the case where central government coordinates prevention policies by setting up incentives through households insurance premium. As we consider full insurance, this policy is equivalent to tax incentives for local jurisdictions. The optimal form of incentives corresponds to a Pigouvian tax. Under full insurance,

central government can implement first-best prevention levels and welfare by using linear premium decrease:

$$\Delta\Pi_1^u(a_1) = -p^0 L \frac{\eta}{1+\eta}(1+\eta e)a_1 \leq 0, \tag{3.36}$$

$$\Delta\Pi_2^u(a_2) = -p^0 L \frac{1}{1+\eta}a_2 < 0. \tag{3.37}$$

Premium incentives are a reward for collective prevention whatever the sign of the externalities, since, under uniform insurance, in the absence of prevention policy coordination, prevention levels are lower than optimum (Equations 3.19 and 3.20). The marginal rate of the premium incentive takes into account both the direct benefits of prevention on the considered jurisdiction and the externalities exerted, since the uniform premium only gives a diluted price signal on risk and prevention externalities. It leads to the first best prevention levels and there exists a transfers policy such that a Pigouvian household insurance premium Pareto dominates the absence of prevention policy coordination.

3.4.2 Deductible incentives

Considering full insurance is an important restriction. Partial insurance is much more realistic and can provide prevention incentives. We compare the impact of coverage limitation on prevention levels under self-protection (when prevention decreases the probability of flood) and self-insurance (when prevention decreases the loss in the case of flood).

We assume that central government introduces a constant deductible D. We assume to be near full insurance. Under partial insurance, an individual living in jurisdiction j has differing wealths between a loss situation (w_j^L) and in the absence of loss (w_j^{NL}).

$$\forall j \in \{1,2\}\ w_j^L = I - \Pi_D^u(a_1,a_2) - D - \frac{c_j}{2N_j}a_j^2 - \frac{T_j}{N_j}, \tag{3.38}$$

$$w_j^{NL} = I - \Pi_D^u(a_1,a_2) - \frac{c_j}{2N_j}a_j^2 - \frac{T_j}{N_j},$$

where the uniform premium $\Pi_D^u(a_1,a_2)$ depends on the deductible amount and T_j is the transfer from central government to jurisdiction j. As insurance is here partial, we need to study separately self-protection and self-insurance.

Under self-protection, jurisdiction j's program is

$$\forall j \in \{1,2\} \ \max_{a_j} N_j[P_j(a_1,a_2)u(w_j^L) + (1-P_j(a_1,a_2))u(w_j^{NL})], \tag{3.39}$$

$$\text{with } P_1(a_1) = p^0(1-a_1), \tag{3.40}$$

$$P_2(a_1,a_2) = p^0(1-a_2-ea_1). \tag{3.41}$$

The uniform premium equals

$$\begin{aligned}\Pi_D^u(a_1,a_2) &= \frac{N_1p^0(1-a_1)(L-D) + N_2p^0(1-a_2-ea_1)(L-D)}{N_1+N_2},\\ &= p^0(L-D)\left(1-\frac{1+\eta e}{1+\eta}a_1 - \frac{\eta}{1+\eta}a_2\right).\end{aligned} \tag{3.42}$$

Under self-protection, introducing a small deductible increases the prevention levels realized by the two jurisdictions. Indeed, it provides two opposite additional incentives to prevention: on the one hand, the probability of suffering the deductible can be reduced by increasing the prevention level (deductible incentive, DI); on the other hand, the incentive for prevention via the premium is decreased by the introduced deductible (premium incentive, PI). These two incentives have to be balanced by the cost of additional prevention.

$$\frac{c_j}{N_j}\frac{\partial a_j^{u*}}{\partial D}\bigg|_{D=0} = \underbrace{-\frac{\partial P_j}{\partial a_j}}_{\text{DI}\geq 0}\underbrace{-\frac{\partial^2\Pi_D^u}{\partial a_j \partial D}\bigg|_{D=0}}_{\text{PI}\leq 0} \geq 0. \tag{3.43}$$

Because the uniform premium only gives a diluted price signal on risk and prevention externalities, the premium incentive is dominated by the deductible incentive. Thus, the prevention levels increase in the two jurisdictions.

We can now study the impact of coverage limitation on inhabitants' expected utility. Introducing a deductible increases the amount of risk that the inhabitants bear (deductible effect, DE), but it decreases their insurance premium (premium effect, PE). These two opposite effects do not balance each other, as they are respectively proportional to the individual loss probability P_j and the uniform loss probability $\left(\frac{\partial \Pi_D^u}{\partial D} = -p^0\left(1-\frac{1+\eta e}{1+\eta}a_1 - \frac{\eta}{1+\eta}a_2\right)\right)$. Furthermore, since the two prevention levels increase, there are two other effects: the uniform premium decreases (other premium effect, PE') and the cost of prevention increases (cost effect, CE).

$$\left.\frac{\partial EU_j(a_1(D),a_2(D),D)}{\partial D}\right|_{D=0} = u'(w_j)\Bigg(\underbrace{-P_j}_{DE\leq 0}\underbrace{-\frac{\partial \Pi_D^u}{\partial D}}_{PE\geq 0}\underbrace{-\left(\frac{\partial \Pi_D^u}{\partial a_1}\frac{\partial a_1}{\partial D}+\frac{\partial \Pi_D^u}{\partial a_2}\frac{\partial a_2}{\partial D}\right)_{D=0}}_{PE'\geq 0}\underbrace{-a_j^{u*}\frac{c_j}{N_j}\left.\frac{\partial a_j^{u*}}{\partial D}\right|_{D=0}}_{CE\leq 0}\Bigg). \tag{3.44}$$

When calculating the net effect with our specification, we find that the expected utility of inhabitants of jurisdiction 1 increases; the net effect in jurisdiction 2 remains ambiguous:

$$\left.\frac{\partial EU_1(a_1(D),a_2(D),D)}{\partial D}\right|_{D=0} = u'(w_1)p^0\frac{\eta}{1+\eta}(1-e)a_1 \geq 0, \tag{3.45}$$

$$\left.\frac{\partial EU_2(a_1(D),a_2(D),D)}{\partial D}\right|_{D=0} = u'(w_2)p^0\frac{1}{1+\eta}(-(1-e)a_1+a_2) \gtrless 0. \tag{3.46}$$

If externalities are strongly negative, for all (or most) values of η, the loss in expected utility in jurisdiction 2 is too important to be compensated by a transfer from jurisdiction 1. If externalities are positive or not too negative, central government can organize a transfer from jurisdiction 1 to jurisdiction 2 such that coverage limitation Pareto dominates the absence of prevention policy coordination, but only for high values of η. Indeed, as a result of the four effects detailed in (3.44), the gain in expected utility in jurisdiction 1 increases with respect to η (Equation 3.45); if η is low, the gain in expected utility in jurisdiction 1 is not important enough to compensate the loss in jurisdiction 2. This leads to the following proposition.

Proposition 2. *Under uniform insurance, introducing a small deductible in household insurance increases self-protection in the two jurisdictions. If* $e(1-e) \geq -\frac{c_1}{c_2}$, *for* $\eta \geq \max\{\eta_D^0, \eta_D^-\}$, *there exists a transfers policy such that coverage limitation Pareto dominates the absence of prevention policy coordination where*

$$\eta_D^0 = \frac{1}{1-e}, \tag{3.47}$$

$$\eta_D^- = -\frac{c_2(1-e)^2}{2(c_1+c_2e(1-e))}\left(1-\sqrt{1+\frac{4(c_1+c_2e(1-e))}{c_2(1-e)^3}}\right). \tag{3.48}$$

Proof. See Appendix 3.6.4. □

Under self-insurance, jurisdiction j's program is

$$\forall j \in \{1,2\} \ \max_{a_j} N_j[p^0u(w_j^L)+(1-p^0)u(w_j^{NL})], \tag{3.49}$$

and the uniform premium is

$$\begin{aligned}\Pi_D^u(a_1,a_2) &= \frac{N_1 p^0(L(1-a_1)-D)+N_2 p^0(L(1-a_2-ea_1)-D)}{N_1+N_2},\\ &= p^0 L\left(1-\frac{1+\eta e}{1+\eta}a_1-\frac{\eta}{1+\eta}a_2\right)-p^0 D. \end{aligned} \tag{3.50}$$

Under self-insurance, introducing a small deductible does not modify the prevention levels. Indeed, it does not provide additional incentive to do more or less prevention for two reasons. As illustrated by Equation 3.51, the probability of suffering the deductible cannot be decreased by doing more prevention (null deductible incentive, DI = 0); the incentive for prevention via the premium is not modified by the introduced deductible (null premium incentive, PI = 0).

$$\frac{c_j}{N_j}\frac{\partial a_j^{u*}}{\partial D}\bigg|_{D=0} = \underbrace{-\frac{\partial p^0}{\partial a_j}}_{\text{DI}=0}\underbrace{-\frac{\partial^2 \Pi_D^u}{\partial a_j \partial D}\bigg|_{D=0}}_{\text{PI}=0} = 0. \tag{3.51}$$

As the higher order partial derivatives are also null (see Appendix 3.6.5), prevention levels remain unchanged.

As the coverage decreases, the expected utilities remain also unchanged, because introducing a deductible has two opposite effects: it increases the amount of risk borne by inhabitants (deductible effect, DE), but it also decreases the insurance premium (premium effect, PE). Here, these two effects balance each other, as they are both proportional to the same loss probability p^0.

$$\frac{\partial EU_j(a_1(D),a_2(D),D)}{\partial D}\bigg|_{D=0} = u'(w_j)\Bigg(\underbrace{-p^0}_{DE\leq 0}\ \underbrace{-\frac{\partial \Pi_D^u}{\partial D}}_{PE=+p^0\geq 0}\Bigg) = 0. \tag{3.52}$$

As the higher order partial derivatives are also null (see Appendix 3.6.5), the expected utilities are constant. This leads to the following proposition.

Proposition 3. *Under uniform insurance, introducing a small deductible in household insurance creates no incentives for self-insurance and does not modify the expected utility for households.*

Proof. See Appendix 3.6.5. □

Propositions 2 and 3 show how crucial it is to take into account prevention technology when designing prevention incentives.

3.5 Conclusion

This chapter provides a simple and original theoretical framework to address the issue of flood exposure. Indeed, flood risk presents two major specificities: flood collective prevention choices (dams, levees, retention basins) for most exert positive or negative externalities on neighboring jurisdictions; flood coverage is based de facto or de jure on uniform contribution in many countries.

Our results are interesting in several ways. First, uniform coverage scheme is often criticized for providing no prevention incentives. We show that uniform insurance partially integrates prevention externalities and can Pareto dominate actuarial insurance. This finding is specific to flood risk; it is not valid for other risks without prevention externalities, such as storms or earthquakes. Second, we show that, under uniform insurance, limiting insurance coverage creates incentives for self-protection but none for self-insurance. This underlines how crucial it is to take into account prevention technology when designing prevention incentives.

3.6 Appendices

3.6.1 Conditions of validity

Following (3.7), (3.8) and (3.9), the conditions of validity are

- under uniform insurance without coordination of local policies

$$0 < \frac{p^0 L N_1}{c_1} \frac{1+\eta e}{1+\eta} \leq 1, \tag{3.53}$$

$$0 < \frac{p^0 L N_2}{c_2} \frac{\eta}{1+\eta} \leq 1, \tag{3.54}$$

$$p^0 L N_1 \left(\frac{1}{c_2} \frac{\eta}{1+\eta} + \frac{e}{c_1} \frac{1+\eta e}{1+\eta} \right) \leq 1, \tag{3.55}$$

- under actuarial insurance without coordination of local policies

$$0 < \frac{p^0 L N_1}{c_1} \leq 1, \tag{3.56}$$

$$0 < \frac{p^0 L N_2}{c_2} \leq 1, \tag{3.57}$$

$$p^0 L N_1 \left(\frac{\eta}{c_2} + \frac{e}{c_1} \right) \leq 1, \tag{3.58}$$

- under centralization

$$0 < \frac{p^0 L N_1}{c_1}(1 + \eta e) \leq 1, \tag{3.59}$$

$$0 < \frac{p^0 L N_2}{c_2} \leq 1, \tag{3.60}$$

$$p^0 L N_1 \left(\frac{\eta}{c_2} + \frac{e(1+\eta e)}{c_1} \right) \leq 1. \tag{3.61}$$

3.6.2 Proof of Proposition 1

In the absence of prevention policy coordination, the final wealths are respectively under uniform and actuarial insurance

$$W_1^{u*} = N_1 I - p^0 L N_1 + \frac{(p^0 L N_1)^2}{2c_1} \left(\frac{1+\eta e}{1+\eta} \right)^2 + (p^0 L)^2 \frac{N_1 N_2}{c_2} \left(\frac{\eta}{1+\eta} \right)^2, \tag{3.62}$$

$$W_2^{u*} = N_2 I - p^0 L N_2 + (p^0 L)^2 \frac{N_1 N_2}{c_1} \left(\frac{1+\eta e}{1+\eta} \right)^2 + \frac{(p^0 L N_2)^2}{2c_2} \left(\frac{\eta}{1+\eta} \right)^2, \tag{3.63}$$

$$W_1^{a*} = N_1 I - p^0 L N_1 + \frac{(p^0 L N_1)^2}{2c_1}, \tag{3.64}$$

$$W_2^{a*} = N_2 I - p^0 L N_2 + e(p^0 L)^2 \frac{N_1 N_2}{c_1} + \frac{(p^0 L N_2)^2}{2c_2}. \tag{3.65}$$

Therefore

$$W_1^{u*} - W_1^{a*} = \frac{(p^0 L N_1)^2}{2c_1} \left(\left(\frac{1+\eta e}{1+\eta} \right)^2 - 1 \right) + (p^0 L)^2 \frac{N_1 N_2}{c_2} \left(\frac{\eta}{1+\eta} \right)^2, \tag{3.66}$$

$$W_2^{u*} - W_2^{a*} = (p^0 L)^2 \frac{N_1 N_2}{c_1} \left(\left(\frac{1+\eta e}{1+\eta} \right)^2 - e \right) + \frac{(p^0 L N_2)^2}{2c_2} \left(\left(\frac{\eta}{1+\eta} \right)^2 - 1 \right). \tag{3.67}$$

3.6.3 Proof of Corollary 1

As η increases, under uniform insurance, the share of the expected losses that is borne by jurisdiction 1 decreases. Jurisdiction 1 is better off under uniform insurance for high values of η.

$$\eta > \eta_1 \Leftrightarrow W_1^{u*} > W_1^{a*}, \tag{3.68}$$

$$\text{where } \eta_1 = \frac{(1-e^2)}{4}\frac{c_2}{c_1}\left(1+\sqrt{1+\frac{16}{(1-e)(1+e)^2}\frac{c_1}{c_2}}\right). \tag{3.69}$$

The wealth difference between uniform and actuarial insurance for jurisdiction 2 depends on η but also on the externalities sign and magnitude. By denoting

$$\eta_2^0 = 2\frac{c_2}{c_1}(1-e), \tag{3.70}$$

$$\eta_2^- = -\frac{c_1}{4(c_1+c_2e(1-e))}\left(1-\sqrt{1+16(1-e)\left(\frac{c_2}{c_1}+\left(\frac{c_2}{c_1}\right)^2 e(1-e)\right)}\right), \tag{3.71}$$

$$\eta_2^+ = -\frac{c_1}{4(c_1+c_2e(1-e))}\left(1+\sqrt{1+16(1-e)\left(\frac{c_2}{c_1}+\left(\frac{c_2}{c_1}\right)^2 e(1-e)\right)}\right), \tag{3.72}$$

we get

$$\text{if } e(1-e) \leq -\frac{1}{16(1-e)}\left(\frac{c_1}{c_2}\right)^2 - \frac{c_1}{c_2}, \forall\eta, \quad W_2^{u*} \geq W_2^{a*}, \tag{3.73}$$

$$\text{if } -\frac{1}{16(1-e)}\left(\frac{c_1}{c_2}\right)^2 - \frac{c_1}{c_2} < e(1-e) < -\frac{c_1}{c_2}, \{\eta < \eta_2^- \text{ or } \eta > \eta_2^+\} \Leftrightarrow W_2^{u*} > W_2^{a*}, \tag{3.74}$$

$$\text{if } e(1-e) = -\frac{c_1}{c_2},\ \eta > \eta_2^0 \Leftrightarrow W_2^{u*} < W_2^{a*}, \tag{3.75}$$

$$\text{if } e(1-e) > -\frac{c_1}{c_2},\ \eta > \eta_2^- \Leftrightarrow W_2^{u*} < W_2^{a*}. \tag{3.76}$$

3.6.4 Proof of Proposition 2

Under self-protection, each jurisdiction selects its level of prevention by maximizing its expected utility (see Equation 3.39). The first order condition obtained is

$$\forall j \in \{1;2\},\ \frac{\partial P_j}{\partial a_j}u(w_j^L) + P_j u'(w_j^L)\left(- \frac{\partial \Pi_D^u}{\partial a_j} - \frac{c_j}{N_j}a_j \right) - \frac{\partial P_j}{\partial a_j}u(w_j^{NL}) + (1-P_j)u'(w_j^{NL})\left(- \frac{\partial \Pi_D^u}{\partial a_j} - \frac{c_j}{N_j}a_j \right) = 0. \quad (3.77)$$

This defines the optimum prevention level of jurisdiction j, which is a function of D.

The first order condition for $D = 0$ leads to the condition corresponding to the optimum prevention levels under full uniform insurance in the absence of prevention policy coordination. For the clarity of reading, we omit to denote $a_j^{u*}(D=0)$ when necessary and keep instead the notations a_j^{u*}.

$$\forall j \in \{1;2\},\ \frac{c_j}{N_j}a_j^{u*} = -\frac{\partial \Pi_D^u}{\partial a_j}\bigg|_{D=0}. \quad (3.78)$$

We want to determine the sign of $\frac{\partial a_j^{u*}}{\partial D}|_{D=0}$. Thus, we differentiate the first order condition obtained above (see Equation 3.77) with respect to D. For $D = 0$, we get

$$\frac{c_j}{N_j}\frac{\partial a_j^{u*}}{\partial D}\bigg|_{D=0} = -\frac{\partial P_j}{\partial a_j} - \frac{\partial^2 \Pi_D^u}{\partial a_j \partial D}\bigg|_{D=0}, \quad (3.79)$$

that is

$$\frac{c_1}{N_1}\frac{\partial a_1^{u*}}{\partial D}\bigg|_{D=0} = p^0\frac{\eta}{1+\eta}(1-e) \geq 0, \quad (3.80)$$

$$\frac{c_2}{N_2}\frac{\partial a_2^{u*}}{\partial D}\bigg|_{D=0} = p^0\frac{1}{1+\eta} > 0. \quad (3.81)$$

We can compute the first derivative of the expected utility for an inhabitant of jurisdiction j with respect to D.

$$\frac{\partial EU_j(a_1(D),a_2(D),D)}{\partial D}\bigg|_{D=0} = u'(w_j)\left(-P_j - \frac{\partial \Pi_D^u}{\partial D} - \left(\frac{\partial \Pi_D^u}{\partial a_1}\frac{\partial a_1}{\partial D} + \frac{\partial \Pi_D^u}{\partial a_2}\frac{\partial a_2}{\partial D}\right)_{D=0} - a_j^{u*}\frac{c_j}{N_j}\frac{\partial a_j^{u*}}{\partial D}\bigg|_{D=0}\right). \quad (3.82)$$

We get

$$\left.\frac{\partial EU_1(a_1(D),a_2(D),D)}{\partial D}\right|_{D=0} = u'(w_1)p^0\frac{\eta}{1+\eta}(1-e)a_1 \geq 0, \tag{3.83}$$

$$\left.\frac{\partial EU_2(a_1(D),a_2(D),D)}{\partial D}\right|_{D=0} = u'(w_2)p^0\frac{1}{1+\eta}(-(1-e)a_1+a_2). \tag{3.84}$$

More precisely, for jurisdiction 2,

$$\left.\frac{\partial EU_2(a_1(D),a_2(D),D)}{\partial D}\right|_{D=0} = u'(w_2)(p^0)^2LN_1\frac{1}{(1+\eta)^2}\left(\frac{\eta^2}{c_2}-\frac{(1-e)(1+\eta e)}{c_1}\right), \tag{3.85}$$

$$\geq 0 \Leftrightarrow \eta \geq \eta_D, \tag{3.86}$$

where

$$\eta_D = \begin{cases} \dfrac{e(1-e)}{2}\dfrac{c_2}{c_1}\left(1-\sqrt{1+\dfrac{4}{e^2(1-e)}\dfrac{c_1}{c_2}}\right) & \text{if e<0,} \quad (3.87) \\ \sqrt{\dfrac{c_2}{c_1}} & \text{if e=0,} \quad (3.88) \\ \dfrac{e(1-e)}{2}\dfrac{c_2}{c_1}\left(1+\sqrt{1+\dfrac{4}{e^2(1-e)}\dfrac{c_1}{c_2}}\right) & \text{if e>0.} \quad (3.89) \end{cases}$$

Following (3.83) and (3.84), there exists a transfers policy such that coverage limitation Pareto dominates the absence of prevention policy coordination if and only if

$$\eta(1-e)a_1-(1-e)a_1+a_2 \geq 0, \tag{3.90}$$

$$\Leftrightarrow \eta^2(c_1+c_2e(1-e))+\eta c_2(1-e)^2+c_2(e-1) \geq 0. \tag{3.91}$$

We denote

$$\eta_D^0 = \frac{1}{1-e}, \tag{3.92}$$

$$\eta_D^- = -\frac{c_2(1-e)^2}{2(c_1+c_2e(1-e))}\left(1-\sqrt{1+\frac{4(c_1+c_2e(1-e))}{c_2(1-e)^3}}\right), \tag{3.93}$$

$$\eta_D^+ = -\frac{c_2(1-e)^2}{2(c_1+c_2e(1-e))}\left(1+\sqrt{1+\frac{4(c_1+c_2e(1-e))}{c_2(1-e)^3}}\right). \tag{3.94}$$

There is Pareto dominance of coverage limitation with respect to the absence of

prevention policy coordination in the following cases:

$$\text{if } e(1-e) \leq -\frac{(1-e)^3}{4} - \frac{c_1}{c_2}, \forall \eta, \text{ no Pareto dominance,} \tag{3.95}$$

$$\text{if } -\frac{(1-e)^3}{4} - \frac{c_1}{c_2} < e(1-e) < -\frac{c_1}{c_2}, \{\eta < \eta_D^- \text{ or } \eta > \eta_D^+\} \Leftrightarrow \text{no Pareto dominance,} \tag{3.96}$$

$$\text{if } e(1-e) = -\frac{c_1}{c_2},\ \eta > \eta_D^0 \Leftrightarrow \text{Pareto dominance,} \tag{3.97}$$

$$\text{if } e(1-e) > -\frac{c_1}{c_2},\ \eta > \eta_D^- \Leftrightarrow \text{Pareto dominance.} \tag{3.98}$$

3.6.5 Proof of Proposition 3

Under self-insurance, each jurisdiction selects its level of prevention by maximizing its expected utility (see Equation 3.49). The first order condition obtained is

$$\forall j \in \{1;2\},\ p^0 u'(w_j^L)\left[-\frac{\partial \Pi_D^u}{\partial a_j} - \frac{c_j}{N_j}a_j\right] + (1-p^0)u'(w_j^{NL})\left[-\frac{\partial \Pi_D^u}{\partial a_j} - \frac{c_j}{N_j}a_j\right] = 0. \tag{3.99}$$

This defines the optimum prevention level of jurisdiction j, which is a function of D. Here again, the first order condition for $D = 0$ leads to the condition corresponding to the optimum prevention levels under full uniform insurance in the absence of prevention policy coordination (Equation 3.78).

In order to determine the sign of $\frac{\partial a_j^{u*}}{\partial D}|_{D=0}$, we differentiate the first order condition obtained above (see Equation 3.99) with respect to D.

$$\forall j \in \{1;2\},\ \frac{c_j}{N_j}\frac{\partial a_j^{u*}}{\partial D}\bigg|_{D=0} = 0. \tag{3.100}$$

More generally, we can verify that

$$\forall k \geq 1,\ \forall j \in \{1;2\},\ \frac{\partial^k a_j^{u*}}{\partial D^k}\bigg|_{D=0} = 0. \tag{3.101}$$

We can compute the derivatives of the expected utility for jurisdiction j with respect to D. When $D = 0$, by using Equations 3.78 and 3.101, we get

$$\forall k \geq 1,\ \forall j \in \{1;2\},\ \frac{\partial^k EU_j(a_1(D), a_2(D), D)}{\partial D^k}\bigg|_{D=0} = 0. \tag{3.102}$$

Chapter 4

Natural Disasters: Exposure and Underinsurance in Overseas France

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"If the misery of our poor be due not to the laws of nature, but to our institutions, great is our sin." Charles Darwin, The Voyage of the Beagle.

Abstract

The French overseas departments are much more exposed to natural catastrophic risks than continental France. However, half of households living in these departments do not purchase home insurance, which includes coverage against natural disasters, whereas almost all households living in continental France are insured. Several explanations can be considered: relatively high home insurance premiums, perception biases, anticipation of financial assistance after natural disasters or traditional individual housing. The estimation of a structural model enables to disentangle the determinants of insurance demand and supply. Standard explanations are precluded; the importance of anticipated assistance and traditional individual housing is underlined.

Keywords: natural disasters, insurance, public assistance

JEL classification: D12, Q54, G22, H81

Résumé long

Les DOM sont bien plus exposés aux catastrophes naturelles que ne le sont les ménages métropolitains. Pourtant, la moitié des ménages vivant dans les DOM n'ont pas souscrit d'assurance habitation, qui inclut la couverture contre les catastrophes naturelles, alors que la quasi-totalité des ménages métropolitains sont assurés. La sous-assurance des ménages ultramarins est un enjeu en matière de politique publique du fait des aides versées par les pouvoirs publics aux ménages non assurés et de l'implication financière de l'Etat dans le régime d'assurance contre les catastrophes naturelles.

Jusqu'à présent, les causes de la sous-assurance dans les DOM n'ont pas été étudiées. Plusieurs explications peuvent être envisagées. Tout d'abord, il se peut que les primes d'assurance soient trop chères pour ces ménages. Certains rapports locaux de l'Association Française de Génie Parasismique mentionnent des primes d'assurance très élevées. Le niveau de vie dans les DOM étant par ailleurs inférieur à celui de la France métropolitaine, il se peut que les ménages ultramarins ne puissent tout simplement pas s'assurer au vu de leurs capacités budgétaires. De plus, le risque de catastrophes naturelles est peut-être sous-estimé par les ménages, car les biais de perception sont fréquents dans le cas des risques extrêmes. Une autre explication possible repose sur l'anticipation d'aides en cas de catastrophe naturelle. Les ménages d'Outre-mer reçoivent en effet des aides importantes de la part de l'Etat, des autorités locales et de leurs proches (voisins, famille). Enfin, le faible taux de souscription pourrait être dû à l'habitat traditionnel individuel, répandu en Outre-mer : de nombreux ménages construisent eux-mêmes leurs maisons, parfois sans respecter les normes de construction ou sans permis de construire. Ces logements peuvent ne pas être assurables.

Ce chapitre spécifie et estime un modèle structurel d'offre et de demande d'assurance. Une équation d'offre permet d'estimer la prime d'assurance habitation proposée par les assureurs ; une équation de demande explique la probabilité de souscrire une assurance de la part des ménages, en tenant compte du fait que la décision d'assurance dépend de la prime d'assurance proposée. Ce modèle très classique n'a pas encore été estimé faute de données adéquates. L'estimation de ce modèle requiert en effet des données microéconomiques fines sur les assurés et les non assurés. Pour cette étude, une base de données inédite a été constituée en croisant la base Budget de famille 2006 de l'Insee avec des données relatives à l'exposition aux risques naturels fournies par le Ministère de l'Ecologie.

L'estimation de ce modèle structurel permet ainsi d'identifier les déterminants de l'offre et la demande d'assurance. Les explications classiques sont écartées ; le faible taux de souscription dans les DOM est principalement dû à l'anticipation d'aides et à l'habitat individuel traditionnel. Les implications en matière de politique publique sont discutées, ainsi que la portée des résultats pour les autres pays où coexistent assurance et assistance contre les catastrophes naturelles.

4.1 Introduction

The French overseas departments (French Guiana, Guadeloupe, Martinique and Réunion)[1] are much more exposed to natural risks than continental France (Table 4.1). In particular, Guadeloupe and Martinique are exposed to more intense seismic activity than continental France;[2] according to scientists, a major earthquake is foreseen in each of these two islands in the very next decades.[3] Furthermore, the three islands - i.e. Guadeloupe, Martinique and Réunion - present active volcanos (Grande Soufrière in Guadeloupe, Mount Pelée in Martinique, Piton de la Fournaise in Réunion), whereas the ones in continental France are dormant or extinct (Massif Central, Upper Rhine Plain, Monte Cinto in Corsica). Finally, the three islands are also exposed to strong hurricanes or cyclones,[4] while continental France is only exposed to storms.

Despite their high exposure to natural disasters, half of households living in French overseas departments have not purchased home insurance for their main home, whereas almost all households in continental France have (Table 4.1). In France, the coverage of dwellings against natural disasters is mandatorily included in comprehensive home insurance (Insurance Code, section L. 125-1) and is not offered by any other policy, to my knowledge. Natural disasters insurance is supposed to offer to households a large coverage against main natural events at a regulated price. Indeed, the French natural disasters insurance system corresponds to a tax system: the State provides its unlimited guarantee to the insurance system and regulates in return the price of natural disasters coverage,[5] which is similar to a tax on insured

[1] French Guiana is in South America. Guadeloupe and Martinique are two islands in the Caribbean Sea. Réunion is an island in the Indian Ocean. Until March 2011, the French overseas departments did not include Mayotte. As data was collected in 2006 in French overseas departments, Mayotte is excluded from the study.

[2] See `http://www.planseisme.fr/IMG/jpg/Poster_alea_sismique_avril_2008-2.jpg`.

[3] Major earthquakes occurred in Guadeloupe in 1843 and in Martinique in 1839. Earthquakes of smaller intensity can more frequently happen, such as Les Saintes (Guadeloupe) earthquake on November 21, 2004 and Martinique earthquake on November 29, 2007.

[4] Hurricane Dean damaged Guadeloupe and Martinique on August 16, 2007; Cyclone Dina occurred in Réunion on January 22 and 23, 2002.

[5] The natural disasters premium is a fixed share of the home insurance premium (Insurance Code, section L. 125-2). But insurers are allowed to increase the home insurance premium (and so the natural disasters premium) with respect to natural risk exposure. However, via reinsurance policies and accounting constraints, the State provides low incentives for insurers to strongly increase the natural disasters premium.

Table 4.1: Exposure to major natural risks in France and insurance penetration rate

	French Guiana	Guadeloupe	Martinique	Réunion	Continental France
Exposure to major natural risks					
Earthquakes		x	x	·	·
Volcanism		x	x	x	
Wind effects		x	x	x	·
Tsunamis	·	x	x	x	·
Floods	x	x	x	x	x
Grounds movements	x	x	x	x	x
Forest fires				x	x
Avalanches					x
Population and insurance penetration rate in 2006					
Population (thousands)	202	447	399	784	61 167
Insured households	52%	44%	50%	59%	99%

Caption: x and · respectively design a high and a low risk exposure. The insurance penetration rate is the percentage of insured households.
Notes: Insurance can be purchased by people themselves, by their relatives or their employer. The few households who are insured by their relatives or their employer represent 4% of households living in overseas departments and 2% of households living in continental France. They are here included but will from now be excluded from the analysis.
In French Guiana, the coastal area, which is more exposed to floods, is overrepresented in the sampling plan of the 2006 Family Budget survey (Forgeot and Celma, 2009).
Sources: French Ministry of Ecology; census by INSEE in 1999, registry office and local assessment of population at January 1, 2006; Family Budget survey by INSEE in 2006 (13 374 observations for insurance penetration rate).

households. The scope of the coverage offered to households is wide.[6] In practice, after a natural event, an order establishes, on the basis of scientific reports, whether this event is a natural disaster and which period(s) and jurisdiction(s) are concerned.

The first contribution of this chapter is to determine why exposed overseas households do not purchase home insurance. The causes of underinsurance in French overseas departments have not been studied before, whereas underinsurance in these exposed areas has important consequences in terms of public spending

[6]Natural disasters are defined by the law as "non insurable natural hazards mainly caused by abnormal intensity of a natural agent, when usual measures to prevent from these damages could not prevent their occurring or could not have been taken" (Insurance Code, section L. 125-1, my translation). Natural disasters can be earthquakes, volcanism, hurricanes or cyclones, tsunamis, floods and ground movements. Storms (but neither hurricanes nor cyclones) and fire forests are considered as insurable risks and are covered by unregulated guarantees, which are de facto included in home insurance.

because of the financial implication of the State in the natural disasters insurance system and also in the assistance provided to the uninsured. The strategy consists in considering the different causes of underinsurance and eliminating them one by one.

Conventional wisdom would say that risk exposure increases demand for insurance. A higher risk exposure has two opposite effects on insurance demand: on the one hand, it can increase the premium and so decrease insurance demand; on the other hand, it decreases the expected utility for the uninsured and therefore increases insurance demand. Therefore, the low overseas penetration rate results from the fact that the premium increase effect overcomes the utility loss effect.

The premium increase effect would be important according to the French association of earthquake engineering. Indeed, some of their local reports (Balandier, 2005) describe huge home insurance premiums in overseas departments, which is surprising since the State regulates the price of natural disasters insurance. Nevertheless, given that the median standard of living in French overseas departments is almost 40% lower than the one in continental France (Michel et al., 2010), overseas households could not afford insurance, even at a reasonable price.

The utility loss effect that is anticipated by households can be distorted by perception biases. A wide literature deals with cognitive biases in the perception of extreme risks and their impact on demand for natural disasters insurance (see Tallon and Vergnaud (2007) for a review). For example, perception of low probabilities is reduced because of availability bias (Tversky and Kahneman, 1973), "gambler's fallacy" following from a "belief in the law of small numbers" (Tversky and Kahneman, 1981), the presence of a minimum threshold to look for information because of information cost (Kunreuther and Pauly, 2004), the disability of comparing with other risks (Kunreuther et al., 2001) or wrong discounting future losses (Kunreuther and Kleffner, 1992).

The anticipated utility loss effect can also be reduced by charity hazard: households can rely on financial assistance by government, local authorities, non-governmental

organizations or relatives in the case of a natural disaster. Aid is a substitute for formal insurance and decreases demand for insurance. The amount of financial aid provided to households is important. The main channel of State assistance is the rescue fund for overseas, funded by budgetary credits. The fund compensates partially households for damages due to natural disasters.[7] Other types of financial assistance for reconstruction can be organized by the State.[8] The amount of financial aid that is anticipated by households is difficult to quantify, because of the numerous assistance channels. Furthermore, official statements after natural disasters can make the uninsured believe that they can rely on an important compensation from the State,[9] partly because statements provide a multiplicity of numbers without specifying the identity of the beneficiaries.[10] These announcements have all the more weight in that the amounts of financial assistance can be decided ex post.[11]

The low insurance penetration rate could also be due to a specificity of overseas France: traditional individual housing. Many households live in dwellings that may not meet building standards or may have been built without permit. These dwellings may not be insurable, as building permit can be required by insurers.[12] In French overseas departments, traditional individual dwellings - i.e. made of light materials as wood or sheet metal, of heterogenous quality - represent 13% of dwellings in 2006 (Castéran and Ricroch, 2008); illegal building concerns more of

[7] Low income and uninsured households are eligible to the rescue fund for overseas. Compensation is dedicated to essential furniture in the main home. However, in "extraordinary conditions", compensation for repair or reconstruction of the main home can be given to landowners; the compensation rate for real estate goods is then between 20% and 30%. Homes built in a forbidden area or without building permit and mobile homes are excluded. See order of December 8, 2010 relative to the implementation of help facility by the rescue fund for overseas.

[8] For example, in French Polynesia, following Storm Oli from February 1 to 6, 2010, financial assistance relied on a convention between the Ministry for Overseas and the Caisse des Dépôts et Consignations (Ministry, 2010).

[9] Such as after Les Saintes (Guadeloupe) earthquake on November 21, 2004 (Senate, 2005).

[10] This is confirmed by some back analyzes after disasters, such as the one realized by the French Ministry of Ecology after Hurricane Lenny that hit Guadeloupe and Martinique in November 1999 (Sarant, 2004).

[11] The aid provided by relatives, non-governmental organizations and local authorities is defined ex post. It was also the case for government assistance until 2010: each disaster was followed by a particular order that specified the details of assistance allocation. Allocation amounts and criteria are now defined by the order of December 8, 2010 relative to the implementation of help facility by the rescue fund for overseas.

[12] In practice, this check can be done by insurers, not before selling the contract but, once a loss has occurred, before paying compensation. This check can be easily anticipated by households. Moreover, households living in traditional individual dwellings may already be "outside the administrative system" and may unlikely consider insurance purchase.

30% of individual dwellings.[13] The importance of illegal building is partly explained by the specific building property right in the overseas departments: households can own the walls of their dwelling without owning the ground on which it is built.

Proof by elimination requires to identify the determinants of insurance supply and demand, and so to estimate a structural model of insurance market. The second contribution is the specification and the estimation of a classical structural insurance model (Rothschild and Stiglitz (1976), Pauly (1974) and Abel (1986)), which has not (to my knowledge) been tested before. A supply equation explains the insurance premium; a demand equation explains the probability of purchasing insurance and takes into account the fact that the decision to purchase insurance depends on the insurance price. Such an estimation of demand and supply has been performed on other markets such as labor market (Laroque and Salanié, 2002), but is rare and original on insurance market. For example, Browne and Kim (1993) use the national insurance loading charges as a proxy for insurance price to explain the demand for life insurance; Outreville (1996) estimates the national life insurance premium at the equilibrium on insurance market by macroeconomics data on which depend the life insurance demand and supply. Showers and Shotick (1994) use the 1987 Consumer Expenditure Survey and do not get information about the risk exposure of households; they explain the overall demand for insurance (life, health, vehicle...) with respect to households characteristics holding constant the overall unit price of insurance coverage.

Structural approach of insurance supply and demand has not been applied to insurance market, highly probably because finding adequate data is difficult (Chiappori and Salanié, 1997). Indeed, such an analysis requires household-level micro-data combining information about insurance expenditure for the insured, risk exposure and other economic variables for the insured and the uninsured. An original database has been built by crossing the Family Budget survey by INSEE in 2006 - a comprehensive national survey on households' expenditures - with

[13] Illegal building concerns 30% of individual dwellings in Martinique (DIREN, 2005). Similarly, are illegal from 30% to 40% of individual houses in Réunion and in French Antilles - a set of islands to which belong Guadeloupe and Martinique - (Olive and Riviere, 2010). This proportion would be even higher in French Guiana (Garnesson and Hecquet, 2007).

data relative to exposure to natural disasters provided by the French Ministry of Ecology. The Family Budget survey enables to compare the standard of living of French households and their consumption of goods and services, and especially their insurance choices and expenditures. 3 134 households living in French overseas departments have been interviewed. Concerning home insurance, they have detailed whether they have purchased insurance, and, if they have, why and the amount of their premium. The database of the French Ministry of Ecology provides the overall number of orders in each jurisdiction from 1990 (date of the enforcement of the natural disasters insurance system in French overseas departments)[14] to the sampling date.

Elimination strategy enables to preclude standard explanations and to reveal two singular explications for the low overseas insurance penetration rate: traditional individual housing and anticipated assistance. These findings partly fill in the gap in the literature mentioned by Landry and Jahan-Parvar (2011), who explore the determinants of flood insurance demand in the American coastal zone: "finding data that will allow for an assessment of charity hazard vis-à-vis other determinants of flood insurance demand remains an important topic for future research".

The chapter is organized as follows. Section 4.2 presents the model. Supply and demand estimation results are commented by respectively Section 4.3 and Section 4.4. Section 4.5 discusses their implications in terms of public policy. Section 4.6 shows that these findings are of significance not only for French overseas departments but also for many other countries where public assistance coexists with insurance.

4.2 Model specification and estimation method

I estimate a classical structural model of insurance supply and demand (Rothschild and Stiglitz (1976), Pauly (1974) and Abel (1986)). Insurance supply is defined by the nullity of the insurers' expected profit. Insurance demand from households comes from the comparison between their expected utilities with and without insurance and takes into account the fact that the decision to purchase insurance

[14]The French natural disasters insurance regime was created in 1982 and applied first only to continental land. Since August 1, 1990 this law has been enforced in the overseas departments.

depends on the insurance price. The specification is fully parametric and is thereafter detailed; nonparametric identification is also discussed. The estimation relies on a method used in labor economics (Laroque and Salanié, 2002).

The model is estimated within French overseas departments. Indeed, as natural disasters correspond to events of no comparable importance in overseas departments and in continental France, comparison between overseas departments and continental land is limited.[15]

4.2.1 Risk

Risk structure. Each year, a dwelling suffers a loss L_d caused by natural disasters with probability p_d. I assume that uninsured households receive assistance A_d after a disaster. The net loss is thus $L_d - A_d$. Other risks (such as theft, fire, water damages) cause a loss L_o with probability p_o. There is no assistance for damages due to the other risks, as they are individual risks.

For the sake of simplicity, damages due to individual risks (for example theft, fire or water damages) and losses caused by natural disasters (earthquakes or tsunamis) are assumed to be independent events. The wealth $\widetilde{W}$ of a household with an initial income W depends on the state of nature that is realized:

$$\begin{array}{ll} \text{with probability } p_o p_d, & \widetilde{W} = W_{od} = W - L_o - L_d + A_d, \\ \text{with probability } p_o(1-p_d), & \widetilde{W} = W_o = W - L_o, \\ \text{with probability } (1-p_o)p_d, & \widetilde{W} = W_d = W - L_d + A_d, \\ \text{with probability } (1-p_o)(1-p_d), & \widetilde{W} = W. \end{array} \tag{4.1}$$

Loss probabilities. The historical probability of natural disaster depends linearly on the number of past disasters, denoted S, between the enforcement of the insurance system (1990) to the sampling date (2006).[16] S is public information and is so

[15] Nevertheless, I will be able to compare insurance supply between overseas departments and continental land: I will test for a pricing of an overall overseas risk, i.e. of an overall higher probability of natural disasters in the overseas departments.

[16] For example, if we assume that at most one disaster occurs each year, the historical probability that a natural disaster occurs in a jurisdiction is the number of past disasters between 1990 and 2006 over the corresponding number of years, that is $p_d(S) = \frac{S}{17}$. Note that in reality, conditionally on the occurrence of a natural disaster in the jurisdiction, a dwelling located in a jurisdiction is damaged with a certain probability that depends on some characteristics of the dwelling (building

observed by insurers and households. However households can have a biased risk assessment. Therefore I assume that the probabilities of natural disaster as estimated by insurers and by households both increase linearly with respect to jurisdictional past sinistrality, but the two probability coefficients may be different.

$$\text{Insurers: } p_d(S) = pS,\ p \geq 0, \tag{4.2}$$

$$\text{Households: } p'_d(S) = p'S,\ p' \geq 0. \tag{4.3}$$

I also allow for a biased risk assessment p'_o by households, i.e. different from the one p_o by insurers. Neither p_o nor one of its proxies (floor, past losses) are observed.

Losses. The losses due to natural disasters L_d and to other risks L_o both depend on the dwelling characteristics. More precisely, they depend on the furniture and building values. The standard of living Y, i.e. the wealth divided by the household's size,[17] is a proxy for furniture value (mainly jewels and furniture). The number of rooms N is a proxy for building value. Losses also depend on occupancy status, since tenants T do not have to purchase coverage of losses which are already included in the home insurance policy paid by their landlords.[18] These effects are assumed to be multiplicative: the value of furniture in each room increases with respect to the standard of living Y; tenants insure only a fraction $(1-\tau),\ \tau \geq 0$ of the dwelling value; l_o is a multiplicative constant. This leads to

$$L_o = l_o Y^y N^n (1 - \tau T). \tag{4.4}$$

Furthermore, the two losses are assumed to be proportional.

$$L_d = \beta L_o, \beta \geq 0. \tag{4.5}$$

resilience, floor). But these characteristics are not observed.

[17] The standard of living is measured by the income per consumption unit. The first adult counts for one consumption unit. The second adult and each child older than 14 count for 0.5. Younger children count for 0.3.

[18] Coverages already included in landlord's insurance policy are relative to the potential damages to furniture - for the 4% of tenants who rent here a furnished dwelling -, to the structure (walls, foundations) or the ones implying the landlord's liability (structural defects). The difference between furnished and unfurnished rentals is not significant in the premium equation.

Assistance. Data on assistance is not available. I assume that assistance is proportional to the loss L_d in the case of a natural disaster.

$$A_d = \beta'' L_d, 0 \leq \beta'' \leq 1. \tag{4.6}$$

Therefore we get

$$\begin{aligned} L_d - A_d &= (1 - \beta'')\beta L_o, \\ &= \beta' L_o \text{ with } 0 \leq \beta' \leq \beta. \end{aligned} \tag{4.7}$$

Note that this specification of risk exposure means that a household who is more exposed to natural disasters (respectively to other risks), all other things being equal, has a higher probability p_d (respectively p_o) to face the same loss $L_d - A_d$ (respectively L_o).

4.2.2 Supply

Insurance contract. For the sake of simplicity, I assume that a unique standardized contract with full coverage is offered by insurers. Therefore households either purchase home insurance ($\alpha = 1$) or not ($\alpha = 0$).

Nullity of expected profit. Insurance companies are assumed to be price takers. Competition on insurance market and risk neutrality of insurers imply the nullity of the insurers' expected profit on each group of identical households (for what is observed by the insurers). Nullity of expected profit means that the amount of collected premiums equals the expected losses. As I do not observe p_o, I can only consider the nullity of the expected profit of home insurance on every set of identical households for what I observe, in particular for an average $\overline{p_o}$.

$$\begin{aligned} \pi &= \overline{p_o} L_o + p_d L_d, \\ &= \overline{p_o} L_o + pS\beta L_o, \\ &= \overline{p_o} \left(1 + \frac{p\beta}{\overline{p_o}} S\right) L_o. \end{aligned} \tag{4.8}$$

By denoting

$$P = \frac{p\beta}{\overline{p_o}}, \tag{4.9}$$

$$P_o = \overline{p_o} l_o. \tag{4.10}$$

and using (4.4), we get

$$\log(\pi) = \log(P_o) + \log(1 + PS) + y\log(Y) + n\log(N) + \log(1 - \tau T). \tag{4.11}$$

Furthermore, the identity of the different insurers is not observed. Therefore only the nullity of the expected profit over all insurers confounded can be considered.

Hazard. Finally, a hazard ε is attached to the supply equation. It corresponds to an error term, which depends in particular on p_o. It is assumed to be normally distributed. Therefore the supply equation becomes

$$\begin{cases} \text{if } \alpha = 1,\ \log(\pi) = \log(P_o) + \log(1 + PS) + y\log(Y) + n\log(N) + \log(1 - \tau T) + \sigma\varepsilon, \\ \text{if } \alpha = 0,\ \pi = 0. \end{cases} \tag{4.12}$$

4.2.3 Demand

Comparison of expected utilities. A household is a risk averse person: his utility function $U(\cdot)$ is concave in income. A household purchases insurance ($\alpha = 1$) if and only if his expected utility EU is higher if he is insured ($\alpha = 1$) than if he is not ($\alpha = 0$).[19]

$$\alpha = 1 \Leftrightarrow EU|_{\alpha=1} \geq EU|_{\alpha=0}. \tag{4.13}$$

Given full insurance of price π, the expected utility of the insured is

$$EU|_{\alpha=1} = U(W - \pi). \tag{4.14}$$

[19]The few households who are insured by their employer or their relatives are excluded from our study.

The expected utility of the uninsured is linear with respect to S and can be written as

$$\begin{aligned} EU|_{\alpha=0} &= p'_o p'_d U(W_{od}) + p'_o(1-p'_d)U(W_o) + (1-p'_o)p'_d U(W_d) + (1-p'_o)(1-p'_d)U(W), \\ &= p'_o U(W_o) + (1-p'_o)U(W) + p'S\Big(p'_o(U(W_{od}) - U(W_o)) + (1-p'_o)(U(W_d) - U(W))\Big), \\ &= EU|_{\alpha=0,S=0} + S\frac{\partial EU|_{\alpha=0}}{\partial S}. \end{aligned} \tag{4.15}$$

To take into account the specificities of overseas departments, I complete this demand equation.

Traditional individual housing. A significant number of houses are traditional individual dwellings, which may not meet building standards and may have been realized without building permit. Data do not provide information about the compliance of the dwellings with building standards or permits. However I can partly control for the dwelling quality by adding a dummy H_c for houses still in construction and three dummies for houses without modern conveniences: without hot water H_w, without drainage H_d and without toilets inside the house H_t.

Insurance incentives. Purchasing home insurance is compulsory for tenants and often required as a condition for obtaining a mortgage. These households have not been excluded from the analysis, because only 70% tenants and 77% homebuyers are insured. This can be explained by the fact that some tenants and some homebuyers choose not to renew their insurance contracts the years following their settling in. Indeed, as there are very few controls once people have moved in, some households choose to cancel insurance expenditure as soon as possible.[20] Dummies for tenants T and for homebuyers B are added to control for these insurance incentives and to measure their impact.

Selection bias. As p'_o is not observed, I can only estimate this demand equation for an average $\overline{p'_o}$. I add the term $\rho\varepsilon$, where ε is the hazard attached to the insurance premium. This term allows for a selection bias, i.e. for correlation between unobserved heterogeneity factors (in particular p_o) that affect the insurance premium

[20] Similarly, in the United States, banks or financial institutions can require the purchase of flood insurance to deliver a mortgage (Browne and Hoyt (2000), Office (1983)). But there is very little monitoring of insurance renewal and many households do not renew their flood insurance policies (Kunreuther and Pauly, 2005).

and the decision to purchase insurance.

Hazard. Another hazard η is also attached to the decision to purchase insurance. It can be interpreted as an assessment error made by households. It is also assumed to be normally distributed. Note that ε and η are assumed to be independent, since possible correlation is taken into account by the selection bias term.

The demand equation is[21]

$$\begin{aligned}\alpha = 1 \Leftrightarrow U(W-\pi) - EU|_{\alpha=0,S=0} - S\frac{\partial EU|_{\alpha=0}}{\partial S} \\ + H_c h_c + H_w h_w + H_d h_d + H_t h_t + Tt + Bb + \rho\varepsilon + \eta \geq 0. \end{aligned} \tag{4.16}$$

Utility function. As recalled by Chiappori and Salanié (2008), risk aversion is very heterogenous between agents. However the model does not enable to identify the individual risk aversion. I assume that

$$U(W) = \log(W). \tag{4.17}$$

This choice is motivated by the following procedure. If I consider a constant relative risk aversion r with respect to income, that is $U(W) = \frac{W^{1-r}}{1-r}$, I cannot identify simultaneously r and some key variables of the demand. Therefore I estimate the relative risk aversion r by fixing the other coefficients as parameters. As this estimation can be sensitive to the parameters choice, I performed it for numerous sets of initial parameters and found values close to 1. Therefore I assume $U(W) = \log(W)$, which is the limit case of $U(W) = \frac{W^{1-r}}{1-r}$ as r tends to 1.

The demand equation becomes

$$\begin{aligned}\alpha = 1 \Leftrightarrow \gamma \log(W-\pi) - \overline{p'_o}\log(W-L_o) - (1-\overline{p'_o})\log(W) \\ - p'S\left[\overline{p'_o}\Big(\log(W-(1+\beta')L_o) - \log(W-L_o) - \log(W-\beta' L_o) + log(W)\Big) + log(W-\beta' L_o) - log(W)\right] \\ + H_c h_c + H_w h_w + H_d h_d + H_t h_t + Tt + Bb + \eta + \rho\varepsilon \geq 0. \end{aligned} \tag{4.18}$$

[21] Note that here hazard η is normalized, but any other term could have been normalized.

4.2.4 Identification

As only expected losses matter to insurers, I can identify separately neither the probability coefficient p and the magnitude of loss β nor the probability coefficient $\overline{p_o}$ and the magnitude of loss l_o in the supply equation. Similarly, the demand equation does not enable to simultaneously identify β', $\overline{p'_o}$, and p'. I estimate p' and consider β', $\overline{p'_o}$ as parameters. Sections 4.3 and 4.4 present the results under the assumptions that

$$(\overline{p_o}, \overline{p'_o}, \beta') = (0.1, 0.1, 2)\,. \tag{4.19}$$

The significativeness and the sign of all the estimated coefficients are robust to the choice of these parameters.

Identifying variables. Identification requires the presence of variables that explain the probability of purchasing insurance but not the insurance premium. These identifying variables are the dummies for houses still in construction and without modern conveniences (H_c, H_w, H_d and H_t).[22] Economically, it means that houses still in construction and without modern conveniences have a lower probability of being covered, because an important proportion of them correspond to uninsurable traditional individual dwellings, but once a house is covered, the price of the coverage does not depend on these characteristics.

Note that the model is overidentified. Identification requires to exclude only one of the four variables to be excluded from the demand equation. In that case, at least two of the three remaining variables are not significant in the premium equation and the one that is significant is so because of correlation with other predictors. Therefore, I choose to keep as identifying variables the whole set of proxies for traditional individual housing.

Nonparametric identification. The estimation relies on a full parametric specification of the model. It remains of interest to see whether the model is non-

[22] When the supply equation is estimated independently from the demand equation, these variables do not significantly explain the premium, except the one for H_d (house without drainage), because this variable is correlated with income: the wealthy households are equipped with drainage.

parametrically identified. Das et al. (2003)' results apply: the model is non-parametrically identified except for the intercept in the premium equation, as a common predictor to the two equations is continuous and one of the identifying variables is discrete.

4.2.5 Estimation method

Estimation is based on maximum likelihood. The probability density function of centered normal distribution with unit variance is denoted $\varphi(\cdot)$ and the cumulative density function is denoted $\Phi(\cdot)$. Besides, I denote

$$\begin{aligned} Z_\alpha = & -\overline{p'_o}\log(W-L_o) - (1-\overline{p'_o})\log(W) \\ & - p'S\left[\overline{p'_o}\Big(\log(W-(1+\beta')L_o) - \log(W-L_o) - \log(W-\beta' L_o) + \log(W)\Big) + \log(W-\beta' L_o) - \log(W)\right] \\ & + H_c h_c + H_w h_w + H_d h_d + H_t h_t + Tt + Bb \qquad (4.20) \\ Z_\pi = & \log(P_o) + \log(1+PS) + y\log(Y) + n\log(N) + \log(1-\tau T). \qquad (4.21) \end{aligned}$$

By symmetry of the normal distribution, the probability of purchasing insurance is

$$Pr\Big(\eta \geq -(\gamma\log(W-\pi) + Z_\alpha + \rho\varepsilon)\Big) = \Phi\Big(\gamma\log(W-\pi) + Z_\alpha + \rho\varepsilon\Big). \qquad (4.22)$$

If the household is insured, the premium is observed and $\varepsilon = (\log(\pi) - Z_\pi)/\sigma$ with probability $1/\sigma\varphi((\log(\pi) - Z_\pi)/\sigma)$. Therefore, if $\alpha = 1$, the likelihood is

$$\frac{1}{\sigma}\varphi\left(\frac{\log(\pi) - Z_\pi}{\sigma}\right)\Phi\left(\gamma\log(W-\pi) + Z_\alpha + \rho\frac{\log(\pi) - Z_\pi}{\sigma}\right), \qquad (4.23)$$

The probability of not purchasing insurance is

$$Pr\Big(\eta \leq -(\gamma\log(W-\pi) + Z_\alpha + \rho\varepsilon)\Big) = 1 - \Phi\Big(\gamma\log(W-\pi) + Z_\alpha + \rho\varepsilon\Big). \qquad (4.24)$$

Here, the premium is not observed and the expected value of this probability has so to be computed over ε. Therefore if $\alpha = 0$, the likelihood is

$$1 - \int_{\mathbb{R}} \underbrace{\Phi\Big(\gamma\log(W - \exp(Z_\pi + \sigma\varepsilon)) + Z_\alpha + \rho\varepsilon\Big)}_{F(\varepsilon)} \varphi(\varepsilon)d\varepsilon. \qquad (4.25)$$

I use the method exposed by Laroque and Salanié (2002) to approximate the integral that appears in the likelihood.[23] Following their estimation method, I denote ε_i the ith m-quantile ($\Phi(\varepsilon_i) = \frac{i}{m}$) and compute $\bar{\varepsilon}_i$, the average normal-weighted point in each interval $[\varepsilon_i, \varepsilon_{i+1}]$. As $x\varphi(x) = -\varphi'(x)$,

$$\bar{\varepsilon}_i = \frac{\int_{\varepsilon_i}^{\varepsilon_{i+1}} x\varphi(x)dx}{\Phi(\varepsilon_{i+1}) - \Phi(\varepsilon_i)} = m\Big[\varphi(\varepsilon_i) - \varphi(\varepsilon_{i+1})\Big], \tag{4.26}$$

and the integral can be approximated by

$$\int_{\mathbb{R}} F(\varepsilon)\varphi(\varepsilon)d\varepsilon \approx \frac{1}{m}\sum_{i=0}^{m-1} F(\bar{\varepsilon}_i). \tag{4.27}$$

The results of the estimation are robust with respect to the choice of the parameter m.

4.3 Supply estimations

4.3.1 Supply within overseas departments

Table 4.2 presents the results of the estimation of the insurance premium (Equation 4.12). The premium increases with respect to the number of natural disasters that occurred in the jurisdiction. An estimation of the probability coefficient $\hat{p}$ for natural disasters can be computed from Table 4.2. Similarly, the loss coefficient $\hat{l_o}$ for other risks can be assessed. Indeed, giving Equations 4.9, 4.10 and 4.19, we get

$$\hat{p} = 0.0008, \tag{4.28}$$

$$\hat{l_o} = 222. \tag{4.29}$$

Furthermore, as expected, the insurance premium increases with respect to the standard of living and the number of rooms of the dwelling, which are proxies for the insured value (furniture and building values). The premium also depends on the occupancy status, because the policy coverage depends on this status.

Note that this estimation takes into account the presence of a selection bias with

[23] Laroque and Salanié (2002) explain the wage and the participation decision on labor market, taking into account the fact that the decision to work depends on the wage. Their estimation is based on maximum likelihood and requires the approximation of a similar integral.

Table 4.2: Estimation results: supply equation

Coefficient	Estimate	Standard error	Pr > |t value|
$\log(P_o)$	3.1	0.25	<0.0001
P	0.016	0.0074	0.0310
y	0.16	0.023	<0.0001
n	0.49	0.056	<0.0001
τ	0.34	0.026	<0.0001
σ	0.58	0.013	<0.0001

Source: Family Budget survey by INSEE in 2006. 2 828 observations.

the demanded quantity of insurance (Table 4.5). In other words, there are some unobserved heterogeneities that explain the probability of purchasing insurance and the insurance premium. The premiums offered to the uninsured can be estimated using the coefficients of the premium equation, that correct the selection bias, and by randomly drawing the residuals in the empirical distribution of the residuals of the premium equation.[24] The premiums offered to the uninsured are in average 2% below the premiums paid by the uninsured; the budget weight of the premium is higher for the uninsured (Table 4.3). Indeed, the uninsured are in average poorer than the insured. The premium and the income of the uninsured are both lower but the premium increases less than proportionally with respect to their income ($\hat{y} < 1$ in Table 4.2).

Table 4.3: Home insurance: premium and budget weight

		Mean	Lower quartile	Upper quartile
Uninsured households				
Overseas departments	Premium (€ 2006)	247	126	281
	Budget weight	2.3%	0.8%	2.5%
Insured households				
Overseas departments	Premium (€ 2006)	253	120	300
	Budget weight	1.3%	0.5%	1.4%
Continental France	Premium (€ 2006)	286	139	298
	Budget weight	1.3%	0.5%	1.3%

Source: Family Budget survey by INSEE in 2006. 13 033 observations.

[24] I follow here the method used by Gurgand and Margolis (2001) to estimate wage offered to the unemployed.

4.3.2 Supply between overseas departments and continental land

Insurance premiums could be priced differently in overseas departments and in continental land. I compare the structures of home insurance premiums in overseas departments and in continental land. Note that I consider the premiums paid by the insured and also the premiums offered to the uninsured.[25]

In order to compare the two pricing structures, I build crossed variables: for example N_{os} and N_{cl} denote the number of rooms of a dwelling located respectively in overseas departments and in continental land. As natural disasters correspond to events of no comparable importance in overseas departments and in continental France, comparing the coefficients of the number of past natural disasters in overseas departments and in continental land is not relevant. I use instead a location dummy in overseas departments $\mathbf{1}_{\text{os}}$ to test for a pricing of an overall overseas risk, i.e. of an overall higher probability of natural disasters or of other losses in overseas departments. Note that the inclusion of the coverage of other dwellings in the policy in continental land D_{cl} is added.[26] I estimate the following equation

$$\begin{aligned}\log(\pi) = \log(P_o) + y_{\text{os}}\log(Y_{\text{os}}) + n_{\text{os}}\log(N_{\text{os}}) + \log(1-\tau_{\text{os}}T_{\text{os}}) + \log\left(1+P_g\mathbf{1}_{\text{os}}\right)\\ + y_{\text{cl}}\log(Y_{\text{cl}}) + n_{\text{cl}}\log(N_{\text{cl}}) + \log(1-\tau_{\text{cl}}T_{\text{cl}}) + \log(1+d_{\text{cl}}D_{\text{cl}}) + \nu\varepsilon'. \quad (4.30)\end{aligned}$$

The pricing structure is similar between overseas departments and continental land (Table 4.4). The slight difference between coefficients is probably due to the difference in the costs of furniture and building materials. An overall overseas risk is not significantly priced and insurance premiums are not significantly higher in overseas departments, all other things being equal. The premiums are in average 12% higher in continental France (Table 4.3), because the insured households have different characteristics: they are wealthier and their premium include the coverage of other dwellings. At the end, the distribution of the budget weight for the insured

[25] Within continental land, as almost all households living in continental France are insured, the premium offered to the few uninsured is simulated thanks to the estimation of the premiums paid by the insured without correcting for a possible selection bias.

[26] The inclusion of the coverage of other dwellings in the policy in overseas departments is not added, because this variable (put to zero for the uninsured) is not significant in the model within overseas departments (Equation 4.12). Note that only very few households in overseas departments possess a second home.

overseas households is quite similar to the one for the insured households living in continental France (Table 4.3).

Table 4.4: Home insurance premium in continental land and overseas departments

Coefficient	Estimate	Standard error	Pr > |t value|
$\log(P_o)$	3.6	0.11	<0.0001
P_g	-0.15	0.15	0.31
y_{os}	0.15	0.016	<0.0001
y_{cl}	0.12	0.011	<0.0001
n_{os}	0.45	0.032	<0.0001
n_{cl}	0.46	0.015	<0.0001
τ_{os}	0.34	0.017	<0.0001
τ_{cl}	0.25	0.011	<0.0001
d_{cl}	0.20	0.04	0.31
ν	0.60	0.0037	<0.0001

Source: Family Budget survey by INSEE in 2006. 13 033 observations.

4.3.3 Insurance pricing

Insurance pricing can strongly vary between companies, for instance between mutual insurance companies and other companies. What is estimated here corresponds to the average pricing over all insurers confounded. These results are not sufficient to determine whether the average pricing of natural risks within overseas departments is actuarial, over- or under-priced. Actually, pricing is said actuarial only with respect to the precision of information used by insurers. In practice, insurers use hazard maps that are build on official maps and supplemented by other information. For example, the French official earthquake map delineates five hazard zones[27] and can be supplemented by public information relative to jurisdictional past sinistrality or by private information collected by insurers on building resilience. Applying an actuarial pricing with respect to one hazard map means that the tariff increases with respect to the hazard degree but is the same inside each hazard zone delimited by the map. Therefore there are inevitably cross-subsidizations between more and less exposed dwellings belonging to a same zone (see Chapter 2 for an analysis of hazard maps used for insurance pricing).

[27]French Guiana belongs to the zone of very low hazard; Guadeloupe and Martinique are in the zone of strongest hazard; Réunion is located in the zone of low hazard. See `http://www.planseisme.fr/spip.php?article19`.

Nevertheless, overseas departments are much more exposed to natural risks than continental France (Table 4.1) and there is no significant pricing of an overall overseas risk (Table 4.4). Thus, beyond the cross-subsidizations due to technical imprecision of risk assessment, overseas departments benefit likely from an insurance subsidy from continental France.

Despite this insurance subsidy, overseas households could not afford insurance, as the median standard of living in French overseas departments is almost 40% lower than the one in continental France (Michel et al., 2010). However, basic statistics relative to the budget weight of insurance premium suggest that insurance premiums do not likely discourage households from purchasing insurance (Table 4.3). Answering properly that question requires estimation of insurance demand and in particular estimation of the effect of premium on insurance demand.

4.4 Demand estimation within overseas departments

4.4.1 Causes of underinsurance

Table 4.5 presents the estimation results for the demand equation in overseas departments (Equation 4.18).

Table 4.5: Estimation results: demand equation

Coefficient	Estimate	Standard error	Pr > |t value|
γ	1.0	0.0067	<0.0001
p'	-0.55	0.098	<0.0001
h_c	-0.66	0.23	0.0037
h_w	-0.93	0.072	<0.0001
h_d	-0.43	0.062	<0.0001
h_t	-0.79	0.19	<0.0001
t	0.41	0.064	<0.0001
b	0.93	0.090	<0.0001
ρ	0.22	0.10	0.0283

Source: Family Budget survey by INSEE in 2006. 2 828 observations.

Small elasticity of insurance demand with respect to premium. The elasticity of insurance demand with respect to the premium can be computed from these results: as the premium increases by 50%, the number of households who are willing to purchase insurance decreases by only 0.8%. Therefore the impact of premium on insurance demand is very limited. We can conclude that households are not discouraged from purchasing insurance by insurance premiums.

Traditional individual housing. As expected, households living in a house in construction or without modern conveniences have a smaller probability of purchasing insurance. Traditional individual dwellings that may not be insurable. Furthermore, their occupants could be "outside the administrative system" and may unlikely consider insurance purchase. Thus, results strongly suggest that this specificity of overseas France partly explains households underinsurance.

Insurance incentives. Tenants and even more homebuyers have a higher probability of purchasing insurance than homeowners. The existing constraints relative to insurance purchase are so operant. These findings relative to traditional individual housing and insurance incentives confirm the basic qualitative conclusions drawn by a preliminary version (Calvet and Grislain-Letrémy, 2010).

Charity hazard. The probability of purchasing insurance decreases with respect to the local past sinistrality.[28] Perception bias could certainly decrease p' and so the demand for insurance but not imply a negative sign for the estimated coefficient $\hat{p}'$: even in the presence of perception bias, the perceived probability of natural disasters increases with respect to past sinistrality. Even when considering the belief in the law of small numbers (once the dwelling has been damaged by a disaster, the probability of being touched again is lower), it may apply after the first disaster, but not after repeated ones.

[28] This result is robust: the negative sign of $\hat{p}'$ and its significance remain when the dummies for tenants and homebuyers or the dummies relative to the quality of the dwelling are not included in the estimation. Furthermore, when estimating the model with $U(W) = \frac{W^{1-r}}{1-r}$ for different relative risk aversions close to 1 ($r \in (0.85, 1.15)$, I found very similar results: especially, $\hat{p}'$ remains significantly negative ($\hat{p}' \in (-1.35, -0.21)$).

I interpret the negative sign of $\hat{p}'$ by the presence of charity hazard. As the probability of natural disaster increases, there are two effects on insurance demand: premium increase and utility loss. As S increases, the price of insurance may increase and reduce this way insurance demand: it is the premium increase effect (PIE). The anticipated loss of utility may also increase and this should on the contrary increase insurance demand: it is the utility loss effect (ULE). If anticipated assistance increases with respect to past sinistrality, this reduces the utility loss effect. This is the charity hazard effect (CHE). More precisely, the sign of $\frac{\partial \alpha}{\partial S}$ is the one of

$$\underbrace{-\frac{\partial \pi}{\partial S}\frac{dU}{dW}}_{\text{PIE}\leq 0}\ \underbrace{\underbrace{-\frac{\partial EU|_{\alpha=0}}{\partial S}}_{\text{ULE}=-p'\text{UL}\geq 0}\ \underbrace{-S\frac{\partial A_d}{\partial S}\frac{\partial^2 EU|_{\alpha=0}}{\partial S \partial A_d}}_{\text{CHE}\leq 0}}_{\text{ULE+CHE}=-\hat{p}'\text{UL}}. \tag{4.31}$$

As data on assistance is not available, estimation enables to capture the charity hazard effect only if it overcomes the utility loss effect, i.e. only if $|\text{CHE}| \geq \text{ULE}$. The negative sign of $\hat{p}'$ confirms the presence of charity hazard and indicates that anticipated assistance by households increases with respect to jurisdictional past sinistrality. Indeed, there is probably a cumulative effect in the anticipation of assistance: households living in jurisdictions where numerous disasters occurred have noticed the importance of assistance, probably more than the other households have; therefore they anticipate higher amounts of ex post aid.

Self-selection on housing market. However, this comparison involves households and dwellings that may not be comparable because of heterogeneities in perception biases or risk aversion. In other words, more exposed households may not purchase insurance because they have higher perception biases or a lower risk aversion. Some other heterogeneities such as in dwelling quality or in wealth are already taken into account in the demand equation.

Even with strong and heterogenous perception biases, it is very unlikely that the more past disasters occur, the lower is the perceived disaster probability. Furthermore, data shows that households who are presumed to be more risk averse do not live in less exposed areas (Table 4.6). The location choice of old people, women, households with children or the ones who purchase car insurance is not significantly

correlated with risk exposure. The households who buy full car coverage even live in more exposed areas. However this effect can traduce a difference more in wealth than in risk aversion: owners of expensive cars have a higher willingness to pay for full coverage. Wealthier households are indeed more numerous to live exposed areas; similarly, note that dwellings of good quality are in average built in more exposed areas, probably because of risk amenities (river sight, fertile ground). Finally, people born in continental land could also be considered as managing risk differently, but their location choice is not significantly correlated with risk exposure.

Table 4.6: Self-selection on housing market: correlation between key variables and past sinistrality

Variable	Correlation value	Pr > |r|
Age	0.025	0.19
Sex (women)	0.035	0.064
Children	-0.0091	0.63
Insured car	0.0070	0.71
Full car coverage	0.067	0.0003
Wealth	0.039	0.038
Place of birth (continental France)	0.00079	0.97

Source: Family Budget survey by INSEE in 2006. 2 828 observations.

Therefore we can conclude that the comparison between households living in more or less exposed areas is valid. Households are not discouraged from purchasing insurance by relatively high insurance premiums but by assistance provided after disasters. Traditional individual housing also decreases demand for home insurance.

4.4.2 Importance of charity hazard

Comparison of the premium increase effect and the charity hazard effect. Estimation results of insurance demand suggest that, as the probability of natural disaster increases, i.e. as S increases, the decrease of insurance demand is mainly explained by charity hazard and not by insurance pricing. However it is worth quantifying the difference between the premium increase effect (PIE) and the charity

hazard effect (CHE). Remind that the sign of $\frac{\partial \alpha}{\partial S}$ is the one of

$$\underbrace{-\frac{\partial \hat{\pi}}{\partial S}\frac{\hat{\gamma}}{W-\hat{\pi}}}_{\text{PIE}\leq 0}\underbrace{-\hat{p}'\hat{U}\hat{L}}_{\text{ULE+CHE}\leq 0}, \tag{4.32}$$

where the assistance effect is captured by the negative estimated value of the sum of the utility loss effect (ULE) and the charity hazard effect, because the latter effect dominates the first one. I estimate and compare the mean values of PIE (-5.6^{-5}) and (ULE+CHE) (-0.08). More precisely, the mean value of the ratio of (ULE+CHE)/PIE is 677 and the variance is low (Table 4.7).

Table 4.7: Comparison of the effects of insurance price and charity hazard on insurance demand

	Mean	Lower quartile	Upper quartile
PIE	-5.6^{-5}	-6.7^{-5}	-2.7^{-5}
ULE+CHE	-0.039	-0.045	-0.018
Ratio (ULE+CHE)/PIE	677	669	681

Source: Family Budget survey by INSEE in 2006. 2 828 observations.

Crowd-out effect on the demand for insurance against other losses. Thus, overseas households probably purchase home insurance mainly to be covered against multiple other losses included in the policy, such as thief or fire. However note that charity hazard induces a crowd-out effect (COE) on the demand for coverage against other losses. S being fixed, an increase in $\overline{p_o}$ and the same increase in $\overline{p'_o}$ modify the demand for insurance. The sign of $\frac{\partial \alpha}{\partial \overline{p_o}}$ is the one of

$$\underbrace{-\frac{\partial \hat{\pi}}{\partial \overline{p_o}}\frac{\hat{\gamma}}{W-\hat{\pi}}}_{\text{PIE}_o\leq 0}+\underbrace{\log(W)-\log(\hat{W}_o)}_{\text{ULE}_o\geq 0}\underbrace{-\hat{p}'S\Big(\log(\hat{W}_{od})-\log(\hat{W}_d)+\log(W)-\log(\hat{W}_o)\Big)}_{\text{COE}\leq 0}. \tag{4.33}$$

The first term is the premium increase effect (PIE$_o$), which decreases insurance demand. Its estimated mean value is negative (-0.039). The second term (ULE$_o$) is to the utility loss effect in the absence of natural disasters, which increases insurance demand; it is positive (+0.034). Without charity hazard, the third term (COE) is the utility loss in the case of natural disaster; it should be positive as well by concavity of the utility function (here the log function). Because of charity hazard, it is negative

(-0.018) (Table 4.8). Therefore, charity hazard decreases the net utility loss in the case of a natural disaster, and this way it decreases the demand for coverage against other losses.

Table 4.8: Crowd-out effect of charity hazard on insurance demand

	Mean	Lower quartile	Upper quartile
PIE_o	-0.039	-0.046	-0.018
ULE_o	0.034	0.016	0.041
COE	-0.018	-0.012	-0.0015

Source: Family Budget survey by INSEE in 2006. 2 828 observations.

External effect of charity hazard. Finally, charity hazard reinforces itself for two main reasons (Kunreuther and Pauly, 2005). First, the more people are uninsured around you, the less you need to insure since the political power of the uninsured grows.[29] Second, social norms impact the decision to purchase insurance: individuals may decide to purchase insurance because they know others who did so; they may think that their relatives have similar preferences to them or have already spent the search costs of gathering information on risk, insurance or relief.

I test for the external effect of charity hazard at the departmental level (Table 4.11 in Appendix). This external effect seems to be unverified at that aggregate level: by comparing these estimation results with the insurance penetration rate ranking (Table 4.1),[30] the charity hazard effect does not decrease with respect to the departmental penetration rate. However this finding may result from different assistance payments histories and other economic and social differences between the four departments.

[29] For example, in health insurance, "there are many different safety net providers of charity care, and these providers may increase their supply of charity care in response to larger numbers of uninsured" (Herring, 2005).

[30] Indeed, the ranking is the same when excluding the households for whom insurance is purchased by their relatives or their employer. In that case, the insurance penetration rate is 47% in French Guiana, 40% in Guadeloupe, 46% in Martinique and 53% in Réunion.

4.5 Discussion

The analysis reveals two main reasons for the low insurance penetration rate in overseas departments: traditional individual housing and charity hazard.

4.5.1 Traditional individual housing

In French overseas departments, traditional individual housing is important, especially in French Guiana. Nevertheless, it is in decline (Table 4.9).

Table 4.9: Dwellings in French overseas departments

Share of (%)	Permanent structures		Dwellings in wood		Traditional huts		Makeshift dwellings	
	in 1999	in 2007	in 1999	in 2007	in 1999	in 2007	in 1999	in 2007
French Guiana	68.0	73.0	16.8	16.4	10.3	6.5	4.8	4.2
Guadeloupe	74.8	89.6	10.1	5.5	12.6	3.6	2.5	1.2
Martinique	88.5	93.7	5.3	3.6	4.4	1.1	1.8	1.7
Réunion	73.7	86.2	10.3	4.2	14.0	8.5	2.1	1.1

Note: only main homes are considered. Dwelling can be a house or an apartment.
Source: population census by INSEE in 1999 and 2007.

Indeed, building aid is already in place (Tjibaou, 2004). This housing policy contributes to the decrease of traditional individual housing in overseas departments and probably partly explains why the penetration rate has been progressively increasing (expect in French Guiana) since 1995 (Table 4.10).[31]

However, the penetration rate remains significantly lower in French overseas departments than in continental France because of charity hazard.

4.5.2 Charity hazard

Charity hazard is not a new issue in the insurance field. It has been shown in particular that providing government aid reduces households' demand for health insurance (Herring (2005), Chernew et al. (2005), Brown and Finkelstein (2008)). As providing ex post assistance reduces households' incentives to purchase insurance

[31] Furthermore, legal evolutions enable landowners of squalid dwellings with neither right nor title to be compensated if public operations require their dwelling to be demolished. See law n^{0}2011-725 of June 23, 2011 relative to informal housing districts and fight against bad housing on overseas departments and regions.

Table 4.10: Evolution of home insurance penetration rate (%) in French overseas departments

	1995	2001	2006
French Guiana	47	38	52
Guadeloupe	29	32	44
Martinique	39	41	50
Réunion	29	45	59

Sources: Family Budget survey by INSEE in 1995, 2001 and 2006. 2 922 observations in 1995, 3 302 in 2001, 3 134 in 2006.

ex ante, it creates a typical Samaritan's dilemma.

One can argue that ex post public assistance is not that much different from ex ante insurance subsidy: public assistance is a cross-subsidization from less exposed taxpayers to more exposed ones; similarly, insurance subsidy is a cross-subsidization from less exposed insured households to more exposed ones. Thus the high proportion of uninsured households would not be a key issue. Coate (1995) answers this very precise objection: the main difference is that compensation by insurance is defined ex ante, whereas compensation by aid is often defined ex post.

First, ex post assistance by the State and local authorities is inefficient because there is no reason to expect that people who provide assistance will choose the optimal level of assistance. In practice, assistance may rely on approximate loss assessment or, even worse, on discretionary decisions. On the contrary, in the framework of the insurance system, the order that establishes whether an event is a natural disaster relies on scientific elements relative to the intensity of the natural event. Besides, as natural disasters assistance is provided by the public and the private sectors, the uninsured can free-ride. To that respect, the assistance providers themselves can consider that the level of assistance is not optimal.

Second, providing ex post assistance reduces self-responsibility and gives no incentive for prevention. It does not refrain households from living in exposed areas or from building vulnerable houses, while these choices increase future losses and so the burden for the whole society. Certainly, in France insurance subsidy

also reduces self-responsibility, but the insurance deductible increases with respect to past sinistrality in order to provide more incentives to undertake prevention measures;[32] increasing the premium with respect to past sinistrality could also be considered.[33] Efficiency of such insurance policies clearly requires that the most exposed households had purchased insurance.

A third argument can be added to Coate (1995)'s ones: public assistance may distort the fiscal system and so redistribution between the rich and the poor. Theory predicts that, if absolute risk aversion decreases with respect to income, demand for actuarial insurance decreases with respect to income (Schlesinger, 2000); therefore the insured are the poor. Interestingly, the insured are here the rich. The first reason is that premiums are likely not actuarial, since insured households benefit from an insurance subsidy. The second and probably more important reason is that low income households benefit from more assistance in the case of disaster: for example, financial assistance by the rescue fund for overseas decreases with respect to income.

A simple reduction of public assistance after disasters is unpopular and so may not be considered by politicians. Economic or regulatory incentives to purchase home insurance would enable to increase the proportion of insured households and then to decrease ex post public financial assistance. The results show that the existing insurance purchase constraints at the moment of the settling in are operant. New regulatory measures - checking insurance renewal and targeting the other uninsured - could be considered.

4.6 Conclusion

This chapter provides additional keys to understand prevention and insurance behaviors in exposed territories. The results are significant not only for the French overseas departments but also for many other countries where public assistance

[32] The individual insurance deductible can be increased in jurisdictions which suffered several natural disasters and made however no risk prevention plan (Insurance Code, section L. 125-1, annex I). As the wide majority of the jurisdictions in French overseas departments have already undertaken or set up such plans, this rule has a small impact in these departments.

[33] For now, increasing the premium with respect to past sinistrality is only considered for comprehensive firm insurance. See `http://www.tresor.bercy.gouv.fr/secteur_financier/haut_comite_place/index.htm`.

coexists with insurance.

In countries which combine public assistance and public insurance against natural disasters, the findings plead for a close coordination of aid and insurance policies. In the United States, flood insurance is offered by the Federal State and is not compulsory. It is purchased by a minority of households (Dixon et al. (2006), Kunreuther (1984)).[34] As there is no supply limitation by the Federal government, the low insurance penetration rate results from a low demand for insurance. Until now, several studies dedicated to natural disasters insurance show that a key explanation for the low demand for natural disasters insurance from households is their biased risk perception and not charity hazard (Kunreuther and Pauly (2006), Browne and Hoyt (2000)).[35] However, "[i]t will be interesting to see whether Hurricane Katrina changes this view [the unexpectedness of Federal assistance] given the highly publicized commitment by the Bush administration to provide billions of dollars in disaster relief to victims" (Kunreuther and Pauly, 2005).[36]

In many other countries, public assistance coexists with private insurance. In Germany, even if assistance is not officially organized by an official entity, provided compensation is important: public aid (funded by the Federal State and the Länder) to households and businesses reached Bn€ 1.7 following the Elbe floods in 2002 (Dumas et al., 2005). Less than 10% of German households have purchased flood insurance (Bouwer et al., 2007). In Canada, public assistance is also developed (through the Disaster Financial Assistance Arrangements and local funds created by some provinces) and Canadian households "do not distinguish between public aids and compensations provided by insurers" (Dumas et al. (2005), my translation). However it is difficult to determine the causality between the development of public

[34] In the United States, flood insurance is purchased by around half of the single-family homes living in Special Flood Hazard Areas - i.e. zones with a 100-year recurrence interval for flood - and by only 1% of single-family homes outside (Dixon et al., 2006).

[35] Browne and Hoyt (2000) test the presence of charity hazard and find a positive correlation between governmental aid and flood insurance purchase - and not a negative one. Their interpretation is that flood exposure may increase both governmental aid and insurance purchase.

[36] In the United States, public assistance has distorted the redistribution system. For example, after Hurricane Andrew in 1992, assistance was funded by the poor. Indeed, to limit public debt, Federal assistance was "counterbalanced by a proportional reduction of social budget. The poor were thus forced to fund the rich's damages" (Davis (1998) as quoted by Favier and Pfister (2007), my translation).

assistance and the low penetration rate of private insurance: was demand for private insurance reduced because of public aid? Or was assistance initially developed to make up for a limited private insurance supply? Investigation of that causality is an object of future research.

4.7 Appendix

Table 4.11: Estimation results when measuring the external effect of charity hazard

Coefficient	Estimate	Standard error	Pr > |t value|
	Supply equation		
$\log(P_o)$	2.6	0.29	<0.0001
P	0.020	0.0077	0.011
y	0.20	0.026	<0.0001
n	0.47	0.055	<0.0001
τ	0.31	0.029	<0.0001
σ	0.59	0.017	<0.0001
	Demand equation		
γ	1.0	0.0080	<0.0001
p'	-0.53	0.13	<0.0001
p'_{FrGui}	-2.04	0.60	0.0006
p'_{Gua}	-0.77	0.22	0.0004
p'_{Mart}	-0.11	0.15	0.48
h_c	-0.66	0.24	0.0047
h_w	-0.88	0.076	<0.0001
h_d	-0.47	0.068	<0.0001
h_t	-0.84	0.20	<0.0001
t	0.42	0.069	<0.0001
b	0.93	0.093	<0.0001
ρ	0.39	0.13	0.0041

Source: Family Budget survey by INSEE in 2006. 2 828 observations.

Chapter 5

Industrial Risks and Housing Prices

This chapter is cowritten with Arthur Katossky (Ecole des Hautes Etudes en Sciences Sociales and French Ministry of Ecology). This work corresponds to the translation of a forthcoming working paper of the French Ministry of Ecology. The conclusions and analysis set in this chapter are those of the authors and indicate neither the views nor the opinions of their institutions.

Abstract

Housing prices can decrease because of proximity to hazardous industrial plants. This effect depends on households' perception of risk and can so be modified by events that change risk perception, such as technological risk prevention plans in France. The impact of these plans is difficult to estimate because their implementation in urban zones is very recent. However, the study of other events modifying risk perception provides partial answer.

This chapter studies areas in the vicinity of hazardous industrial plants near Bordeaux, Dunkirk and Rouen. Applying hedonic price method enables to estimate the effect of proximity to hazardous industrial plants on housing prices. Results suggest that these price differences are modified neither by local incidents, the AZF accident, information policies, nor by the implementation of the technological disasters insurance system.

Keywords: environment, industrial risk, land use, hedonic price method

JEL classification: Q51, R52

Résumé long

Le prix des logements peut diminuer du fait de leur proximité aux installations industrielles dangereuses. Cet effet dépend de la perception du risque par les populations et est donc potentiellement modifié par des événements changeant la perception du risque, tels que les plans de prévention des risques technologiques en France. L'impact de ces plans est difficile à estimer, car les plans mis en œuvre en zones urbanisées sont récents. Cependant, l'analyse d'autres événements modifiant la perception du risque permet d'apporter des premiers éléments.

Ce chapitre étudie trois zones urbaines situées à proximité d'installations industrielles appartenant aux agglomérations françaises de Bordeaux, Dunkerque et Rouen. Ces trois sites industriels correspondent à des perceptions du risque très différentes. La poudrerie de Bordeaux n'est pas forcément vécue comme dangereuse par les riverains. En effet, il s'agit d'une ancienne installation militaire dont seuls les barbelés qui l'entourent sont visibles depuis certains endroits du périmètre d'étude. Par ailleurs, l'installation est particulièrement étendue (650 bâtiments répartis dans 350 hectares) ; le risque est ainsi perçu comme contenu à l'intérieur du complexe industriel. Au contraire, les industries chimiques présentes à Dunkerque et Rouen sont identifiées par les populations comme des industries dangereuses. Les bâtiments, les cheminées ou tout du moins les panaches de fumée sont visibles depuis l'ensemble du périmètre d'étude à Dunkerque. A Rouen par contre, sur certaines zones du périmètre d'étude, les cheminées et silos sont cachés du fait du relief.

Ce chapitre a nécessité un travail important de recueil de données, notamment quant aux caractéristiques extrinsèques des logements (distance aux commerces et services publics, exposition au risque industriel, à d'autres risques et nuisances). L'application de la méthode des prix hédoniques permet d'estimer l'effet de la proximité des usines sur les prix des logements. Ce chapitre montre que les prix sont plus bas à proximité des usines sur les sites de Dunkerque et de Rouen. Les écarts de prix ne sont pas significativement modifiés par les incidents locaux, la catastrophe d'AZF, les dispositifs d'information ni par la mise en place du régime d'assurance catastrophes technologiques.

5.1 Introduction

As in practice households partly bear the cost of a potential industrial accident,[1] housing prices can decrease because of proximity to hazardous industrial plants. Numerous empirical works show that exposure to industrial risks or pollutions decreases the price of dwellings. Different industrial activities have been studied to that respect, in particular chemistry (Carroll et al. (1996), Decker et al. (2005)), waste treatment and storage (see Farber (1998) for a review), storage and distribution of oil (Flower and Ragas, 1994) and of natural gas (Boxall et al., 2005), proximity to an oil pipeline (Simons, 1999) or proximity to an industrial area (Travers (2007), Travers et al. (2009), Sauvage (1997)).

The effect of industrial risk on housing prices depends on households' perception of risk and can so be modified by events that change risk perception. Several empirical works show that real estate prices can be so significantly modified by insurance,[2] information policies (Kohlhase (1991), Maani (1991), Gayer et al. (2000)) or prevention policies, such as technological risk prevention plans in France. These plans were created in 2003 in reaction to the AZF accident on September 21, 2001 in Toulouse.[3] They define high-risk areas and prevention measures, in particular land use limitation near hazardous plants. The 420 plans concern more than 600 plants over more than 900 jurisdictions (communication of the French Ministry of Ecology). Some local players fear that the implementation of these plans will decrease housing prices in high-risk areas (Chabbal, 2005).[4] This price modification is difficult to estimate because the few plans implemented in urban zones are recent.[5] However, the study of other events modifying risk perception

[1] Damages certainly imply the liability of the industrialist, but compensation can be delayed and remain partial. In particular, some physical and moral damages cannot be repaired.

[2] Flood insurance shapes real estate prices (MacDonald et al. (1990), Harrison et al. (2001), Morgan (2007) and Bin et al. (2008)).

[3] See law n^{O}2003-699 of July 30, 2003 relative to prevention of technological and natural risks and to damages repair.

[4] According to Chabbal (2005), local players also fear an increase of the price of technological disasters insurance for households. This fear is not justified, because insurance of households is an insurance for victims: it advances repayment expenses and covers the risk of no responsible identification or its insolvency. Technological disasters premium amounts to a few euros per year. On the contrary, the insurance price for industrialists has strongly increased after the AZF accident (Picard and Chemarin, 2004).

[5] "On September 1st, 2010, 335 plans over 420 were initiated and 50 were implemented " (press release by Chantal Jouanno, French Minister of State for Ecology, October 14, 2010, our traduc-

provides partial answer.

This chapter studies three different areas around industrial plants in France near Bordeaux, Dunkirk and Rouen. The three areas are very different in terms of risk perceptions (Table 5.1). The gunpowder factory near Bordeaux is not necessarily perceived as hazardous by neighboring populations. Indeed, it is a former military plant; only barbed wire can be seen from some places of the study area. Furthermore, the plant is wide (650 buildings over 350 hectares); risk is so perceived as contained. The only nuisance associated to the plant is the transportation of hazardous materials on a precise and limited route.[6] On the contrary, chemical activities near Dunkirk or Rouen are clearly identified as hazardous by local populations. Buildings, chimneys or at least plumes of smoke can be seen from every point of the study area near Dunkirk. However, the presence of a nuclear plant in Gravelines (18 km from Dunkirk) can overshadow the exposure to industrial risks here studied. Near Rouen, chimneys or silos are hidden by landscape in some points of the study area.

All local and national events that can modify risk perception during the study period, that is between 2000 and 2008 inclusive, are considered (Table 5.2).[7] Local events are accidents and information mechanisms. Only one accident happened on January 12, 2007 at Rubis Terminal (storage of liquid flammable and agrochemical products) near Dunkirk.[8] Local policies include the distribution of information leaflets, the update of the emergency plan for households and the implementation of local committees for information and consultation.

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tion).

[6]Source: reports by Technical Studies Center of Public Works of Normandy and Centre, Nord and Picardy, and South West France.

[7]A technological risk prevention plan has been initiated after the end of the study period: on December 15, 2009 near Bordeaux, on February 20, 2009 near Dunkirk and on April 14, 2010 near Rouen.

[8]Neighboring populations saw flames and plumes of smoke. The accident triggered an emergency plan inside the plant and required the intervention of civil fire brigades.

Table 5.1: The three studied areas

Jurisdiction	INSEE code	Population (a)	Population density (a)	Percentage of built area (b)	Average tax revenue (a)	Sports and sociocultural facilities (c)	Distance to labor pool (d)	Nuisances in terms of air quality / odor (due or not to the plants) (e) / complains for sound pollutions due to the plants (f)	Industrial plants
Bordeaux									
Le Haillan	33200	8 378	904 per sq km	8%	26 817 €	14	5.9 km	-	2 high-level Seveso plants. Activities: gunpowder and explosives manufacture. Risk: explosion.
Martignas-sur-Jalles	33273	6 633	251 per sq km	2%	29 005 €	27	9.2 km	-	
Mérignac	33281	65 469	1 359 per sq km	9%	23 181 €	72	4.4 km	-	
Saint-Aubin-de-Médoc	33376	5 550	159 per sq km	1%	41 577 €	12	11.1 km	-	
Saint-Médard-en-Jalles	33449	26 984	315 per sq km	3%	27 599 €	48	4.8 km	-	
Le Taillan-Médoc	33519	8 668	571 per sq km	5%	30 412 €	14	4.9 km	-	
Dunkirk									
Coudekerque-Branche	59155	22 994	2 515 per sq km	11%	18 641 €	23	4.3 km	-	5 plants: 4 Seveso, 1 subject to authorization. Activities: storage of oil products, manufacture of lubricants and pharmaceutical products. Risks: explosion, fire, toxic effects.
Dunkirk	59183	69 274	1 855 per sq km	12%	20 218 €	18	4.1 km	-	
Fort-Mardyck	59248	3 586	2 543 per sq km	13%	18 610 €	7	9 km	Odor, complains	
Saint-Pol-sur-Mer	59540	22 100	4 299 per sq km	16%	14 711 €	14	6.2 km	Complains	
Rouen									
Grand-Couronne	76319	9 346	552 per sq km	5%	20 083 €	18	20.5 km	-	13 plants: 2 high-level Seveso, 1 Seveso, 5 subject to authorization and to an emergency plan, 5 authorized. Activities: storage of liquid petroleum gas and refining, paper manufacture, production of Diester oil (biodiesel) and liquid carbon dioxide, goods transportation, perfumes storage and warehouses. Risks: explosion, fire, toxic effects.
Hautot-sur-Seine	76350	9 346	160 per sq km	1%	26 423 €	2	19.3 km	Odor	
Moulineaux	76457	881	238 per sq km	2%	21 287 €	10	20.6 km	-	
Petit-Couronne	76497	8 690	679 per sq km	5%	19 638 €	28	21.1 km	Air quality, odor	
Sahurs	76550	1 310	117 per sq km	1%	27 017 €	5	26.8 km	-	
Val-de-la-Haye	76717	751	74 per sq km	1%	23 673 €	5	20.5 km	Air quality, odor	

Sources: (a) INSEE, (b) building database of the Geographical National Institute, (c) topology database of the Geographical National Institute, (d) Sitranet, (e) Air Quality Agency, (f) Regional Office for Environment, Planning and Housing.

Relevant national events are the AZF accident and the law steps during the study period. The 2003 law created not only technological risk prevention plans, but also the technological disasters insurance system. The aim of this system is to manage the basic coverage for victims by avoiding long litigation and by covering the residual risk of no responsible identification. In addition, by this very same law, the seller or the landlord has to precise in writing whether his dwelling is located in an area covered by a technological (or natural) risk prevention plan.[9] Mandatory information for buyers and tenants was implemented on June 1st, 2006.

Table 5.2: Local and national events that can modify industrial risk perception during the study period

Year	Bordeaux	Dunkirk	Rouen	National level
2001	-	-	-	AZF accident
2002	-	Information leaflets	-	-
2003	-	-	-	Law
2004	-	Update of the emergency plan for households	-	-
2005	-	-	Creation of local committee for information and consultation	-
2006	-	Creation of local committee for information and consultation + information leaflets about the emergency plan for households	-	Mandatory information for buyers and tenants
2007	-	Accident	Information leaflets about the emergency plan for households (∗)	-

(∗) Distribution of information leaflets in all jurisdictions except Moulineaux.
Source: reports by Technical Studies Center of Public Works of Normandy and Centre, Nord and Picardy, and South West France.

Housing prices decrease with respect to the proximity of hazardous plants near Dunkirk and Rouen. Results indicate that these price differences are modified neither by local incidents, the AZF accident, information policies, nor by the implementation of the technological disasters insurance system.

[9] If so, he should also mention whether the dwelling has been damaged by a technological (or natural) disaster. A technological disaster is defined by the law as a non nuclear accident damaging an important number of buildings (more than 500 dwellings made as uninhabitable) and happening either in a plant classified for the environment protection, in an underground storage of hazardous products or on the occasion of hazardous materials transportation (Insurance Code, sections L128-1 and R128).

Our analysis follows hedonic price method formalized by Rosen (1974). The author considers that a dwelling is defined by K attributes $Z = (z_1, ..., z_K)$. Dwelling price corresponds to the combination of attributes at their implicit prices. $Z \rightarrow P(Z)$ is the hedonic price function. A household of income w maximizes his utility function $U(y, Z)$, where y denotes money, under his budget constraint $w = y + P(Z)$.

$$\begin{aligned} &\max_{y, z_1, ..., z_K} U(y, z_1, ..., z_K) \\ &\text{s.t. } w = y + P(z_1, ..., z_K). \end{aligned} \tag{5.1}$$

Households maximize their utility by equalizing their marginal rate of substitution between attribute z_k and money with the marginal price $\partial P(Z)/\partial z_k$, henceforth called implicit price.

$$\frac{\partial P(Z)}{\partial z_k} = \frac{U_{z_k}(y, Z)}{U_y(y, Z)}. \tag{5.2}$$

This marginal rate of substitution corresponds to household's marginal willingness to pay for increasing z_k by one unit. Thus, estimation of the hedonic price function provides an estimation to households' marginal willingness to pay to go one more meter away from the hazardous plants.

The main contribution of this chapter is the quality of data. Indeed, hedonic price method requires data on price and characteristics of the dwellings. These characteristics are intrinsic (number of rooms, of bathrooms, etc.) and extrinsic (proximity to shops and public utilities, exposure to risks or pollutions, etc.). The price of the dwelling and its intrinsic characteristics come from PERVAL notarial data in the years 2000, 2002, 2004, 2006 et 2008. Following Travers et al. (2009), only dwelling purchases (as opposed to rentings) have been considered. Detailed data relative to extrinsic characteristics of the dwelling have been collected, standardized and merged with notarial data: the proximity of the dwelling to shops and public utilities, its exposure to industrial risk, other risks or pollutions (Table 5.3). Other characteristics of the jurisdiction have been collected and merged (Table 5.1). The database here used is so unique and much more complete than the ones used for similar studies.[10]

[10]The authors thank Vincent Binet, Rémi Borel, Olivier Dupret, François Filior, Martine Giloppe, Jeanne-Marie Gouiffès and Brigitte Pouget from Technical Studies Center of Public Works of Normandy and Centre, Nord and Picardy, and South West France for data collection and standardization..

An important practical question for data collection was the definition of the study area. It results from a tradeoff between two requirements: the area has to be limited enough to correspond to an homogenous real estate market and broad enough to include dwellings far from the plants than can be considered as a control group. This second criterion aims to limit a potential selection bias: households living near plants may have different unobserved characteristics and may so not be a representative sample of the local population.

The choice of variables measuring risk perception is also crucial. In the literature, three types of variables have been used (Travers et al., 2009): the effective distance between the dwelling and the plant (Kohlhase (1991), Carroll et al. (1996)), a dummy for location in the exposed area (Flower and Ragas, 1994), this area being defined by physical or administrative criteria, or quantitative variables that traduce a gradation of exposure to risk or pollutions created by the plant (Boxall et al. (2005), Decker et al. (2005)).

We use here effective distance between the dwelling and the plant. We consider "authorized plants" (subject to the regime of classified plants for the environment protection) and we distinguish among them "highly hazardous plants" (mainly Seveso plants). Furthermore, four exposed areas had been considered to test for an additional effect of location in these areas on housing prices. The considered areas were the zone of the emergency plan for households and the areas of control for future land use: Z1 area (which corresponds to the area with lethal damages in the case of accident), Z2 (irreversible damages) and Z3 area (breaking of windows). Our analysis could not be based on theses variables as these zones are not wide enough to include a large number of transactions during the study period.[11] Finally, as a same level of risk exposure can be more or less felt depending on the perception of industrial pollutions, we have built a dummy for dwellings near Rouen for view of plants from the dwelling. Other elements relative to pollution perception have also been collected at the jurisdictional level (air or odor pollutions, complains because of sound pollutions) and enable to interpret the effect of the jurisdiction on housing

[11]For example, there is no transaction in the land use control areas during the study period near Bordeaux or Dunkirk; similarly, there is no transaction in the zone of the emergency plan for households near Bordeaux.

price.

Table 5.3: Data at the dwelling level

Intrinsic characteristics (a)	*Extrinsic characteristics*	
Price (including tax) (∗)	Distance to market square	(b), (c)
House or apartment	Distance to drugstore	(b), (c)
Less than 5 years	Distance to food shop	(b), (c), (d)
State (○)	Distance to bus stop	(e)
Living space (⋆)	Distance to park	(e)
Number of rooms	Distance to nursery or primary school	(d), (f)
Number of bathrooms	Distance to high school	(d), (f)
Number of parking lots	Distance to highly dangerous plants (†)	(g)
Presence of terrace	Distance to authorized plants (‡)	(g)
Presence of balcony	View of industrial plants (near Rouen) (◇)	(f)
Presence of elevator	Location in a land use control area (Z1, Z2, Z3)	(h)
Presence of swimming pool	Location in the zone of the emergency plan for households	(i)
Presence of basement	Location in an area exposed to natural risks (▷)	(h)
Presence of cellar	Location in an area exposed to other risks (▷)	(h)
Presence of annexes	Location in a residual pollution area	(j)
Presence of outbuildings	Sound exposure to a land transport facility	(k), (l)
Area of land	Sound exposure to an air transport facility	(k), (l)
	Location in environmental protection area	(h)
	Location in conservation easement area	(h)

Sources: (a) PERVAL, (b) Chambers of Commerce and Industry database, (c) jurisdictional database, (d) phone book, (e) topology database of National Geographical Institute, (f) building database of National Geographical Institute, (g) database for classified plants per jurisdiction, (h) land use plan, (i) prefecture, (j) Regional Office for Environment, Planning and Housing, (k) sound map of Departmental Office for Territories and Sea, (l) sound map of Technical Studies Center of Public Works.

Notes: each distant to a facility is built as the distance to the closest facility.
(∗) Database is essentially composed by older property. Thus prices have been discounted by the seasonally adjusted price index for older property. This index (built by INSEE) is based on PERVAL database.
(○) Good, works to do or to renovate.
(⋆) Living space is filled in for 81% of observations near Bordeaux, 80% near Dunkirk and 62% near Rouen. The imputed value for missing values is the average living space over the five closest neighboring dwellings with the same number of rooms. Price per square meter is thus inferred.
(†) Most hazardous plants among the classified plants for the environment protection (mainly Seveso plants).
(‡) Plants subject to the regime of classified plants for the environment protection.
(◇) View from the dwelling of red and white Pétroplus chimney or of Senalia silo.
(▷) Area of servitude or notification.

5.2 Model

Estimation of the hedonic price function enables to measure the effect of proximity to hazardous plants on housing prices and to what extend considered events modify this effect.

5.2.1 Estimation problems

Some estimation problems are specific to hedonic price method. First, functional form of hedonic price function depends on underlying assumptions on demand and supply. Unless making very specific assumptions, the hedonic price function is not linear and has no known explicit form (see Freeman (2003) for a review on hedonic price method).

Second, there can be a spatial dependency, called *spatial autocorrelation*, between geographical observations. This corresponds to effects of close neighborhood. The dwelling price can directly depend on the price of former neighboring transactions. This dependency is so called *spatial lag*. For example, the buyer gets information relative to former neighboring transactions (on the web or via real estate agencies) and uses these elements to establish his willingness to pay for the dwelling. Spatial autocorrelation can also result from the error term, because some omitted or unobserved variables present a spatial configuration. With this dependency called *spatial errors*, estimation is potentially biased. For example, if areas close to industrial plants are characterized by strong criminality and if households care for safety, then omitting safety variables leads to an overestimation of households' willingness to pay to reduce their exposure to industrial risk. Note that here, historical links between cities and industries suggest that the most exposed areas are not the most deprived,[12] but other omitted variables can bias results.

5.2.2 Answers brought by literature

Literature brings answers to these estimation problems. To choose the functional form, the usual approach consists in narrowing this form as less as possible and then in determining the form that explains at best the housing price. The wide majority of articles applying hedonic price method use Box-Cox transformations for the dependent variable (housing price) or for continuous regressors (Kuminoff et al.,

[12]Near Bordeaux, jurisdictions in the neighborhood on the gunpowder factory were initially developed thanks to its activity; urban development was then explained by attraction to Bordeaux center. Near Dunkirk, after World War II, urbanization was realized around industrial activities which were not perceived as hazardous (shipyards, steel industry); hazardous plants (chemistry, petrochemistry) only appeared in Dunkirk harbor in the 1970s. Near Rouen, cities get closer and closer to the plants.

2010). According to Box and Cox (1964), the transformation $x^{(\beta)}$ of variable x is

$$x^{(\beta)} = \begin{cases} \dfrac{x^\beta - 1}{\beta} & \text{if } \beta \neq 0, \quad (5.3) \\ \log(x) & \text{if } \beta = 0. \quad (5.4) \end{cases}$$

This transformation generalizes log or power functions. However, the aim of this chapter is not to estimate the hedonic price function, but only the implicit price of one characteristic of the dwelling. Given this goal, several articles warn of a very elaborated specification. Cassel and Mendelsohn (1985) and Cropper et al. (1988) show that the form that explains at best the housing price does not necessarily lead to a more precise estimation of the implicit price of the considered characteristics.[13]

The majority of articles consider one or several of the following models: the linear model (Lin), the log-linear one (Loglin), the log-log one (Loglog), the quadratic one (Quad), the linear Box-Cox one (BoxCox) and the quadratic Box-Cox one (Quad-BoxCox). K denotes the set of regressors and among them K_d is the set of discrete regressors and K_c is the set of continuous ones.

Linear	P	$= \sum_{k \in K} p_k z_k,$	(Lin)
Log-linear	$\ln(P)$	$= \sum_{k \in K} p_k z_k,$	(Loglin)
Log-log	$\ln(P)$	$= \sum_{k \in K_c} p_k \ln(z_k) + \sum_{k \in K_d} p_k z_k,$	(Loglog)
Quadratic	P	$= \sum_{k \in K} p_k z_k + \sum_{(k,k') \in K^2} \frac{p_{kk'}}{2} z_k z_{k'},$	(Quad)
Linear Box-Cox	$P^{(\beta_p)}$	$= \sum_{k \in K_c} p_k z_k^{(\beta_z)} + \sum_{k \in K_d} p_k z_k,$	(BoxCox2)
Quadratic Box-Cox	$P^{(\beta_p)}$	$= \sum_{k \in K_c} p_k z_k^{(\beta_z)} + \sum_{k \in K_d} p_k z_k + \sum_{(k,k') \in K_c^2} \frac{p_{kk'}}{2} z_k^{(\beta_z)} z_{k'}^{(\beta_z)}$	
		$+ \sum_{(k,k') \in K_c \cdot K_d} \frac{p_{kk'}}{2} z_k^{(\beta_z)} z_{k'} + \sum_{(k,k') \in K_d^2} \frac{p_{kk'}}{2} z_k z_{k'}.$	(QuadBoxCox)

Note: the number for the linear Box-Cox model corresponds to the number of estimated Box-Cox coefficients. There are two of them: β_p for the dependent variable and the same β_z for all continuous regressors.

Some articles use simulated data (Cropper et al. (1988), Kuminoff et al. (2010)). Model is said to perform if it corresponds to a small measurement error, i.e. a small difference between the implicit price as estimated and the one initially simulated.

[13] It corresponds to a typical tradeoff between bias et variance: the number of estimated parameters decreases the bias in the implicit prices estimation but increases their variance.

Cropper et al. (1988) compare estimation errors for the implicit prices between the different considered functional forms, with and without omitted variables. In their article, omitted variables are intrinsic characteristics of the dwelling. They show that "when all attributes are observed, linear and quadratic Box-Cox forms produce lowest mean percentage errors; however, when some attributes are unobserved or are replaced by proxies, linear and linear Box-Cox functions perform best."

Thus, Cropper et al. (1988) recommend to estimate a linear Box-Cox function where all transformed regressors have the same Box-Cox coefficient, except for the regressors of interest. Palmquist (1991) and Freeman (2003) also suggest to estimate one coefficient β_i for the regressor of interest and one same coefficient β_z for all other continuous regressors. We will keep this functional form on the basis of likelihood criteria.

Still with simulated data, Kuminoff et al. (2010) revisit Cropper et al. (1988) results and take into account the increasing size of samples and the evolution of omitted variables (most of the time, extrinsic characteristics of the dwelling). With spatial omitted variables, estimation bias increase in the two quadratic models but these models remain the most performing ones. Furthermore, Kuminoff et al. (2010) show that adding fixed spatial effects pleads for the estimation of flexible functional forms. This addition enables to take into account a potential *spatial heterogeneity*, i.e. the existence of different local real estate markets. It enables this way to capture price variations due to spatial variables potentially omitted. Kuminoff et al. (2010) show that, when adding fixed spatial effects (dummies for *census tract*), estimation biases due to omitted spatial variables disappear almost entirely for every functional form and that variance is reduced.

From the chosen functional form, spatial autocorrelation can be estimated and if needed corrected. Different models corresponding to different types of spatial dependency (spatial errors, spatial lag) or combining them can be estimated. Specific tests enable to compare these models (Figure 5.1).

5.2.3 Comparing estimated models

The linear, log-linear, log-log and linear Box-Cox forms are estimated. Quadratic forms are not considered because the number of variables becomes too important in comparison with the number of observations and because the majority of crossed variables are not significant (in particular the ones which imply the regressors of interest). Following Palmquist (1991) and Freeman (2003), the linear Box-Cox model is estimated with one, two and three coefficients. By denoting K_i the set of regressors of interest:

$$\begin{aligned}
&\text{Linear} && P = \sum_{k\in K} p_k z_k, && \text{(Lin)}\\
&\text{Log-linear} && \ln(P) = \sum_{k\in K} p_k z_k, && \text{(Loglin)}\\
&\text{Log-log} && \ln(P) = \sum_{k\in K_c} p_k \ln(z_k) + \sum_{k\in K_d} p_k z_k, && \text{(Loglog)}\\
&\text{Linear Box-Cox 1} && P^{(\beta)} = \sum_{k\in K} p_k z_k, && \text{(BoxCox1)}\\
&\text{Linear Box-Cox 2} && P^{(\beta_p)} = \sum_{k\in K_c} p_k z_k^{(\beta_z)} + \sum_{k\in K_d} p_k z_k, && \text{(BoxCox2)}\\
&\text{Linear Box-Cox 3} && P^{(\beta_p)} = \sum_{k\in K_i} p_k z_k^{(\beta_i)} + \sum_{k\in K_c\setminus K_i} p_k z_k^{(\beta_z)} + \sum_{k\in K_d} p_k z_k. && \text{(BoxCox3)}
\end{aligned}$$

Note: the number given for the linear Box-Cox models corresponds to the number of estimated Box-Cox coefficients.

Fixed spatial effects are added via dummies for jurisdictions. The linear Box-Cox 3 model is the one that explains at best housing prices near Dunkirk according to the AIC; near Bordeaux and Rouen, the linear Box-Cox 2 model is the one that fits at best data, but the AIC of the linear Box-Cox 2 and 3 models are very close (Table 5.4). As this study aims to estimate the implicit price of distance to plants, we keep the linear Box-Cox 3 model which allows the most flexible link between price and regressors of interest.

From the linear Box-Cox 3 model, models traducing or combining different types of spatial dependency are estimated and compared (Figure 5.1 and Table 5.5). We keep a linear Box-Cox 3 model with spatial errors near Bordeaux and Dunkirk and a Kelejian-Prucha linear Box-Cox 3 near Rouen.

Table 5.4: Comparison of functional forms

Functional form	β_p	β_z	β_i	Parameters	Log-likelihood	AIC
			Bordeaux			
Linear	1	1	1	36	-21 909	43 891
Log-linear	0	1	1	36	-21 828	43 728
Log-log	0	0	0	36	-21 753	43 577
Linear Box-Cox 1	0.4	1	1	37	-21 766	43 606
Linear Box-Cox 2	0.4	0.1	0.1	38	-21 689	43 455
Linear Box-Cox 3	0.4	0.1	0.9	39	-21 689	43 456
			Dunkirk			
Linear	1	1	1	24	-13 152	26 351
Log-linear	0	1	1	24	-13 239	26 525
Log-log	0	0	0	24	-13 205	26 458
Linear Box-Cox 1	0.7	1	1	25	-13 135	26 320
Linear Box-Cox 2	0.7	0.2	0.2	26	-13 106	26 263
Linear Box-Cox 3	0.7	0.1	1.2	27	-13 097	26 247
			Rouen			
Linear	1	1	1	26	-9 575	19 202
Log-linear	0	1	1	26	-9 604	19 260
Log-log	0	0	0	26	-9 599	19 250
Linear Box-Cox 1	0.5	1	1	27	-9 517	19 089
Linear Box-Cox 2	0.5	0.4	0.4	28	-9 506	19 067
Linear Box-Cox 3	0.5	0.4	0.5	29	-9 505	19 069

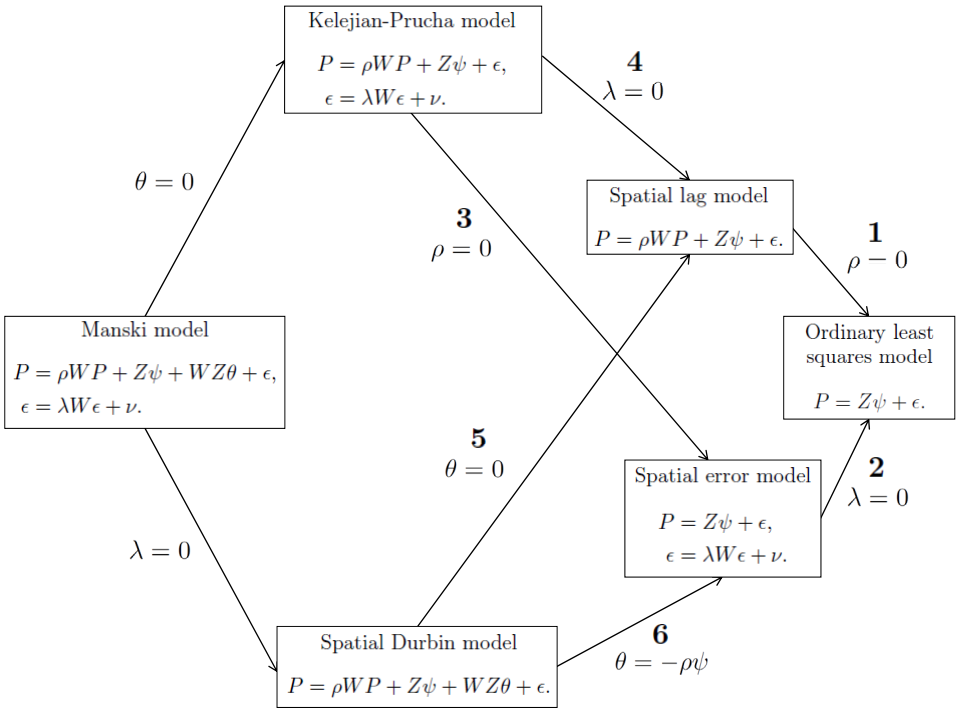
Sources: French solicitors - PERVAL and data collected and standardized by Technical Studies Center of Public Works of Normandy and Centre, Nord and Picardy, and South West France. 1786 observations near Bordeaux, 1134 near Dunkirk and 810 near Rouen.
Note: the Akaike Information Criterion (AIC) enables to compare the likelihoods of the models by taking into account the number of estimated parameters: $AIC = 2m - 2\ln(L)$ where m is the number of parameters and L the likelihood. The model that explains at best housing prices is so the one with the lowest AIC.

Table 5.5: Tests for spatial autocorrelation

	Bordeaux	Dunkirk	Rouen
Moran's test	***	***	***
SARMA test	***	*	***
ρ in *Lag*	*n.s.*	*n.s.*	*n.s.*
λ in *Errors*	***	*	***
ρ in *Kelejian-Prucha*	.	*n.s.*	*
λ in *Kelejian-Prucha*	***	**	***
Test 1	*n.s.*	*n.s.*	**
Test 2	***	*	***
Test 3	*n.s.*	*n.s.*	**
Test 4	***	*	**

Sources: French solicitors - PERVAL and data collected and standardized by Technical Studies Center of Public Works of Normandy and Centre, Nord and Picardy, and South West France. 1786 observations near Bordeaux, 1134 near Dunkirk and 810 near Rouen.
Caption: ./*/**/*** : null hypothesis rejected at the threshold of 10%/5%/1%/0.1%.
Note: these tests are defined by Figure 5.1. They have been performed on the linear Box-Cox 3 model. Their results can be read the following way: the result of test 2 near Bordeaux is significant; null hypothesis $\lambda = 0$ is so rejected and the spatial errors model is so preferred to the ordinary least squares model.

Figure 5.1: Link between the different models taking into account spatial dependency



Source: Elhorst (2010).

Notes: P denotes the housing price, Z the matrix of regressors, n the number of observations and $W = (w_{ij})_{1 \leq i,j \leq n}$ the neighborhood matrix. Let's consider two transactions i and j are realized at dates t_i and t_j and d_{ij} away one from the other. Following Anselin (2002), we choose the weight of transaction j on transaction i as $w_{ij} = \frac{1}{1+d_{ij}}$ if $t_j < t_i$ and 0 otherwise. This way, we assume that only *previous* neighboring transactions weigh on the considered transaction.
The Manski model is the most general model but is difficult to interpret, as "the parameter estimates cannot be interpreted in a meaningful way since the endogenous $[WZ]$ and exogenous $[WP]$ effects cannot be distinguished from each other" (Elhorst, 2010).
The Durbin model badly converges because of collinearity between regressors and lagged regressors. This is due to the fact that many regressors are spatial variables. Thus, tests 5 and 6 which compare the Durbin model with respectively the spatial lag model and the spatial error model are not performed.
We denote $LM_{M/CM}$ the Lagrange multiplier test between the model M and the constraint model CM. The tests for spatial autocorrelation are

$$\begin{array}{ll} \text{Moran's test :} & \text{under } H_0 : \text{ no spatial autocorrelation, } T_{\text{Moran}} \sim \mathcal{N}(0,1), \\ \text{SARMA test :} & \text{under } H_0 : \rho = \lambda = 0, \; T_{\text{SARMA}} = LM_{\text{Kelejian-Prucha/OLS}} \sim \chi^2_2, \end{array}$$

where T_{Moran} is the centered and reduced value of $I = \frac{\tilde{\varepsilon}' W \tilde{\varepsilon}/S_0}{\tilde{\varepsilon}'\tilde{\varepsilon}/n}$ with $S_0 = \sum_i \sum_j w_{ij}$.

We perform the following tests to compare the Kelejian-Prucha, spatial lag, spatial error and ordinary least squares (OLS) models:

$$\begin{array}{lll} \text{Test 1 :} & (\lambda = 0), \text{ over } H_0 : \rho = 0, & LM_{\text{Lag/OLS}} \sim \chi^2_1 \\ \text{Test 2 :} & (\rho = 0), \text{ over } H_0 : \lambda = 0, & LM_{\text{Error/OLS}} \sim \chi^2_1, \\ \text{Test 3 :} & \forall \lambda, \text{ over } H_0 : \rho = 0, & LM_{\text{Kelejian-Prucha/Error}} \sim \chi^2_1, \\ \text{Test 4 :} & \forall \rho, \text{ over } H_0 : \lambda = 0, & LM_{\text{Kelejian-Prucha/Lag}} \sim \chi^2_1. \end{array}$$

5.2.4 Effect of events that can modify risk perception

How to measure the effect of these events on the implicit price of distance to plants? First, we assume that the considered events that can modify risk perception (Table 5.2) do not change the equilibrium price equation. This is all the more realistic in that exposure to industrial risk affects only a fraction of observations and in that these events do not radically change risk perception.

Let's then consider that there are only two zones, one exposed and one safe. The exposed zone is treated in the sense that is concerned by events modifying risk perception; the safe zone corresponds to the control group. The *difference in differences* method (Greenstone and Gayer, 2009) can be then applied to measure the evolution of the implicit price for the location in the exposed area: it consists in comparing the price difference between the two areas, that is the price for location in the safe area, before and after the event. This would require to cross the dummy for location in exposed area with a dummy for transactions occurring after the event, and to add fixed temporal effects. If prices are discounted, significant coefficients of fixed temporal effects traduce a uniform change on the real estate market. Note that this way we only control for concomitant events that would uniformly modify housing prices.[14]

Here however, the exposure is not defined by the dummy for location in one area but by the continuous variable that is the distance to plants. There are no two groups anymore but numerous groups, which are all the more treated in that they are closer to the plants. The method consists so in comparing the implicit price of distance to plants before and after the event. Following McMillen and McDonald (2004) and Travers et al. (2009), we cross the variable of distance to plants with a dummy for transactions occurring after the event. Otherwise, as explained, we discount prices (Table 5.3) and we add fixed temporal effects via dummies for the transaction year.

[14]Local players have not mentioned any other concomitant event that would modify more or less prices depending of the dwelling location.

Table 5.6: Estimation of the hedonic price function

	Bordeaux		Dunkirk		Rouen	
Intercept	*n.s.*		***	−	***	+
House or apartment *(ref: house)*						
- *apartment*	***	+	***	+	*ex*	
Less than 5 years	***	+	***	+	***	+
State *(ref: missing)*						
- *good*	*ex*		***	+	***	+
- *to renovate or works to do*	***	−	***	−	***	−
Living space	***	+	***	+	***	+
Number of rooms *(ref: 5 rooms)*						
- *1 room or less*	*n.s.*		*ex*		*ex*	
- *2 rooms or less*	***	−	***	−	***	−
- *3 rooms or less*	***	−	*ex*		*	−
- *4 rooms or less*	***	−	***	−	**	−
- *6 rooms or more*	.	+	*	+	*ex*	
Number of bathrooms *(ref: 1 bathroom)*						
- *2 bathrooms and more*	***	+	***	+	***	+
Number of parking lots *(ref: no parking lot)*						
- *1 parking lot and more*	**	+	***	+	***	+
- *2 parking lots and more*	***	+	*ex*		.	+
Terrace	*ex*		*ex*		***	+
Balcony	*ex*		*n.s.*		.	+
Elevator	*n.s.*		*n.s.*		*n.s.*	
Swimming pool	***	+				
Basement	***	+	*	−	***	+
Cellar	*ex*		.	−	*ex*	
Annexes	**	+	***	+	***	+
Outbuildings	*	+	*ex*		*n.s.*	
Area of land	***	+	***	+	***	+
Distance to market square	***	−	*ex*			
Distance to drugstore	.	−	*ex*			
Distance to food shop	*n.s.*		*n.s.*			
- *food shop at less than 250m*	*	−	*ex*		*ex*	
Distance to bus stop	*n.s.*		*n.s.*			
- *bus stop at less than 250m*	*ex*		*	−	*ex*	
- *bus stop at less than 400m*	**	−	*ex*			
Distance to park	***	+	**	+		
- *park at less than 500m*	**	+	*ex*		*n.s.*	
Distance to nursery or primary school	*ex*		*ex*			
Distance to high school	*ex*		*ex*			
- *high school at less than 500m*	*ex*		***	−	*ex*	

	Bordeaux		Dunkirk		Rouen	
Distance to highly hazardous plants	***	−	***	+	*	+
- *2000*	*ref.*		*ref.*		*ref.*	
- *2002*	*n.s*		*n.s.*		*ex*	
- *2004*	*n.s*		*n.s.*		*ex*	
- *2006*	*n.s*		*n.s.*		*ex*	
- *2008*	*n.s*		*n.s.*		*ex*	
Distance to authorized plants	*ex*		*ex*		***	+
View of industrial plants					*n.s.*	
Location in Z1 area					*	+
Location in emergency plan area			*ex*		*n.s.*	
Location in natural risks area	*n.s.*				*n.s.*	
Year						
- *2000*	*ref.*		*ref.*		**	+
- *2002*	*	+	*ex*		*ex*	
- *2004*	*n.s.*		*ex*		*ex*	
- *2008*	*n.s.*		*ex*		*	+
Bordeaux *(ref: Saint-Médard-en-Jalles)*						
- *Le Taillan*	*	−				
- *Le Haillan*	*n.s.*					
- *Martignas-sur-Jalles*	.	+				
- *Saint-Aubin-de-Médoc*	***	+				
Dunkirk *(ref: other jurisdictions)*						
- *Coudekerque-Branche*			.	−		
Rouen *(ref: other jurisdictions)*						
- *Petit-Couronne*					***	+
λ (spatial errors coefficient)	***	0.096	**	0.050	***	0.091
ρ (spatial lag coefficient)					***	0.0067

Caption: grey cell: irrelevant variable in the considered model;
ex: variable excluded by a stepwise procedure;
ref: reference modality; *n.s.*: non significant;
./*/**/***: significant to the threshold of 10%/5%/1%/0.1%.

Sources: French solicitors - PERVAL and data collected and standardized by Technical Studies Center of Public Works of Normandy and Centre, Nord and Picardy, and South West France.
1786 observations near Bordeaux, 1134 near Dunkirk and 810 near Rouen.

Notes: we estimate a linear Box-Cox 3 model with spatial errors near Bordeaux and Dunkirk and a Kelejian-Prucha linear Box-Cox 3 near Rouen. Variables of distance to plants are given in meters in all cases. However, the other distance variables are given in meters near Bordeaux and Dunkirk and in classes near Rouen. Near Bordeaux and Dunkirk, classes have been created; continuous variables and the one per classes have been kept to control for an additional threshold effect.

5.3 Results

5.3.1 Determinants of housing prices

Table 5.6 presents the results of the performed estimations.

Intrinsic characteristics. As expected, the price of the dwelling increases with respect to its state, the fact that it has been built since less than 5 years, its living space, its number of rooms, bathrooms or parking lots, the presence of a terrace, a balcony, a swimming pool, annexes or outbuildings or the area of land.[15]

Extrinsic characteristics. Unsurprisingly, near Bordeaux, distances to market square, drugstore or park decrease housing prices.[16] On the contrary, distances to food shop or bus stop increase housing prices. As the majority of inhabitants own a car, proximity to food shop or bus stop is probably less valued than in cities; they can even correspond to a sound pollution for very close dwellings. Similarly, near Dunkirk, distances to bus stop, park and high school raise the dwelling price. Note that sound pollution due to transport facilities does not modify significantly housing prices.

Distance to hazardous plants. Near Dunkirk and Rouen, proximity to highly dangerous plants decrease housing prices. Near Rouen, proximity to authorized plants has a significant additional effect. But view of plants does not significantly modify housing prices. Still near Rouen, location in Z1 area has a positive effect on prices, all other things being equal and in particular distance to plants. Forbidding building may protect from new neighbors and increase this way housing prices. Location in emergency plan area does not product a significant additional effect on prices. Indeed, the emergency plan for households is an administrative area that future buyers may ignore: information leaflets were distributed in 2006 near Dunkirk and in 2007 near Rouen (Table 5.2) but only inhabitants living in the area

[15] More surprisingly, apartments can be more expensive than houses all other things being equal. But this can be explained by the fact that on average apartments have a lower living space than houses and that this effect is already taken into account via the living space variable.

[16] Distance to park and the fact that the park is at less than 500 meters both increase housing prices, but the magnitude of the latter variable is more important.

at the time of the distribution were informed.

Near Bordeaux, proximity to the gunpowder factory raises housing prices. As mentioned in Introduction, industrial risk is almost not perceived. Anstine (2003) shows that industrial risk, if neither visible nor perceived by odor, air pollution, does not modify real estate prices. Here, proximity to the gunpowder factory is even valued, perhaps because the neighborhoods of the plant are characterized by a green setting and are very quiet places. Besides, the presence of this industry may protect from new neighbors or activities.

Jurisdictional effects. Near Bordeaux, since the beginning of the 2000s, numerous inhabitants choose to live further from Bordeaux in houses with greater area of land. Jurisdictions of Saint-Médard-en-Jalles, Martignas-sur-Jalles and Saint-Aubin-de-Médoc are especially prized, particularly by business executives who work for aerospace industry in the neighborhoods.

Temporal fixed effects. Near Bordeaux, dwellings are more expensive in 2002 all other things being equal; near Rouen, they are more expensive in 2000 and in 2008. Events that can explain these effects have not been identified.

5.3.2 Implicit price of distance to plants

Table 5.7 provides the average implicit price of distance to hazardous plants over the study period.

Table 5.7: Average implicit prices

Variable	Bordeaux	Dunkirk	Rouen
Distance to highly hazardous plants	-	12€/m	3€/m
Distance to authorized plants	-	-	21€/m
Living space	-	502€/m^2	953€/m^2

Sources: French solicitors - PERVAL and data collected and standardized by Technical Studies Center of Public Works of Normandy and Centre, Nord and Picardy, and South West France. 1786 observations near Bordeaux, 1134 near Dunkirk and 810 near Rouen.
Notes: with (BoxCox3), the implicit price equals $\partial \hat{P}/\partial z_k = \hat{p}_k z_k^{\beta_i - 1}/P^{\beta_p - 1}$.
Comparing the precise values between the three regions is not relevant, as this comparison would require similar local real estate markets and risk perceptions.

The average implicit price of distance to plants corresponds to the *average over all buyers* of their marginal willingness to pay to go one more meter away from the plants. Note that this value can be biased because there is a taste-based sorting on housing market. For example, more risk averse households have a higher willingness to pay to live far from the plants; they will therefore choose dwellings that are more distant from the plants. As the study area is centered around the plants, even if it is wide enough, the average implicit price of distance to plants may be underestimated.

As shown by Table 5.7, on average over all the considered buyers, the willingness to pay to go one more meter away from highly dangerous plants is of a few euros near Dunkirk and Rouen. In comparison, on average, the willingness to pay to get one additional square meter is of hundreds of euros. Besides, near Rouen, on average, the willingness to pay to go one more meter away from authorized plants is superior to the one to go one more meter away from highly dangerous plants. This is probably due to the fact that households may more perceive pollutions generated by authorized plants. For example, scrapyards in Grand-Couronne, Moulineaux and Petit-Couronne create sound pollutions; heat production plant in Grand-Couronne creates odor pollutions.

5.3.3 Impact of events that can change risk perception

Let's understand why the events that can change risk perception have no impact on the implicit price of distance to plants.

Local information releases. The creation of a local committee for information and consultation during the study period near Dunkirk and Rouen does not modify housing prices. This is partly explain by the low participation of households to these committees. Information leaflets about risk exposure and prevention measures (for example about emergency plan for households) have no impact either. As we said, very probably some future buyers were not informed. Furthermore, these administrative measures combine information and prevention. Prevention measures can reassure and so balance the impact of risk revelation.

The AZF accident. The absence of impact of the AZF accident on housing prices confirms the results of Travers et al. (2009) near Port-Jérôme harbor (Seine-Maritime, France). However, near Rouen, Grande Paroisse Normandy is settled in. This plant has a similar activity to the AZF plant and belongs to the same company, Grande Paroisse (a subsidiary of Total group). Its presence could have raised public awareness of dangers due to industrial activities.

The 2003 law and the technological disasters insurance system. The technological disasters insurance system improves the coverage of households; its creation in 2003 should so decrease the implicit price of the distance to plants. This coverage is mandatorily included in home insurance, which is widely purchased in metropolitan France (Chapter 4). Nevertheless, the coverage provided by this guarantee is limited to the real estate of main home and probably even ignored by households. This ignorance is all the more probable in that the technological disasters premium is included in the home insurance premium and amounts to a few euros per year. Besides, even if households knew the 2003 law, they could have been more aware of other publicized measures implemented by the law.

The implementation of mandatory information for buyers and tenants. Since June 1st, 2006, the seller or the landlord has to precise in writing whether his dwelling is located in an area covered by a technological (or natural) risk prevention plan and, if so, he should also mention whether the dwelling has been damaged by a technological (or natural) disaster. As technological risk prevention plans were started after the study period, no such information was released. Therefore we cannot estimate the impact of mandatory information on the implicit price of distance to plants.[17]

[17] Only the estimation of the impact of mandatory information on the implicit price of exposure to natural disasters would be possible. Unfortunately, the dwellings near Dunkirk are not exposed to natural risks; near Bordeaux and Rouen, exposure to natural risks does not significantly decrease housing prices (Table 5.6), but this result is not robust as too few dwellings are exposed to natural risks (29 near Rouen and 69 near Bordeaux).

5.4 Conclusion

Results show that housing prices decrease with respect to the proximity of hazardous plants near Dunkirk and Rouen, but not near Bordeaux. The effect of hazardous industrial plants on housing prices depends so on the nature of industrial activities, historical links between cities and industries, and local real estate market. Furthermore, results indicate that these price differences are modified neither by local incidents, the AZF accident, information policies, nor by the implementation of the technological disasters insurance system.

These results provide partial answer on the impact of technological risk prevention plans on housing prices. These plans can reveal risk, but results suggest that the impact on housing prices would probably be low.[18] In addition, implementing plans could *increase* housing prices via three mechanisms. First, setting up additional measures of risk reduction by the industrialists could reduce households' exposure and so increase the price of their dwellings. Second, the plan could imply an exclusion zone in very exposed areas. Results relative to Z1 area near Rouen suggest that this measure could increase housing prices in these zones (by limiting local housing supply and most of all by protecting these dwellings from new neighbors). Third, expropriations could raise housing prices in exposed areas and even beyond, but given the small number of concerned dwellings, this effect probably would be negligible.

Thus, the net impact of technological risk prevention plans on housing prices could be an increase or a decrease of prices in the vicinity of the hazardous plants. The net impact could also be null, as it is the case for natural risk prevention plans (Deronzier and Terra, 2006). Answering properly this question requires a deep analysis several years after the implementation of several technological risk prevention plans in urban areas.

5.5 Appendices

[18] Besides, a plan brings information that will be ineluctably revealed. Thus, in any case, this potential decrease of housing prices would penalize only the current landowners.

Table 5.8: Descriptive statistics of intrinsic characteristics of the dwellings

Variable	Area	Mean	Standard error	Minimum	Maximum
Price (including tax) au January 1st, 2009	Bordeaux	242 727	98 100	31 887	788 572
	Dunkirk	125 920	42 358	13 399	332 241
	Rouen	146 054	63 802	12 159	570 817
House or apartment	Bordeaux	House: 83%		Apartment: 17%	
	Dunkirk	House: 87%		Apartment: 13%	
	Rouen	House: 72%		Apartment: 28%	
Less than 5 years	Bordeaux	Less than 5 years: 23%		More than 5 years: 77%	
	Dunkirk	Less than 5 years: 3%		More than 5 years: 97%	
	Rouen	Less than 5 years: 22%		More than 5 years: 78%	
State (†)	Bordeaux	Good: 91%	Works to do: 7%	To renovate: 2%	
	Dunkirk	Good: 72%	Works to do: 23%	To renovate: 5%	
	Rouen	Good: 80%	Works to do: 13%	To renovate: 7%	
Living space (⋄)	Bordeaux	108	42	19	350
	Dunkirk	96	27	27	300
	Rouen	87	35	30	300
Number of rooms (∗)	Bordeaux	4.6	1.5	0	10
	Dunkirk	4.7	1.3	0	13
	Rouen	4.4	1.6	0	11
Number of bathrooms	Bordeaux	1.3	0.5	0	6
	Dunkirk	-	-	-	-
	Rouen	1.2	0.4	0	3
Number of parking lots	Bordeaux	No parking lot: 357; 1 parking lot: 1196; 2 or more: 233			
	Dunkirk	No parking lot: 1108; 1 parking lot: 77; 2 or more: 11			
	Rouen	No parking lot: 218; 1 parking lot: 407; 2 or more: 211			
Presence of terrace, balcony or loggia	Bordeaux	Yes: 19%		No: 81%	
	Dunkirk	Yes: 4%		No: 96%	
	Rouen	Yes: 15%		No: 85%	
Presence of elevator	Bordeaux	Yes: 3%		No: 97%	
	Dunkirk	Yes: 5%		No: 95%	
	Rouen	Yes: 4%		No: 96%	
Presence of swimming pool	Bordeaux	Yes: 12%		No: 88%	
	Dunkirk	Yes: 0%		No: 100%	
	Rouen	Yes: 0%		No: 100%	
Presence of outbuildings	Bordeaux	Yes: 9%		No: 91%	
	Dunkirk	Yes: 13%		No: 87%	
	Rouen	Yes: 15%		No: 85%	
Area of land	Bordeaux	Median: 800			
	Dunkirk	-			
	Rouen	Median: 493			

Sources: French solicitors - PERVAL and data collected and standardized by Technical Studies Center of Public Works of Normandy and Centre, Nord and Picardy, and South West France.
2006 observations near Bordeaux, 1301 near Dunkirk and 874 near Rouen.
Notes: (∗) Maid's rooms are considered with zero room.
(†) For half of observations near Bordeaux, state is not provided.
(⋄) The imputed living space for missing values is the average living space over the five closest neighboring dwellings with the same number of rooms.

Table 5.9: Descriptive statistics of extrinsic characteristics of the dwellings

Variable	Area	Mean	Standard error	Minimum	Maximum
Proximity to shops and public utilities					
Distance to market square	Bordeaux	$<$ 500 m: 24%		$\geq$ 500 m: 76%	
	Dunkirk	$<$ 500 m: 28%		$\geq$ 500 m: 72%	
	Rouen	$<$ 500 m: 21%		$\geq$ 500 m: 79%	
Distance to drugstore	Bordeaux	$<$ 250 m: 21%		$\geq$ 250 m: 79%	
	Dunkirk	$<$ 250 m: 47%		$\geq$ 250 m: 53%	
	Rouen	$<$ 250 m: 25%		$\geq$ 250 m: 75%	
Distance to food shop	Bordeaux	$<$ 250 m: 23%		$\geq$ 250 m: 77%	
	Dunkirk	$<$ 250 m: 69%		$\geq$ 250 m: 31%	
	Rouen	$<$ 250 m: 43%		$\geq$ 250 m: 57%	
Distance to bus stop	Bordeaux	$<$ 250 m: 52%	Between 250 m and 400 m: 22%		$\geq$ 400 m: 26%
	Dunkirk	$<$ 250 m: 86%	Between 250 m and 400 m: 10%		$\geq$ 400 m: 4%
	Rouen	$<$ 250 m: 75%	Between 250 m and 400 m: 22%		$\geq$ 400 m: 3%
Distance to park	Bordeaux	$<$ 500 m: 37%		$\geq$ 500 m: 63%	
	Dunkirk	$<$ 500 m: 72%		$\geq$ 500 m: 28%	
	Rouen	$<$ 500 m: 24%		$\geq$ 500 m: 76%	
Distance to nursery or primary school	Bordeaux	$<$ 500 m: 34%		$\geq$ 500 m: 66%	
	Dunkirk	$<$ 500 m: 92%		$\geq$ 500 m: 8%	
	Rouen	$<$ 500 m: 31%		$\geq$ 500 m: 69%	
Distance to high school	Bordeaux	$<$ 500 m: 14%		$\geq$ 500 m: 86%	
	Dunkirk	$<$ 500 m: 51%		$\geq$ 500 m: 49%	
	Rouen	$<$ 500 m: 26%		$\geq$ 500 m: 74%	
Exposure to industrial risk					
Distance to highly dangerous plants (m)	Bordeaux	4 626	1 922	532	10 379
	Dunkirk	1 680	907	41	4084
	Rouen	1 323	903	64	5 142
Distance to authorized plants (m)	Bordeaux	1 778	1 027	49	5 279
	Dunkirk	1 294	611	188	3 452
	Rouen	892	564	64	2 884
View of industrial plants	Rouen	Yes: 90%		No: 10%	
Location in a land use control area (Z1 or Z2)	Bordeaux	Irrelevant			
	Dunkirk	Outside: 100%			
	Rouen	Z1: 4%; Z2: 3%; outside: 93%			
Location in the zone of the emergency plan for households	Bordeaux	Yes: 1%		No: 99%	
	Dunkirk	Yes: 28%		No: 72%	
	Rouen	Yes: 77%		No: 23%	
Exposure to other risks or pollutions					
Location in the area of servitude or notification for natural (N) or other (O) risks	Bordeaux	(N) Yes: 3%	(N) No: 97%	(O) Yes: 0%	(O) No: 100%
	Dunkirk	(N) Irrelevant		(O) Yes: 0%	(O) No: 100%
	Rouen	(N) Yes: 3%	(N) No: 97%	(O) Yes: 18%	(O) No: 82%
Location in a residual pollution area	Bordeaux	Irrelevant			
	Dunkirk	Irrelevant			
	Rouen	Yes: 4%		No: 96%	
Sound exposure to a land (L) / air (A) transport facility ($\star$)	Bordeaux	(L) Yes: 2%	(L) No: 98%	(A) Yes: 13%	(A) No: 87%
	Dunkirk	(L) Yes: 37%	(L) No: 63%	(A) Irrelevant	
	Rouen	(L) Yes: 32%	(L) No: 68%	(A) Irrelevant	
Location in environmental protection area	Bordeaux	Yes: 1%		No: 99%	
	Dunkirk	Irrelevant			
	Rouen	Yes: 7%		No: 93%	
Location in conservation easement area	Bordeaux	Yes: 0%		No: 100%	
	Dunkirk	Yes: 3%		No: 97%	
	Rouen	Yes: 37%		No: 63%	

Sources: French solicitors - PERVAL and data collected and standardized by Technical Studies Center of Public Works of Normandy and Centre, Nord and Picardy, and South West France.
2006 observations near Bordeaux, 1301 near Dunkirk and 874 near Rouen.
Notes: ($\star$) A dwelling is considered as exposed to a land transport facility if sound is above 60 dB / to an air transport facility if sound is
above 50 dB.

Chapter 6

Conclusion

Cette thèse apporte des éléments d'évaluation des politiques publiques de prévention et de couverture des risques naturels et technologiques. Chacun des chapitres propose des éléments d'évaluation de ces politiques en analysant notamment les liens entre politiques d'assurance et d'urbanisme (chapitre 2), entre politiques d'assurance et de prévention collective (chapitre 3), entre politiques d'assurance et d'aides publiques (chapitre 4), entre politiques de prévention et immobilier (chapitre 5). Les différents chapitres prennent également en compte les liens entre les politiques publiques nationales et locales. Les implications des résultats sont discutées au sein de chaque chapitre. Cette conclusion s'attache à les décliner spécifiquement dans le cas français.

L'une des particularités du régime français d'assurance contre les catastrophes naturelles est qu'une très large majorité de ménages et d'entreprises sont assurés et bénéficient d'une couverture étendue. Les résultats de cette thèse plaident pour le maintien de cette couverture et pour l'utilisation du fort taux de souscription en France métropolitaine pour permettre une coordination réfléchie des politiques publiques d'assurance et de prévention (chapitres 2 et 3). En Outre-mer, où le taux de pénétration de l'assurance est faible, la situation requiert tout d'abord une meilleure coordination entre les politiques d'assurance et d'aides publiques (chapitre 4).

Dans le cas des risques industriels, la présence de l'industrie responsable du risque complique l'acceptabilité des politiques de prévention. La répartition des coûts et bénéfices des mesures de prévention est en effet un sujet sensible. Le pouvoir de négociation entre le maire et l'industriel détermine cette répartition et l'importance des efforts consentis par les populations et les communes (chapitre 2). L'exemple français des plans de prévention des risques technologiques illustre ce point à plusieurs égards.

Tout d'abord, ce plan est financé par une convention tripartite entre l'Etat, les collectivités locales et l'industriel ; les modalités de cette convention sont décidées au terme de négociations entre les différents acteurs concernés. La répartition d'autres coûts plus indirects fait également l'objet de polémiques. Les acteurs locaux craignent en effet que la mise en place de ces plans révèle le risque industriel et diminue ainsi le prix des logements situés dans les zones exposées. Les résultats suggèrent que cet impact sera limité. En effet, sur les sites de Dunkerque et Rouen, les prix des logements à proximité des usines dangereuses ne sont pas significativement modifiés par les dispositifs d'information (chapitre 5).

Bibliography

Abel, A., 1986. Capital Accumulation with Adverse Selection and Uncertain Lifetimes. Econometrica 54, 1079–97.

AFP, 2011. Xynthia : Le Maire de la Faute-sur-Mer Toujours en Garde A Vue. Technical Report. Agence France Presse - Sud Ouest.

Anderson, J., 2006. Climate Change and Natural Disasters: Scientific Evidence of a Possible Relation Between Recent Natural Disasters and Climate Change. Technical Report. European Parliament.

Anselin, L., 2002. Under the Hood. Issues in the Specification and Interpretation of Spatial Regression Models. Agricultural Economics 27, 247–267.

Anstine, J., 2003. Property Values in a Low Populated Area when Dual Noxious Facilities are Present. Growth and Change 34, 345–358.

Bagstad, K.J., Stapleton, K., D'Agostino, J.R., 2007. Taxes, Subsidies, and Insurance as Drivers of United States Coastal Development. Ecological Economics 63, 285–298.

Balandier, P., 2005. Rapport de Mission de l'AFPS sur le Séisme des Saintes (Guadeloupe) du 21 Novembre 2004. Technical Report. AFPS.

Barredo, J.I., 2009. Normalised Flood Losses in Europe: 1970-2006. Natural Hazards and Earth System Sciences 9, 97–104.

Basta, C., 2009. Risk, Territory and Society: Challenge for a Joint European Regulation. Ph.D. thesis. Civil Engineering and Geosciences / Sustainable Urban Areas Research Centre.

Bevere, L., Rogers, B., Grollimund, B., 2011. Sigma Report: Natural Catastrophes and Man-made Disasters in 2010: A Year of Devastating and Costly Events. Technical Report. Swiss Re.

Bidan, P., 2000. Indemnisation des Catastrophes Naturelles : De la Naissance Vers l'Age Adulte. Risques Numéro 42.

Bin, O., Kruse, J.B., Landry, C.E., 2008. Flood Hazards, Insurance Rates, and Amenities: Evidence from the Coastal Housing Market. Journal of Risk and Insurance 75, 63–82.

Blume, L., Rubinfeld, D.L., Shapiro, P., 1984. The Taking of Land: When Should Compensation be Paid? Quarterly Journal of Economics 99, 71–92.

Botzen, W., Aerts, J., van den Bergh, J., 2009. Willingness of Homeowners to Mitigate Climate Risk through Insurance. Ecological Economics , 2265–2277.

Bouwer, L.M., Huitema, D., Aerts, J.C., 2007. Adaptive Flood Management: The Role of Insurance and Compensation in Europe. Technical Report. 2007 Amsterdam Conference - Conference on the Human Dimensions of Global Environmental Change, 24-26 May 2007, Amsterdam, The Netherlands.

Box, G.E.P., Cox, D.R., 1964. An Analysis of Transformations. Journal of the Royal Statistical Society 26, 211–252.

Boxall, P.C., Chan, W.H., McMillan, M.L., 2005. The Impact of Oil and Natural Gas Facilities on Rural Residential Property Values: A Spatial Hedonic Analysis. Resource and Energy Economics 27, 248–269.

Boyer, M., Porrini, D., 2008. The Efficient Liability Sharing Factor for Environmental Disasters: Lessons for Optimal Insurance Regulation. Geneva Papers 33, 337–362.

Brown, J.R., Finkelstein, A., 2008. The Interaction of Public and Private Insurance: Medicaid and the Long-Term Care Insurance Market. American Economic Review 98, 1083–1102.

Browne, M.J., Hoyt, R.E., 2000. The Demand for Flood Insurance: Empirical Evidence. Journal of Risk and Uncertainty 20:3, 291–306.

Browne, M.J., Kim, K., 1993. An International Analysis of Life Insurance Demand. Journal of Risk and Insurance 60, 616–634.

Burby, R.J., 2001. Flood Insurance and Floodplain Management: the US Experience. Global Environmental Change Part B: Environmental Hazards 3, 111–112.

Burby, R.J., 2006. Hurricane Katrina and the Paradoxes of Government Disaster Policy: Bringing About Wise Governmental Decisions for Hazardous Areas. Annals of the American Academy of Political ad Social Science 604, 171–191.

Burdeau, C., 2004. Environmental Lawyer Pessimistic About Beachfront Change. http://www.chiefengineer.org/content/content_display.cfm/seqnumber_content/1856.htm. Technical Report. Associated Press.

California Hearing, 2005. Risks and Liability: Who is Responsible for Avoiding a California "Katrina", and Who Will Pay If We Do Not? Technical Report. A Joint Hearing of the Judiciary Committee, the Water, Parks and Wildlife Committee, and the Insurance Committee of the California Assembly.

Calvet, L., Grislain-Letrémy, C., 2010. La Faible Couverture des Ménages des DOM Face aux Catastrophes Naturelles : Analyse de la Souscription de l'Assurance Habitation. Etudes et Documents, Ministère de l'Ecologie, de l'Energie, du Développement Durable et de l'Aménagement du Territoire Numéro 24.

Carroll, T.M., Clauretie, T., Jensen, J., Waddoups, M., 1996. The Economic Impact of a Transient Hazard on Property Values: The 1988 PEPCON Explosion in Henderson, Nevada. Journal of Real Estate Finance and Economics 13, 143–167.

Cassel, E., Mendelsohn, R., 1985. The Choice of Functional Forms for Hedonic Price Equations: Comment. Journal of Urban Economics 18, 135–142.

Castéran, B., Ricroch, L., 2008. Les Logements en 2006. Le Confort s'Améliore, Mais Pas Pour Tous. Insee Première Numéro 1202.

Chabbal, J., 2005. Le Risque Invisible, la Non-émergence d'un Problème Public. Politix 18, 169–195.

Chambre d'Agriculture des Ardennes, 2006. Zone de Ralentissement Dynamique des Crues de la Meuse à Mouzon, État des Lieux : Étude Agricole et Foncière 2005-2006. Technical Report.

Charpentier, A., 2008. Insurability of Climate Risks. Geneva Papers 33, 91–109.

Chernew, M., Cutler, D., Keenan, P.S., 2005. Charity Care, Risk Pooling, and the Decline in Private Health Insurance. American Economic Review Papers and

Proceedings of the One Hundred Seventeenth Annual Meeting of the American Economic Association, January 7-9, 2005 95, 209–213.

Chiappori, P.A., Salanié, B., 1997. Empirical Contract Theory: The Case of Insurance Data. European Economic Review 41, 943–950.

Chiappori, P.A., Salanié, B., 2008. Modeling Competition and Market Equilibrium in Insurance: Empirical Issues. American Economic Review: Papers & Proceedings 98, 146–150.

Coate, S., 1995. Altruism, the Samaritan's Dilemma, and Government Transfer Policy. American Economic Review 85, 46–57.

Cropper, M.L., Deck, L.B., McConnell, K.E., 1988. On the Choice of Funtional Form for Hedonic Price Functions. Review of Economics and Statistics 70, 668–675.

Das, M., Newey, W.K., Vella, F., 2003. Nonparametric Estimation of Sample Selection Models. The Review of Economic Studies 70, 33–58.

Davis, M., 1998. Ecology of Fear: Los Angeles and the Imagination of Disaster. Vintage.

Decker, C.S., Nielsen, D.A., Sindt, R.P., 2005. Residential Property Values and Community Right-to-Know Laws: Has the Toxics Release Inventory Had an Impact? Growth and Change 36, 113–133.

Demougin, D., Fluet, C., 2007. Rules of Proof, Courts, and Incentives. CESifo Working Paper Series 2014.

Deronzier, P., Terra, S., 2006. Bénéfices Economiques de la Protection contre le Risque d'Inondation. Document de travail de la Direction des Etudes Economiques et de l'Evaluation Environnementale, Série Etudes 06-E05 Numéro 5.

DIREN, 2005. Tableau de Bord de l'Environnement, Martinique 2005. Technical Report. Direction Régionale de l'Environnement Martinique.

Dixon, L., Clancy, N., Seabury, S.A., Overton, A., 2006. The National Flood Insurance Program's Market Penetration Rate. Technical Report. RAND Corporation.

Doherty, N.A., Grace, M.F., Klein, R.W., Kunreuther, H.C., Michel-Kerjan, E.O., Pauly, M.V., 2008. Managing Large-Scale Risks in a New Era of Catastrophes: Insuring, Mitigating and Financing Recovery from Natural Disasters in the United States. Technical Report. Wharton Risk Management and Decision Processes Center.

Dumas, P., Legrand, A.C.H., Macaire, A., Dimitrov, C., Martin, X., Queffelec, C., 2005. Rapport Particulier sur la Prévention des Risques Naturels et la Responsabilisation des Acteurs. Mission d'Enquête sur le Régime d'Indemnisation des Victimes de Catastrophes Naturelles. IGF, CGPC, IGE.

Ehrlich, I., Becker, G.S., 1972. Market Insurance, Self-insurance, and Self-protection. Journal of Political Economy 80, 623–648.

Elhorst, J.P., 2010. Applied Spatial Econometrics: Raising the Bar. Spatial Economic Analysis 5, 9–28.

Fanchette, S., 2006. De l'Importance des Liens Géographie Physique/Géographie Humaine pour Comprendre les Risques de Submersion des Deltas Surpeuplés. Technical Report 121. Hérodote.

Farber, S., 1998. SURVEY Undesirable Facilities and Property Values: A Summary of Empirical Studies. Ecological Economics 24, 1–14.

Faure, M.G., 2006. Economic Criteria for Compulsory Insurance. Geneva Papers 31, 149–168.

Faure, M.G., Fiore, K., 2008. The Civil Liability of European Nuclear Operators: Which Coverage for the New 2004 Protocols? Evidence from France. International Environmental Agreements: Politics, Law and Economics 8, 227–248.

Favier, R., Pfister, C., 2007. Solidarité et Assurance : Les Sociétés Européennes Face aux Catastrophes (17e-21e s.). CNRS MSH-Alpes. chapter Introduction. pp. 9–13.

FEMA, 2007. Myths and Facts about the National Flood Insurance Program. http://www.floodplain.org/cmsAdmin/uploads/FEMAMythsaboutNFIP.pdf. Technical Report. Federal Emergency Management Agency.

FEMA, 2008. Nearly 5,000 Missouri Families Made Safer Since 1993 Floods. March 28, 2008. http://www.fema.gov/news/newsrelease.fema?id=43074. Technical Report. Federal Emergency Management Agency.

Ferrante, J., 2011. Sociology: A Global Perspective. Wadsworth Cengage Learning.

Flower, P.C., Ragas, W.R., 1994. The Effects of Refineries on Neighborhood Property Values. Journal of Real Estate Research 9, 319–338.

Forgeot, G., Celma, C., 2009. Les Inégalités aux Antilles Guyane : Dix Ans d'Evolution. Technical Report. Institut National de la Statistique et des Etudes Economiques and Caisses d'Allocations Familiales d'Antilles-Guyane.

Frame, D.E., 1998. Housing, Natural Hazards, and Insurance. Journal of Urban Economics 44, 93–109.

Frame, D.E., 2001. Insurance and Community Welfare. Journal of Urban Economics 49, 267–284.

Freeman, A.M., 2003. The Measurement of Environmental and Resource Values: Theory and Methods. Resource for the Future. chapter Property Value Models.

Fujita, M., Thisse, J.F., 2002. Economics of Agglomeration, Cities, Industrial Location and Regional Growth. Cambridge University Press.

Garnesson, C., Hecquet, V., 2007. Le Logement Dans les DOM. Technical Report 67. Antiane.

Garric, A., 2011. Le Colossal Barrage des Trois-Gorges Inquiète la Chine. Le Monde.fr blogs May 24, 2011. http://ecologie.blog.lemonde.fr/2011/05/24/le-colossal-barrage-des-trois-gorges-inquiete-la-chine/.

Gawande, K., Jenkins-Smith, H., 2001. Nuclear Waste Transport and Residential Property Values: Estimating the Effects of Perceived Risks. Journal of Environmental Economics and Management 42, 207–233.

Gayer, T., Hamilton, J.T., Viscusi, W.K., 2000. Private Values of Risk Tradeoffs at Superfund Sites : Housing Market Evidence on Learning about Risk. Review of Economics and Statistics 82, 439–451.

Greenstone, M., Gayer, T., 2009. Quasi-experimental and Experimental Approaches to Environmental Economics. Journal of Environmental Economics and Management 57, 21–44.

Grislain-Letrémy, C., Lemoyne de Forges, S., 2011. Coordinating Flood Insurance and Collective Prevention Policies: A Fiscal Federalism Perspective. CREST Working Papers 11-07.

Grislain-Letrémy, C., Peinturier, C., 2010. Le Régime des Catastrophes Naturelles en France Métropolitaine. Etudes et documents, Ministère de l'Ecologie, de l'Energie, du Développement Durable et de l'Aménagement du Territoire Numéro 22.

Grislain-Letrémy, C., Peinturier, C., 2012. Xynthia, Un An Après. Société Météorologique de France. chapter L'indemnisation des Risques Naturels en France : Enjeux et Perspectives. *A paraître*.

Grossman, S.J., Hart, O.D., 1980. Takeover Bids, The Free-Rider Problem, and the Theory of the Corporation. Bell Journal of Economics 11, 42–64.

Gurgand, M., Margolis, D., 2001. RMI et revenus de travail : une évaluation des gains financiers à l'emploi. Economie et Statistiques 6/7, 103–115.

Harrison, D.M., Smersh, G.T., Schwartz, A.L., 2001. Environmental Determinants of Housing Prices : The Impact of Flood Zone Status. Journal of Real Estate Research 21, 17–38.

Hayes, T.L., Neal, D.A., 2009. Actuarial Rate Review, National Flood Insurance Program. Technical Report. Federal Emergency Management Agency.

Herring, B., 2005. Does Access to Charity Care for the Uninsured Crowd Out Private Health Insurance Coverage? Journal of Health Economics 24, 225–252.

Hofmann, A., 2007. Internalizing Externalities of Loss Prevention Through Insurance Monopoly: An Analysis of Interdependent Risks. Geneva Risk and Insurance Review 32, 91–111.

Kiel, K., McClain, K., 1995. The Effect of an Incinerator Siting on Housing Appreciation Rates. Journal of Urban Economics 37, 311–323.

Kleindorfer, P.R., Kunreuther, H.C., 1999. The Financing of Catastrophic Risks. Chicago Press. chapter Challenges Facing The Insurance Industry in Managing Catastrophic Risks. pp. 149–194.

Kohlhase, J.E., 1991. The Impact of Toxic Waste Sites on Housing Values. Journal of Urban Economics 30, 1–26.

Kok, M., Gelder van, P.H.A.J.M., Vrijling, J.K., Vogelsang, M.P., 2002. Risk of Flooding and Insurance in the Netherlands. New York: Science Press.

Kousky, C., Michel-Kerjan, E., 2010. Come Rain or Shine: Evidence on Flood Insurance Purchases in Florida. Journal of Risk and Insurance 77, 369–397.

Kuminoff, N.V., Parmeter, C.F., Pope, J.C., 2010. Which Hedonic Models Can We Trust to Recover the Marginal Willingness to Pay for Environmental Amenities? Journal of Environmental Economics and Management 60, 145–160.

Kunreuther, H., 1984. Causes of Underinsurance Against Natural Disasters. Geneva Papers on Risk and Insurance 9, 206–220.

Kunreuther, H., 2000. Handbook of Insurance. Kuwers Academic Publishers. chapter Linking Insurance and Mitigation to Manage Natural Disaster Risk. pp. 593–618.

Kunreuther, H., Kleffner, A., 1992. Should Earthquakes Mitigation Measures be Voluntary or Required? Journal of Regulatory Economics 4, 321–333.

Kunreuther, H., Novemsky, N., Kahneman, D., 2001. Making Low Probabilities Useful. Journal of Risk and Uncertainty 23, 103–120.

Kunreuther, H., Pauly, M., 2004. Neglecting Disaster: Why Don't People Insure Against Large Losses? Journal of Risk and Uncertainty 28, 5–21.

Kunreuther, H., Pauly, M., 2005. Insurance Decision-Making and Market Behavior. Foundations and Trends in Microeconomics 1, 63–127.

Kunreuther, H., Pauly, M., 2006. Rules Rather than Discretion: Lessons from Hurricane Katrina. Journal of Risk and Uncertainty 33, 101–116.

Lakdawalla, D., Zanjani, G., 2005. Insurance, Self-Protection and the Economics of Terrorism. Journal of Public Economics 89, 1891–1905.

Landry, C.E., Jahan-Parvar, M.R., 2011. Flood Insurance Coverage in the Coastal Zone. Journal of Risk and Insurance 78, 361–388.

Laroque, G., Salanié, B., 2002. Labour Market Institutions and Employment in France. Journal of Applied Econometrics 17, 25–48.

Latruffe, L., Picard, P., 2005. Assurance des Catastrophes Naturelles: Faut-il Choisir Entre Prévention et Solidarité? Annales d'Économie et de Statistique 78, 33–56.

Letrémy, C., 2009. Assurance des Risques Naturels en France : Sous Quelles Conditions les Assureurs Peuvent-ils Inciter à la Prévention des Catastrophes Naturelles ? en collaboration avec Nicolas Grislain pour la partie modélisation. Etudes et documents, Ministère de l'Ecologie, de l'Energie, du Développement Durable et de l'Aménagement du Territoire Numéro 1.

Lipsey, R.G., Lancaster, K., 1956-1957. The General Theory of Second Best. Review of Economic Studies 24, 11–32.

Lohse, T., Robledo, J.R., Schmidt, U., 2010. Self-insurance and Self-protection as Public Goods. Journal of Risk and Insurance DOI: 10.1111/j.1539-6975.2010.01391.x.

Lünenbürger, B., 2006. The Economics of River Flood Management: A Challenge for the Federal Organization? Ph.D. thesis. Ruprecht-Karl-Universität Heidelberg.

Maani, S.A., 1991. Risk and Information: A Hedonic Price Study in the New Zealand Housing Market. Economic Record 67, 227–236.

MacDonald, D.N., White, H.L., Taube, P.M., Huth, W.L., 1990. Flood Hazard Pricing and Insurance Premium Differentials: Evidence from the Housing Market. Journal of Risk and Insurance 57, 654–663.

McMillen, D.P., McDonald, J., 2004. Reaction of House Prices to a New Rapid Transit Line: Chicago's Midway Line, 1983-1999. Real Estate Economics 32, 463–486.

Miceli, T., Segerson, K., 2006. A Bargaining Model of Holdouts and Takings. University of Connecticut Department of Economics Working Paper Series 22.

Michel, C., Theulière, M., Missègue, N., 2010. Les Inégalités de Revenus entre les DOM et la Métropole. Insee Première Numéro 1279.

Mileti, D.S., 1999. Disasters by Design. A Reassessment of Natural Hazards in the United States. Joseph Henry Press.

Ministry, F.O., 2010. 10 Millions d'Euros pour la Reconstruction de Logements en Polynésie Française à la suite du Cyclone "OLI". Communication by the French Overseas Ministry March 18, 2010. http://www.outre-mer.gouv.fr/?10-millions-d-euros-pour-la-reconstruction-de-logements-en-polynesie.html.

Morgan, A., 2007. The Impact of Hurricane Ivan on Expected Flood Losses, Perceived Flood Risk, and Property Values. Journal of Housing Research 16, 47–60.

Muermann, A., Kunreuther, H., 2008. Self-Protection and Insurance with Interdependencies. Journal of Risk and Uncertainty 36, 103–123.

Naik, G., Oster, S., 2009. Scientists Link China's Dam to Earthquake, Renewing Debate. Wall Street Journal February 7, 2009. http://online.wsj.com/article/SB123391567210056475.html.

Nosal, E., 2001. The Taking of Land: Market Value Compensation Should Be Paid. Journal of Public Economics 82, 431–443.

Office, U.G.A., 1983. The Effect of Premium Increases on Achieving the National Flood Insurance Program's Objectives. Technical Report RCED-83-107.

Olive, V., Riviere, F., 2010. L'Habitat Dans les Outre-mer Français : Progrès, Enjeux, Disparités. Technical Report. Institut d'Emission des Départements d'Outre Mer, Institut d'Emission d'Outre Mer.

Outreville, J.F., 1996. Life Insurance Markets in Developing Countries. Journal of Risk and Insurance 63, 263–278.

Palmquist, R.B., 1991. Measuring the Demand for Environmental Improvement. Amsterdam: North-Holland. chapter Hedonic Methods.

Pauly, M.V., 1974. Overinsurance and Public Provision of Insurance: The Roles of Moral Hazard and Adverse Selection. Quarterly Journal of Economics 88, 44–62.

Pénet, S., 2010. Les Régimes Assurantiels Face Aux Catastrophes, in: Conférence de la FFSA et du Haut Comité Français pour la Défense Civile du 2 juin 2010 : L'Assurance Française Contre les Catastrophes.

Persson, T., Tabellini, G., 1996. Federal Fiscal Constitutions: Risk Sharing and Moral Hazard. Econometrica 64, 623–646.

Picard, P., 2008. Natural Disaster Insurance and the Equity-Efficiency Trade-off. Journal of Risk and Insurance 75, 17–38.

Picard, P., Chemarin, S., 2004. Appréhension et Prévention des Risques Industriels. Technical Report. Cepremap.

Pines, D., Sadka, E., 1986. Comparative Statics Analysis of a Fully Closed City. Journal of Urban Economics 20, 1–20.

Rasmussen, J.L., 1999. Levees and Floodplain Management. Technical Report. U.S. Fish & Wildlife Service.

Rosen, S., 1974. Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition. Journal of Political Economy 82, 34–55.

Rothschild, M., Stiglitz, J., 1976. Equilibrium in Competitive Insurance Markets: An Essay on the Economics of Imperfect Information. Quarterly Journal of Economics 90, 629–649.

Sanseverino-Godfrin, V., 1996. L'Etat, les Compagnies d'Assurance et les Risques Majeurs. Ph.D. thesis. Faculté de droit, des sciences économiques et de gestion, Université de Nice-Sophia-Antipolis.

Sarant, P.M.D., 2004. Retour d'Expérience sur la Prise de Décision et le Jeu des Acteurs : Le Cas du Cyclone Lenny dans les Petites Antilles au Regard du Passé. Chapitre II: Les Approches Documentaires : Données Historiques et Analyse de la Presse. Technical Report. Coris risks consulting.

Sauvage, L., 1997. L'impact du Risque Industriel sur l'Immobilier. Association des Etudes Foncières.

Sauvage, L., 2002. La Maîtrise de l'Urbanisation autour des Sites Industriels à Risque. Etudes foncières 95, 28–29.

Schlesinger, H., 2000. The Theory of Insurance Demand. G. Dionne, Handbook of Insurance. chapter 5. pp. 131–151.

Schneider, S., Semenov, S., Patwardhan, A., Burton, I., Magadza, C., Oppenheimer, M., Pittock, A., Rahman, A., Smith, J., Suarez, A., Yamin, F., 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. chapter 19. pp. 779–810.

Senate, F., 2005. Session at the French Senate on February 17, 2005. Comprehensive report of debates. French Senate http://www.senat.fr/seances/s200502/s20050217/s20050217002.html.

Showers, V.E., Shotick, J.A., 1994. The Effects of Household Characteristics on Demand for Insurance: A Tobit Analysis. Journal of Risk and Insurance 61, 492–502.

Sigma, R., 2011. Catastrophes Naturelles et Techniques en 2010 : Une Année Marquée Par des Evénements Dévastateurs et Coûteux. Technical Report 1. Swiss Re.

Simons, R.A., 1999. The Effect of Pipeline Ruptures on Noncontaminated Residential Easment-Holding Property in Fairfax County. The Appraisal Journal .

Skantz, T.R., Strickland, T.H., 1987. House Prices and a Flood Event: An Empirical Investigation of Market Efficiency. Journal of Real Estate Research 2, 75–83.

Strange, W.C., 1995. Information, Holdouts, and Land Assembly. Journal of Urban Economics 38, 317–332.

Tallon, J.M., Vergnaud, J.C., 2007. Incertitude et Information en Economie de l'Environnement. Université Paris 1 Panthéon-Sorbonne (Post-Print and Working Papers). HAL.

Tatano, H., Yamaguchi, K., Okada, N., 2004. Risk Perception, Location Choice and Land-use Patterns under Disaster Risk: Long-term Consequences of Information Provision in a Spatial Economy. In Yasuhide Okuyama and Stephanie Ei-Ling Chang (eds), Modeling Spatial and Economic Impacts of Disasters, Springer. chapter 9. pp. 163–180.

Tiebout, C.M., 1956. A Pure Theory of Local Expenditures. Journal of Political Economy 64, 416–424.

Tjibaou, M.C., 2004. Le Logement Dans l'Outre-mer Français. Technical Report. Conseil Economique et Social.

Tobin, G.A., 2007. The Levee Love Affair: A Stormy Relationship? Journal of American Water Resources Association 31, Issue 3, 359–367.

Travers, M., 2007. Méthode des Prix Hédoniques et Evaluation des Actifs Environnementaux : Application au Cas du Littoral - Application à l'Estuaire de la Seine. Ph.D. thesis. Thèse de Doctorat en Sciences Economiques, Université de Bretagne Occidentale - Ecole Doctorale des Sciences de la Mer.

Travers, M., Bonnet, E., Chevé, M., Appéré, G., 2009. Risques Industriels et Zone Naturelle Estuarienne : Une Analyse Hédoniste Spatiale. Economie et Prévision 4-5, 136–158.

Tsubokawa, H., 2004. Japan's Earthquake Insurance System. Journal of Japan Association for Earthquake Engineering 4, 154–160.

Tversky, A., Kahneman, D., 1973. Availability: A Heuristic for Judging Frequency and Probability. Cognitive Psychology 5, 207–232.

Tversky, A., Kahneman, D., 1981. The Framing of Decisions and the Psychology of Choice. Science, New Series 211, 453–458.

Uranaka, T., 2011. Japan Says No Limits to Tepco Liability from Nuclear Disaster. Reuters May 2, 2011. http://www.reuters.com/article/2011/05/02/us-japan-tepco-idUSTRE7412PK20110502.

Valluet, F., 1978. De la Règle "L'Etat Est Son Propre Assureur". Revue Générale des Assurances Terrestres .

White, G.F., Haas, J., 1975. Assessment of Research on Natural Hazards. Cambridge, MA: MIT Press.

Zhang, H., 2004. China: Flood Management. Technical Report. WMO/GWP Associated Programme on Flood Management.

Zhu, W., Rong, F., 2010. China's Three Gorges Says Yangtze Flooding Exceeds 1998 Level. Bloomberg News July 20, 2010. http://www.bloomberg.com/news/2010-07-20/three-gorges-dam-reports-water-flows-this-morning-that-exceed-1998-levels.html.

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Vu et permis d'imprimer :

Le Vice-Président du Conseil Scientifique Chargé de la Recherche de l'Université Paris-Dauphine.

Résumé : Les catastrophes naturelles et industrielles sont des risques majeurs qui ont pour particularité commune d'avoir une forte empreinte géographique. Leur principale différence est que l'indemnisation des risques naturels repose sur la solidarité, alors que les risques industriels relèvent de la responsabilité privée de l'industriel. Cette thèse apporte des éléments d'évaluation des politiques publiques de prévention et de couverture des risques naturels et technologiques. Chacun des chapitres propose des éléments d'évaluation de ces politiques en analysant notamment les liens entre politiques d'assurance et d'urbanisme (chapitre 2), entre politiques d'assurance et de prévention collective (chapitre 3), entre politiques d'assurance et d'aides publiques (chapitre 4), entre politiques de prévention et immobilier (chapitre 5). Les différents chapitres prennent en compte les liens entre les politiques publiques nationales et locales.

Mots-clés : catastrophes naturelles, catastrophes industrielles, assurance, prévention, aides publiques.

Abstract: Natural and industrial disasters are major risks with the common specificity of a strong geographic dimension. Their main difference is that compensation for natural disasters relies on solidarity, whereas industrial risks imply the liability of the industrialist. This thesis brings parts of assessment of prevention and coverage policies for natural and industrial risks. Each chapter provides some elements of policies assessment and analyzes in particular links between insurance and urbanism policies (Chapter 2), between insurance and collective prevention policies (Chapter 3), between insurance and assistance policies (Chapter 4), between prevention policies and real estate market (Chapter 5). Interaction between national and local public policies is addressed in each chapter.

Keywords: natural disasters, industrial disasters, insurance, prevention, public assistance.