# Essais sur l'assurance, la prévention et les politiques publiques

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# Essays on Insurance, Prevention and Public Policy

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A Emmanuelle. A mes parents.

A ma grand-mère. A Pierre.

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# Summary

This thesis is a collection of four independent essays on insurance, prevention, and public policy.

The first chapter is a short theoretical paper that investigates the issue of the optimal level of prevention in a partial equilibrium, competitive agricultural economy with incomplete state-contingent claims markets. The representative risk-averse farmer can make use of a preventive input that reduces crop loss in case of an unfavourable climate event (such as chemical or irrigation), but has no access to income insurance that would allow him to trade contingent claims with the representative risk-averse consumer. In line with the natural hedge argument, it is shown that the competitive equilibrium prevention level decreases (increases) with the farmer's risk aversion if price elasticity of demand is elsewhere lower (greater) than one in absolute value. In addition, the paper characterizes the conditions for which the competitive prevention level is higher or lower than the social optimum. Under assumptions that are reasonable in the context of an agricultural market, under-prevention is much more likely to occur, providing a potential rationale for efficiency-enhancing government intervention such as a prevention subsidy. Opening trade is shown to have countervailing effects on prevention choices through opposite changes in risk and returns from prevention.

This second chapter, cowritten with Sabine Lemoyne de Forges, examines (re)insurance firms' capital and pricing decisions in a context of imperfect competition. We develop a model in which firms produce a non-stochastic output, (re)insurance coverage, which is sold before the true cost is known. Competing firms behave as if they were risk-averse for a standard reason of costly external finance. Competition is modelled as a two-stage game: at stage 1, each firm chooses her internal capital level; at stage 2, firms compete on price. We characterize the set of subgame perfect Nash equilibria and analyze the strategic impact of capital choice on the market. We discuss the model with regards to insurance industry specificities and insurance regulation.

The third chapter, cowritten with Raja Chakir, investigates the determinants of rapeseed hail insurance and pesticide decisions using an original panel dataset of French farms covering the period from 1993 to 2004. Economic theory suggests that insurance and prevention decisions are not independent due to risk reduction and/or moral hazard effects. We propose a theoretical framework that integrates two statistically independent sources of risk faced by farmers of our sample –hail risk and pest risk. Statistical tests confirm that pesticide and insurance demands are endogenous to each other, simultaneously determined. An econometric model involving two simultaneous equations with mixed censored/continuous dependent variables is thus estimated for rapeseed. Estimation results show that rapeseed insurance demand has a positive effect on pesticide use and vice versa. Insurance demand is positively influenced by the yield's coefficient of variation and the loss ratio, and negatively influenced by proxies for wealth (CAP subsidies) and activity diversification. The analysis of marginal effects shows that the greatest values of elasticities of insurance demand

include the yield's coefficient of variation (0.255), CAP subsidies (-0.192), and activity diversification variables (-0.161).

The fourth chapter studies prevention choices when agents have social preferences in order to examine the role of solidarity in risk decisions. There is a growing body of evidence that informal transfers play a substantial role in consumption smoothing across states of Nature, providing an implicit safety net when formal risk-sharing arrangements are absent. But informal transfers may also lower incentives to ex-ante risk management. In this chapter we reconsider the Samaritan's dilemma game in the case of a prevention activity against risk. Agents are risk-neutral and inequity averse. They choose a level of prevention that reduces the probability of wealth loss. Once the state of Nature is realized, individual outputs are mutually observable inequity averse agents make transfers to the unlucky. In contrast to the previous literature on the Samaritan's Dilemma which mainly assumes pure altruism preferences, we show that inequity aversion may lead to multiple prevention equilibria. We also discuss the traditional normative conclusion concerning the welfare-enhancing role of in-kind transfer of prevention.

# Résumé

Cette thèse propose quatre essais indépendents sur l'assurance, la prévention, et les politiques publiques associées à ces marchés.

Le premier essai, de nature théorique, s'intéresse au problème du niveau de prévention optimal dans un marché agricole en équilibre partiel sous l'hypothèse de concurrence parfaite et de marchés contingents incomplets. Le producteur représentatif est averse au risque et choisit un niveau d'intrant d'auto-assurance réduisant le niveau de perte de rendement en cas de choc climatique. Nous montrons que si l'élasticité est inférieure (supérieure) à l'unité en valeur absolue, le niveau de prévention diminue (augmente) avec le coefficient d'aversion au risque du producteur en raison de l'effet de couverture naturelle du prix sur le revenu. Nous nous intéressons également aux conditions telles que le niveau de prévention à l'équilibre compétitif est supérieur ou inférieur à celui maximisant le bien-être social. Sous des hypothèses typiques des marchés agricoles (demande faiblement élastique au prix et au revenu, producteurs et consommateurs averses au risque), l'équilibre concurrentiel conduit à une niveau de prévention sous-optimal, engendrant un niveau de risque systémique trop élevé pour les consommateurs et les producteurs. Une intervention de l'Etat sous forme d'aide publique à la prévention permet d'atteindre le niveau socialement optimal. L'ouverture des frontières, par le lissage géographique des chocs climatiques qu'elle engendre, a un effet ambigü sur le niveau de prévention.

Le deuxième chapitre, de nature théorique et co-écrit avec Sabine Lemoyne de Forges, s'intéresse à la détermination du prix de l'assurance et du capital interne sur une ligne présentant un risque systémique dans un contexte d'oligopole. Pour cela, nous développons un modèle dans lequel $n$ entreprises caractérisées par un coût de production stochastique (inversion du cycle de l'assurance), leur produit étant vendu sur le marché avant que la réalisation du coût ne leur soit connu. Les firmes sont supposées être averses au risque en raison d'un coût croissant et convexe du capital externe. Nous considérons le jeu à deux étapes suivant: en première étape, les entreprises déterminent simultanément leur niveau de capital interne, en seconde étape elles se font concurrence sur les prix. Nous caractérisons l'ensemble des équilibres de Nash en sous-jeu parfait du jeu, et montrons que le capital interne représente un coût stratégique pour les entreprises. Nous montrons alors que la concurrence imparfaite conduit à un niveau de capital interne inférieur à celui assurant la maximisation du bien-être social, et discutons de l'opportunité d'une régulation de second rang du capital dans ce contexte.

Le troisème chapitre, co-écrit avec Raja Chakir, est une étude économétrique des facteurs influençant la demande d'assurance et de pesticides par les producteurs agricoles. Nos estimations sont menées sur un panel non cylindré d'exploitations agricoles françaises du département de la Meuse couvrant la période 1993-2004. La théorie économique suggère que les choix d'assurance et d'intrant réducteur de risque sont simultanés en raison d'effets de réduction de risque et d'aléa moral, ces effets pouvant être contradictoires. Nous proposons un cadre théorique alternatif intégrant explicitement la prise en compte de deux

risques statistiquement indépendants. Le producteur, supposé averse au risque, choisit simultanément le niveau d'intrant et d'assurance contre ces deux risques indépendants. Les tests statistiques confirment l'hypothèse que les choix de pesticides et d'assurance sont endogènes et donc déterminés simutanément. Par suite, un modèle économétrique à deux équations simultanées à variables mixtes censurées/continues est estimé. Les résultats de cette estimation montrent que la demande d'assurance colza a un effet positif sur l'utilisation de pesticides sur cette cuture et vice versa. La demande d'assurance est positivement influencée par le coefficient de variation du colza et le loss ratio, et négativement influencée par les proxies de la richesse (aides de la Politique Agricole Commune) et de la diversification de l'activité à l'échelle de l'exploitation. L'analyse des effets marginaux des variables explicatives montre que les valeurs d'élasticités les plus élevées concernent le coefficient de variation du rendement du colza (0.255), les aides de la Politique Agricole Commune (-0.192) et la diversification des activités (-0.161).
Le quatrième chapitre est consacré à l'influence des préférences sociales sur les choix de prévention des agents. Les études empiriques montrent que les transferts informels entre agents jouent un rôle important dans le lissage de la consommation entre états de Nature, offrant un filet de sécurité lorsque les instruments formels de partage ou de transfert des risques sont absents ou coûteux. Cependant ces transferts informels peuvent être source d'aléa moral sur les choix de prévention. Nous étudions formellement cet arbitrage à l'aide d'un jeu de dilemme du Samaritain à deux étapes. Les agents sont supposés neutres au risque et présentant de l'aversion à l'inégalité. En première étape, les agents décident d'investir ou non dans un technologie de prévention. En seconde étape, l'état de Nature est réalisé et les agents peuvent effectuer des transferts inter-individuels. A la différence du cas des préférences altruistes pures, l'aversion à l'inégalité peut conduire à une indétermination du choix de prévention à l'équilibre. Nous discutons également de la capacité d'un transfert de prévention en nature via un fonds de prévention des risques à augmenter le bien-être social.

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# Introduction

Because they dislike risks, people have developed a wide range of solutions to share, transfer, reduce or avoid them in order to feel better. In a perfect world of selfish expected utilty maximizers, risks would be traded without transaction costs between agents. Idyosincratic risks would therefore be vanished because of the law of large numbers, and the remaining social risk would be distributed according to the risk tolerance of individuals. Risk prevention, investment decisions and many other decisions involving risks would be chosen efficiently according to the price signal provided by risk markets. Such a perfect world is certainly a guide for the social planner aiming at maximizing social welfare, but not a description of real-world risk-sharing arrangements.

In reality, in several cases, insurance and prevention markets are plagued by a large set of market failures on both demand and supply sides, preventing efficient risk sharing, distorting economic choices and creating inequalities in the opportunities to share risk between individuals. The welfare consequences of such imperfections may be large, since risk sharing modifies the economic environment in which production and consumption decisions are made. The lack of risk-sharing instruments can be of particular importance for the poorest. Being obliged to cope with risk with their own means (technical choices, informal transfers), they can be driven to adopt low risk-low returns strategies, impeding their chances to opt out poverty.

Identifying and understanding the limits to insurability and the ways to overcome them are thus a major economic issue as well as an important subject for policy makers. A major difficulty of this task is that imperfections are multiple and depend on the lines of risks considered. This renders difficult to find appropriate policy responses if any, and to apply the well-knwown targetting principle “one objective, one instrument”. The objective of this thesis is to adress several of these imperfections, analyze their consequences and the potential role that public policy should play to overcome them. Hence we propose four independent but interrelated essays, three theoretical and one empirical, that each one focus on a particular facet of market imperfections. Two of these essays – one theoretical and one empirical– are devoted to the agricultural sector , which is particularly exposed to risks affecting prices and production. Moreover, government intervention in crop insurance markets as well as public price risks management programmes are more the rule than the exception in this sector. In times of trade liberalization and agricultural policy reforms, risk management is a crucial issue for both developed and developing countries. The two other essays deal with more general issues of respectively, insurance supply and prevention choices.

Chapter 1, "Risk Prevention in Agriculture with Incomplete Insurance Markets" investigates the issue of optimal risk prevention against a systemic production risk in the absence of insurance market in agriculture. Choosing technologies that reduce yield losses in case of unfavourable climatic event allows to stabilize farmers' revenues and reduce consumers' exposure to price risk. Several inputs, such as irrigation, pesticides, and the use of resistant varieties not only increase expected yields but also have a preventive role by reducing yield losses coming from natural events. It is well known from the literature on pecuniary externalities that farmers do not internalize the social cost of their production decisions when insurance markets are incomplete. This has lead to reassess the desirability of government intervention in this sector. Hence, several government policies that are usually been proved to be inefficient in a non-stochastic world have been shown to be Pareto improving in the context of production risk and absent insurance markets. The most famous example include price stabilization schemes, target prices programmes and tariffs as insurance. This chapter follows this literature but extends the analysis by focussing on the desirability of a prevention incentive scheme that would reduce yield risk, and so food price risk in terms of social welfare.

Chapter 2, "Raising Capital in an Insurance Oligopoly Market" deals with capital choices of (re)insurance firms in the context of oligopoly. There are two fundamental motives for these firms to hold costly internal capital. The first one is to reduce default risk that matter for insurees and alter their propensity to pay for the insurance contract. The second one is the presence of costly external finance. In the latter case, capital and pricing decisions are interrelated, since holding internal capital reduces the expected cost of risk for (re)insurance firms. The recent trend toward concentration in the insurance industry suggests that pricing and capital allocations can be considered in a more strategic manner. The objective of this chapter is to study the consequences of such strategic context on pricing and capital choices with a theoretical model. To do so, we consider an oligopoly of (re)insurers with stochastic marginal cost, featuring the inversion of the production cycle. Competition is modelled as a two stage game. At stage one, firms strategically choose a level of internal capital. In stage two, they compete in price on the insurance market. The subgame perfect equilibria of this game are characterized and compared with the socially optimal pricing and capital decisions. Then our analysis is discussed in the context of (re)insurance markets and the need for government intervention is analyzed.

Chapter 3, "Insurance and chemical use in French agriculture: an empirical analysis of integrated risk management" deals with multiple risks management in agriculture by investigating the determinants of insurance and pesticide use by French farmers. The context of risk management is strongly evolving. First, current reforms of the Common Agricultural Policy (CAP) tend to increase European farmers' exposure to price risk by removing traditional price stabilization schemes. Decoupled direct payments that exist in the current regime allow farmers to reduce the impact of risks on their activity but may be the subject of negotiations in a near future. Second, environmental issues take more and more importance in the agricultural policy making agenda, in particular pesticide use. The objective of this paper is to better understand the link between pesticide use and insurance demand, and to identify the main factors that influence these choices. After an analysis of the risk management context in the French agricultural sector and a description of the French agricultural insurance system, we propose a theoretical framework that allow to draw some predictions concerning the determinants of insurance demand and its link with pesticide use. We then build an econometric model that is estimated using an original panel dataset of French farms covering the period from 1993 to 2004.

Chapter 4 analyzes the incentives to invest in risk prevention when agents are inequity averse. Several authors have underlined the importance of informal transfers in risk coping as substitute to formal insurance contracts and compared their relative advantages and weaknesses. Once the state of Nature is realized, inequity aversion transfers are desirable since they express the individuals' desires to reduce inequality among agents. In a dynamic context, they may also have unvoluntary negative effects on the incentives to invest in risk prevention –a situation often called the Samaritan's dilemma. Chapter two investigates such problem with a theoretical model. To do so we consider a two-stage game between two risk-neutral, inequity-averse agents. At stage one agents invest in an undivisible risk prevention technology. At stage two they make inequity averse transfers. The subgame-perfect equilibria of the game are derived and analyzed.

# Chapter 1

# Risk Prevention in Agriculture with Incomplete Insurance Markets

**Abstract**

This paper investigates the issue of risk prevention in agriculture in the absence of complete insurance markets. The representative farmer can make use of a prevention input to reduce crop loss in case of a natural unfavorable event. It is shown that, if price elasticity of demand is lower than one in absolute value, then the competitive equilibrium prevention level decreases with the farmer's degree of risk aversion. In addition, the paper characterizes the conditions for which the competitive prevention level is higher or lower than the social optimum. Under assumptions that are reasonable in the context of an agricultural market, it is shown that underprevention is more likely to occur, providing a potential rationale for efficiency-enhancing governement intervention such as a prevention subsidy.

**Keywords**: Risk prevention, Systemic risk, Incomplete contingent-claims markets.

## 1.1 Introduction

In the context of climate change, the issue of prevention against natural hazards is becoming a major preoccupation of researchers and policy makers, and citizens. For several reasons, agriculture is certainly one of the most concerned sector. First, agricultural production is very dependent on climate and biological hazards, and low price and income elasticities of demand that are typical characteristics of basic food products make their prices very sensitive to supply shocks, and so particularly unstable. Second, in spite of substantial innovation for the provision of risk management tools in the agricultural sector in recent years – notably the development of index-based insurance and futures markets in developing countries (Cummins and Mahul, 2009), state-contingent claims markets remain often absent or incomplete in many countries. Third, food price unstability hurt essentially the poor[1]. The issue is not new and has inspired a large strand of research in economics as well as policy interventions in the past in order to stabilize agricultural incomes and food prices.

[1] low-income consumers and poor farmers with limited access to financial markets to diversify risk

The nature of public intervention in this area has strongly evolved in the two recent decades, both in developed and developing countries, and the debate is still open. Traditional public policies such as price stabilization through public storage agencies, agricultural subsidies targetted to the agricultural sector (fertilizers, investment in productive capital) are being replaced by new forms of interventions favorizing the development of market-based risk management instruments, such as innovative index-based insurance, futures and forward markets. At the same time, some economists point out the importance of state intervention specifically targeted to the agricultural sector, underlining the key role of agriculture in the road to economic development and the vast set of market failures that still remains and generates substantial welfare losses (Byerlee et al., 2009; de Janvry and Sadoulet, 2008; Kanwar and Sadoulet, 2008).

The objective of this paper is to investigate the issue of risk prevention in agriculture in a context of incomplete insurance markets. Following the classical contribution of Ehrlich and Becker (1972), risk prevention can be defined in two different ways: self-protection, which is a costly activity that reduces the probability of loss, and self-insurance, which reduces the magnitude of the loss without affecting its probability. In this paper, we consider the case of self-insurance, which seems to be more realistic in the agricultural production context. Self-insurance against crop losses by farmers can take several forms in practice. The most known examples of self-insurance include irrigation water, phytosanitary products such pesticids, herbicids, fungicides etc., and crop varieties that exhibit some form of robustness in adverse states of Nature. The self-insurance formalization of Ehrlich and Becker (1972) appears to be a reasonable description of these technologies. For example, it has been shown that irrigation water modifies the yield distribution in a non-linear way, pushing up yields proportionnally more in high loss states than in low loss states (Roberts et al., 2004). Typically, irrigation is more useful when there is a drought, and less when the weather is rainy.

**Related literature.**— Newbery and Stiglitz (1981) consider a competitive economy with production risk and show that the market equilibrium is, apart from very special cases, inefficient when insurance markets are absent. The incompleteness of insurance markets causes welfare losses because it prevents economic agents to smooth their consumption across states of Nature (direct effect), and because it distorts production choices when the latter modify the producers' risk exposures (indirect effect). Following this fundamental inefficiency result, further research has been devoted to the potential benefits of second-best governement policies in such incomplete markets context. Some typical "real-world" government policies, usually critized for their deadweight losses, have been shown to be Pareto improving under certain circumstances. Newbery and Stiglitz (1981) study the cases of intertemporal price stabilization policies by a public storage agency, income taxation and trade liberalization. Innes (1990) study the case of target prices in a similar closed two-goods (food and numeraire) economy. He shows that under conditions that are realistic in agricultural markets –low price and income elasticities of demand, farmers and consumers risk averse– then there exists a Pareto-improving programme combining a target price with lump-sum transfers between consumers-taxpayers and farmers[2]. Eaton and Grossman (1985) show that tariffs as insurance can be a second-best Pareto improving policy[3].

Nevertheless, to our knowledge, the issue of prevention against climate risks, which is the subject of this chapter, has not been fully considered in the literature. In agriculture, the choice of inputs has direct consequences on production risk. If all inputs increase the expected yield, some do so with a collateral increase in yield risk (for example fertilizers), while other have clearly a preventive action (e.g. irrigation water, pesticides, drought-resistant seeds). In incomplete markets models, the possibility of Pareto improvement relies on the ability of the government to redistribute risks between producers and consumers when private markets are absent. The issue of prevention is a bit different: the problem is those of the optimal degree of reduction of a social risk that alternatively hurt farmers and consumers. When some agents face a social (i.e. non diversifiable) risk they cannot mitigate, a Pareto-efficient allocation implies that the aggregate risk is shared according to the agents' risk tolerances (Gollier, 2001). In the case of an agricultural market, state-contingent claim markets are often incomplete but farmers can reduce the non diversifiable risk by the mean of prevention.

[2]If all the policies cited above potentially increase social welfare, it must be kept in mind that they also have various effects on the *distribution* of the gains between producers and consumers-taxpayers.

[3]This line of research, developed during the 80's, have been subject of several types of criticism. The most fundamental comes from Dixit, that argues that there is a fundamental weakness in these models, which is that the reasons for private risk markets failures are not modelled explicitely. If a government faces the same constraints (typically asymmetric information) than those causing private market failure, the welfare gains may be quantitatively small, and even negative (Dixit, 1987, 1989a,b). Moreover, the potential welfare gains are very sensitive to parameters values.

The paper is organized as follows. Section 2 is a presentation of the model, i.e. the agents and their preferences, the nature of the risk and the prevention technology. Section 3 studies the competitive market and the level of prevention that arises at equilibrium, and the Pareto-constrained efficient level that would be selected under direct control by a benevolent and omniscient government. The case of prevention subsidies is also analyzed. Section 4 studies the potential effects of opening trade on the market level of prevention.

## 1.2 The model

### 1.2.1 Preferences and endowments

We consider a two-goods closed economy[4], with a competitive agricultural sector producing a single good ($Y$), and a representative consumer initially endowed with an exogenous level of numeraire ($I$). The representative farmer is assumed to be risk-averse in the sense of von Neumann and Morgenstern, with an increasing and concave utility function $u_P(.)$, i.e. $u_P'(.) \geq 0$ and $u_P''(.) \leq 0$. Denoting $\tilde{\pi}$ his random profit, the expected utility $U_P$ of the producer has the following form ($\mathbf{E}$ being the expectation operator):

$$U_P = \mathbf{E}u[\tilde{\pi}] \tag{1.1}$$

The assumption of competitive market implies that farmers are price takers, i.e. they consider state-contingent prices of their output as given. It is also assumed that they hold rational expectations, i.e. they correctly forecast the equilibrium state-contingent prices. On the demand side we consider a representative consumer which is risk averse with respect to consumption fluctuations, his preferences being characterized by an increasing and concave utility function $u_C(.)$ over the agricultural good, with $u_C'(.) \geq 0$ and $u_C''(.) \leq 0$. $u_C$ is not necessarily identical to $u_P$. The consumer's preferences can be expressed by the indirect utility function $V(P, I)$ which is defined as follows

$$V(P, I) = \max_Y u_C(Y) \qquad \text{s.t.} \quad PY \leq I \tag{1.2}$$

where $P$ is the price of the agricultural good and $I$ his initial numeraire endowment. $I$ is

[4] We will also discuss the consequences of opening trade using a simplified model with two symmetric countries with anti-correlated shocks.

assumed to be exogenous and non-stochastic. By Roy's identity, the consumer's demand for the agricultural good $Y^d$ is given by

$$Y^d = -\frac{V_P(P,I)}{V_I(P,I)} \tag{1.3}$$

Facing a stochastic price of the agricultural good $\tilde{P}$, the consumer's expected utility $U_C$ is written as

$$U_C = \mathbf{E}V(\tilde{P}, I) \tag{1.4}$$

For a small price risk $\tilde{P}$, the consumer benefits (loses) from stabilizing the price at the mean $\mathbf{E}\tilde{P} = \overline{P}$ if $V$ is concave (convex) in price. The sign of $V_{PP}$ depends on the consumer's income risk aversion, but also on the income elasticity of demand and the price elasticity of demand (see Appendix for an analysis in the context of a small price risk). Throughout the paper, $\varepsilon = \frac{d \log Y}{d \log P}$ and $\eta = \frac{d \log Y}{d \log I}$ will denote respectively the price and income elasticities of demand for the agricultural good, $\phi = \frac{IV_{II}}{V_I}$ the consumer's coefficient of relative risk aversion, and $P(.)$ the inverse demand function.

### 1.2.2 Prevention technology

The farmer can make use of a self-insurance technology (or prevention to be short) that reduces yield risk coming from a particular climate event such as pesticides against biological risks, or irrigation water against drought[5]. The climate risk is assumed to be systemic, i.e. it affects all agricultural producers at the same time. We focus on a static model and consider the most simple formalization of self-insurance, that comes from Ehrlich and Becker (1972). There are two states of Nature, a loss state (indexed by 1), occuring with probability $p$, where the yield is $Y_1 = Y - L(x) > 0$ and a no-loss state (indexed by 2) occuring with probability $1-p$, where it is $Y_2 = Y$, $Y \in \Re^{+*}$. The loss function $L(.)$ is assumed to be decreasing and convex in its single argument $x$, that represents the number of units of the prevention good, which is available at the unitary cost of $c$. At last, we suppose that $\lim_{x \to +\infty} L(x) = \underline{L} > 0$ in order to ensure that state 1 is always the "low yield" state, whatever the prevention effort of the producer.

[5]There is no doubt that in the real world these techniques involve a complex set of sequential decisions. In the case of irrigation, it includes the initial investment in irrigation capacities, the fraction of the area to be irrigated, the choice of irrigation system (such as flood, micro-sprinkler, or drip irrigation), and the level of water on each acre (see Schoengold and Zilberman (2005) for further details on irrigation technologies). It is not our purpose to consider the whole range of such choices and their dynamic aspect.

## 1.3 Risk prevention in a closed market

### 1.3.1 Competitive equilibrium

*Competitive equilibrium without redistribution.* — In a closed market, the climate output shock directly affects the equilibrium price of the agricultural good, since it is impossible to export or import. Let $(P_1, P_2)$ be the price vector anticipated by the farmer. Since state 1 is the low yield state, we will always have $P_1 > P_2$ at equilibrium. The price vector $(P_1, P_2)$ being considered to be fixed for the representative producer making his choice. His expected utility, $U_P$, is

$$U_P = pu\left((Y - L(x))P_1 - cx\right) + (1-p)u\left(YP_2 - cx\right) \tag{1.5}$$

One can easily verify that $U_P$ is concave in $x$ for a given price-vector $(P_1, P_2)$. Assuming an unique solution, the market equilibrium $(x^e, P_1^e, P_2^e)$ is implicitely defined by the following set of equations: the first-order condition (5) and the two state-contingent market equilibrium conditions (6) and (7).

$$\begin{aligned} -p\left[P_1^e L_x(x^e) + c\right] u'(\pi_1(x^e)) &= (1-p)cu'(\pi_2(x^e)) && (1.6) \\ P_1^e &= P(Y - L(x^e)) && (1.7) \\ P_2^e &= P(Y) && (1.8) \end{aligned}$$

with $\pi_1(x^e) = (Y - L(x^e))P_1^e - cx^e$ and $\pi_2(x^e) = YP_2^e - cx^e$.

A first remark the second-order condition has an ambiguous sign, so $x^e(.)$ may have discontinuity points:

**Remark 1** *There may be a multiplicity of equilibria.*

The fact that the unicity of the equilibrium is not always ensured is a typical characteristic of incomplete markets models, and we did not find any restrictions on preferences or technology that would ensure unicity. We examine the effect of the producer's risk aversion on the market equilibrium. Intuitively, we can expect that more risk averse producers will buy more units of the prevention good. After all, in a closed market with output shocks only, the price distribution strictly reflects the output distribution. Hence, except in the very special case of unitary price elasticity of demand (where the farmer's income is the same across states of Nature), reducing the variance of the output reduces the variance of the price, leading at some cost to a less risky revenue for the producer. Following this line of reasoning, a country with a more risk averse representative farmer should self-insure more. We show that such a simple statement is not true in general, and may even be false in the conditions that prevail in agricultural markets, i.e. systemic production risk and low elasticity of demand for the agricultural product. A simple comparative statics analysis allow us to derive the following proposition.

**Proposition 1.** *If $\varepsilon > -1$ (respectively $= -1$, $< -1$), then prevention decreases (respectively does not change, increases) with the farmer's coefficient of risk aversion (absolute under CARA, relative under DARA).*

*Proof.* We consider the case of a power utility function (DARA), but a similar proof could be obtained under CARA. For a level of wealth $W$, let $u$ be of the followning form:

$$u(W) = \frac{W^{1-\gamma}}{1-\gamma} \tag{1.9}$$

where $\gamma$ is the coefficient of relative risk aversion. Using this specification, and substituting the market equilibrium conditions (6) and (7) into the first-order condition (5), we obtain the following equation that defines the prevention at equilibrium $x^e$:

$$-p\left[P_1^e L_x + c\right]\left[(Y - L(x^e))P_1^e - cx^e\right]^{-\gamma} - (1-p)c\left[YP_2^e - cx^e\right]^{-\gamma} = 0 \tag{1.10}$$

Let $H(x^e, .)$ be the LHS of this equation. Differentiating both sides with respect to $\gamma$, and rearranging terms, we get

$$\frac{dx^e(\gamma)}{d\gamma} = -\Delta^{-1}\frac{\partial H(x^e(\gamma), \gamma)}{\partial \gamma} \tag{1.11}$$

where $\Delta = \partial H(x^e(\gamma), \gamma)/\partial x$. Assuming that $\Delta \leq 0$, $dx^e(\gamma)/d\gamma$ has the sign of

$$\frac{\partial H(x(\gamma), \gamma)}{\partial \gamma} = -p\left[P_1^e L_x - c\right]\ln\left[1/\pi_1(x^e)\right]\left[\pi_1(x^e)\right]^{-\gamma} - (1-p)c\ln[1/\pi_2(x^e)]\left[\pi_2(x^e)\right]^{-\gamma} \tag{1.12}$$

Note that when $\pi_1(x^e) = \pi_2(x^e)$, which is the case under the isoelastic specification case $\varepsilon = -1$, this expression reduces to

$$\ln\left[1/\pi_1(x^e)\right] H(x^e) = 0$$

since by definition $H(x^e) = 0$. It is straightforward that if $\pi_1(x^e) > \pi_2(x^e)$ (respectively $<$), then the expression is negative (respectively positive). A sufficient condition for this to occur is $\varepsilon > -1$ (respectively $< -1$). For example, with the isoelastic specification we have

$$\pi_1(x^e) - \pi_2(x^e) = (Y - L(x^e))P_1^e - YP_2^e = [Y - L(x^e)]^{1+1/\varepsilon} - Y^{1+1/\varepsilon}$$

Since by assumption $Y - L(x) < Y$ for all $x$, the sign depends on $\varepsilon$ as described in proposition 1. A similar proof can be obtained in the CARA case. This comparative statics analysis relies on the assumption $\Delta \leq 0$, but in general the sign of $\Delta$ is ambiguous (multiple equilibria). To ensure that this result is really possible, at least in certain cases, we made numerical computations for several coefficients of relative risk aversion, that confirm what is stated in proposition 1. □

Proposition (1) states that, when markets are incomplete, the qualitative effect of the farmer's risk aversion on the equilibrium level of prevention can be reversed, depending on value of the price elasticity of demand. In particular, if $\varepsilon$ is less than one in absolute value everywhere, then prevention decreases with the producer's risk aversion coefficient (absolute under CARA or relative under DARA). Although counterintuitive at a first sight, this result nevertheless relies on standard explanation, i.e. the pecuniary externalities coming from the absence of market for state-contingent claims. Indeed, even if they hold rational expectations, farmers act in a competitive market, and so are price distribution takers. As a consequence, they only consider the marginal effect of prevention on their *own* output distribution, but not the *aggregate* effect on the price distribution, which they consider to be fixed when making their decision. In the case of a prevention activity, farmers do not take into account at the margin the price stabilisation effect that comes from the sum of their individual prevention decisions. The price distribution is a public good for farmers. When the price elasticity of demand is elsewhere less than one, the low output state corresponds to the high revenue state, and a marginal increase in self-insurance *for a given price distribution* increases the quantity of output in the high price (and so revenue) state without changing the quantity output in the low price (revenue) state. Prevention is then seen by the rational and competitive farmer as increasing the variance of his revenue. So the more risk averse he is, the less he will self-insure. This occurs under the assumptions of systemic production risk and low price elasticity of demand, that seem reasonable in the context of agricultural markets. To give some ideas, according to the United States Department of Agriculture (USDA), an estimation for 1996 gives values for price elasticities of demand that are generally greater or equal than $-0,5$ for the majority of food products. Concerning the nature of production risk, there are also some evidence in the literature in favour of a high spatial correlation of crop losses (Miranda and Glauber, 1997), even if the polar case of perfect correlation across losses is a simplifying assumption.

**Competitive equilibrium with redistribution.** — In a non-stochastic economy and/or with risk-neutral agents, a redistribution policy consisting in lump-sum payments from one category to the other (for example from consumers to farmers) has no effect on the market equilibrium. When production is stochastic and farmers risk-averse, this is no longer the case since a wealth effect must be taken into account under IARA or, more realistically, DARA. Under CARA, it is straightforward that redistribution does not modify the equilibrium. The other effect is the consumer's income, which we can assume negligible since income elasticity of demand is in general low in agricultural markets.

### 1.3.2 Socially optimal prevention

We now characterize the socially optimal level of prevention under direct control. Let $M$ and $N$ be respectively the number of producers and consumers in the economy. The socially optimal level of prevention is the one that maximizes the social welfare function $SW$, which is defined as the sum (eventually weighted by $\lambda$) of the representative producer's utilities $U_P$ and the consumer's utilities $U_C$:

$$SW = \lambda M U_P + N U_C \tag{1.13}$$

Let $\alpha = M/N$ denote the fraction of agricultural producers relative to consumers in the economy, and $\lambda$ a parameter that reflects the preferences of the governement for producers ($\lambda > 1$), consumers ($\lambda < 1$), or equal preferences ($\lambda = 1$). The government, which is assumed to be benevolent and omniscient, has a direct control on prevention and can redistribute wealth across the two categories of agents by the mean of a lump-sum transfer $T$ (eventually negative) from consumers to producers. The social welfare function can be expressed as follows

$$\begin{aligned} SW(x,T) = \lambda M \left\{ pu\left[(Y-L(x))P_1 - cx + \frac{T}{\alpha}\right] + (1-p)u\left[YP_2 - cx + \frac{T}{\alpha}\right]\right\} \\ +N\left\{pV(I-T,P_1) + (1-p)V(I-T,P_2)\right\} \end{aligned} \quad (1.14)$$

where the first term and the second term are respectively the expected utility of producers and consumers. Assuming $SW$ concave in $(x,T)$, the optimal government plan $(x^*,T^*)$ is defined by the the two following first-order conditions:

$$\begin{aligned} \frac{\partial SW}{\partial T} = 0 = \lambda M \left\{ p\left[1 + Y_1\frac{\partial P_1}{\partial T}\right]u'(\pi_1) + (1-p)\left[1 + Y_2\frac{\partial P_2}{\partial T}\right]u'(\pi_2)\right\} \\ -N\left\{p\left[V_I^1 - \frac{\partial P_1}{\partial T}V_P^1\right] - (1-p)\left[V_I^2 - \frac{\partial P_2}{\partial T}V_P^2\right]\right\} \end{aligned} \quad (1.15)$$

$$\begin{aligned} \frac{\partial SW}{\partial x} = 0 = \lambda M \left\{-p\left[P_1^* L_x(x^*) + c\right]u'(\pi_1(x^*)) - (1-p)cu'(\pi_2(x^*))\right\} \\ +\lambda M\left\{p\left[Y - L(x^*)\right]\frac{\partial P_1}{\partial x}\right\} + Np\frac{\partial P_1}{\partial x}V_P^1 \end{aligned} \quad (1.16)$$

Following Newbery and Stiglitz (Newbery and Stiglitz (1981)), using Roy's relation allows to rewrite the second equation as follows

$$\begin{aligned} \frac{\partial SW}{\partial x} = 0 = \lambda\left\{-p\left[P_1^* L_x(x^*) + c\right]u'(\pi_1(x^*)) - (1-p)cu'(\pi_2(x^*))\right\} \\ +p\left[Y - L(x^*)\right]\frac{\partial P_1}{\partial x}\left[\lambda u'(\pi_1(x^*)) - V_I\right] \end{aligned} \quad (1.17)$$

We aim at comparing the competitive equilibrium outcome with the socially optimal one. The term in the first line of equation (1.17) corresponds to the first-order condition characterizing the market equilibrium (at a factor $\lambda$). It is not necessary equal to zero when evaluated at $x^e$, since $T^* \neq T^e$ (i.e. the socially optimal lump-sum transfer is not the same in the competitive market than in the social optimum). This is indeed the case in two situations: the first one is when redistribution is not considered, the second one is when the farmer's utility function has the CARA specification. The term in the second line of equation (1.17) represents the pecuniary externality due to the absence of contingent claims markets, which is not taken into account by competitive farmers but is internalized by the government. Hence, a sufficient condition for the market equilibrium to be Pareto-constrained efficient is that this term be equal to zero when evaluated at $x^e$, which is ensured under a narrow set of very specific restrictions (Newbery and Stiglitz, 1981). Hence Pareto constrained efficiency of the competitive market is not likely to occur in most cases. Since we are concerned about a specific technological form, prevention, we focus on the *sense of deviation* that arises between the competitive market and the social optimum. In other words, we wonder if, for realistic values of the parameters, the competitive market is likely to supply too much or too less prevention.

Characterizing the sense of deviation consists in comparing $x^e$ with $x^*$. To do this, we look at the sign of the RHS of equation (1.17) at $x^e$. To avoid the potential ambiguity that could arise from a wealth effect caused by the redistribution policy, we consider the case of a CARA utility function in what follows (but let it written as $u(.)$). Let $(x^e, T^e)$ be the the prevention level and optimal redistribution policy at the market equilibrium. Under CARA, the term in the first line of (1.17) vanishes, so (1.17) can be rewritten as

$$\frac{\partial SW}{\partial x}(x^e) = \underbrace{\alpha p\,[Y - L(x^e)]\,\frac{\partial P_1}{\partial x}(x^e)}_{<0}[\lambda u'(\pi_1(x^e) + T^*/\alpha) - V_I(P_1(x^e), I - T^*)] \quad (1.18)$$

From our assumptions concerning concavity, we have $x^e < x^*$ if $\frac{\partial SW}{\partial x}(x^e) > 0$. The sign of this expression, and thus the sense of the deviation, depend on the sign of the term $\xi = \lambda u'(\pi_1(x^e)) - V_I(P_1(x^e), I)$. The following proposition gives sufficient conditions such that there is under-prevention at the market equilibrium.

**Proposition 2.** *If the following conditions are ensured: i. $u$ has the CARA specification, with $\gamma$ being the coefficient of absolute risk aversion, ii. $V_{IP} \geq 0$ (i.e. $\phi \geq \epsilon$), iii. $\epsilon > -1$ (demand is sufficiently price inelastic), iv. $\partial T^*/\partial\gamma \geq 0$, then there exists $\overline{\gamma} \geq 0$ such that $\gamma \geq \overline{\gamma} \Rightarrow x^e \leq x^s$.*

*Proof.* We consider the term $\xi$ as a function of $\gamma$, the relative risk aversion coefficient:

$$\xi(\gamma) = \lambda u'(\pi_1(x^e(\gamma)) + \frac{T^s(\gamma)}{\alpha}) - V_I(P_1(x^e(\gamma)), I - T^s(\gamma)) \tag{1.19}$$

We study the sense of variation of $\xi(\gamma)$. To do so we calculate its first derivative, which is

$$\frac{d\xi}{d\gamma} = \frac{\partial x^e}{\partial \gamma}\left\{\lambda \frac{\partial \pi_1}{\partial x^e} \underbrace{u''\left(\pi_1(x^e(\gamma)) + \frac{T^*(\gamma)}{\alpha})\right)}_{\leq 0} - \underbrace{\frac{\partial P_1}{\partial x^e}}_{\leq 0} V_{IP}\left(P_1(x^e(\gamma)), I - T^*(\gamma)\right)\right\} + \left[\underbrace{u_1'' + V_{II}^1}_{\leq 0}\right]\frac{\partial T^*}{\partial \gamma} \tag{1.20}$$

From proposition 1, we know that the sign of $\frac{\partial x^e}{\partial \gamma}$ depends on the price elasticity of demand. If it is less than one in absolute value, which is the most reasonable assumption for an agricultural market, then it is negative. We now look at the following term

$$\frac{\partial \pi_1}{\partial x^e} = \frac{\partial P_1}{\partial x^e} Y_1(x^e) + P_1 \frac{\partial Y_1}{\partial x^e} - c \tag{1.21}$$

Again the sign of this expression depends on the price elasticity of demand. If $\varepsilon > -1$, then it is negative because the increase in output at a given price is more than proportionnaly (negatively) compensated by a decrease of the equilibrium price. The last term to study in order to get the result is $V_{IP}(P_1(x^e(\gamma)), I)$. Following Newbery and Stiglitz (1981), this term can be expanded as follows

$$V_{IP} = \frac{V_I}{P}(\phi - \eta) \tag{1.22}$$

where $\phi$ is the consumer's relative risk aversion and $\eta$ his income elasticity of demand for the agricultural good . Thus $V_{IP} \geq$ implies that $\phi \geq \eta$. In other words, it requires that the consumer is sufficiently risk averse and/or has low income elasticity of demand. Following Innes (1990), this seems to be a reasonable for agricultural markets. Finally, combining the signs of the different terms gives the result that $\frac{d\xi}{d\gamma} \leq 0$, so $\xi$ is decreasing under the conditions that are exposed in proposition 2.

To conclude the proof, we show that $\lim_{\gamma \to +\infty} \xi(\gamma) < 0$ to ensure the existence of a positive $\overline{\gamma}$. This is clearly the case since prevention tends to 0 when $\gamma \to +\infty$. Hence, the state 1 price tends to infinity and so the farmer's revenue. Hence, with $\lim_{W\to+\infty} u'(W) = 0$, and $\lim_{P\to+\infty} V_I(P, I) > 0$ we get the result. □

Proposition 2 states that, under conditions that are well-known characteristics of agricultural markets, the level of prevention that arises at the competitive equilibrium is likely to be *less* than would the constrained Pareto level. This means that in a competitive market where contingent claims are absent, the expected price of the agricultural good will be higher and more risky than would be socially desirable. What fundamentally runs this result? First, as stated in proposition 1, the farmer's risk aversion is not a motive, and even is a disincentive for prevention when price elasticity of demand is low. Their unique motive for prevention is the expected benefit they get from it. If price elasticity of demand is strictly less than one, the more they are risk averse, the less they will self-insure, and finally the more price will be risky, and so will be their income. In a certain sense, one could say that *the farmers' risk aversion generates price risk, and so farmers' income risk*. Intutively, one cannot expect such a mechanism to be optimal for the point of the view of agricultural producers, since the more they dislike risk, the more they will get exposed to it. Moreover, this exposes consumers to higher and more risky price for the agricultural good. To get some insight of the nature of the Pareto improvement that would constitute a mandatory increase in prevention, consider as a benchmark what would constitute the socially optimal risk-sharing rule between the two categories. If state-contingent claims markets are complete, the efficient risk-sharing rule implies that

$$\frac{u'(\pi_1 + T)}{u'(\pi_2 + T)} = \frac{V_I(P_1, I - T)}{V_I(P_2, I - T)} \tag{1.23}$$

i.e. the ratio of marginal utilities of income in the two states are equal between individuals (Gollier, 2001). If contingent-claims markets are incomplete, we cannot have such equality. When prevention is suboptimal at the market equilibrium, the state 1 price is too high, so we have

$$\frac{u'(\pi_1^e + T)}{u'(\pi_2^e + T)} < \frac{V_I(P_1^e, I - T)}{V_I(P_2^e, I - T)} \tag{1.24}$$

When the government increases $x$ up from $x^e$ to its socially optimal level $x^*$, it reduces the state 1 price, and so the farmer's profit in this state. This also reduces his profit in state 2 by increasing the expense in prevention. If price elasticity of demand is sufficiently low, the producer's ratio will increase. At the same time, the consumer's ratio will decrease, since his marginal utility is constant in state 2 and decreases (because of the decrease in price) in state 1. Hence, a mandatory increase in prevention reduces the gap between the consumer's and producer's ratios of marginal utilities. Perfect equality is however unattainable since markets are incomplete and prevention is costly and exhibits decreasing returns to scale. Perfect equality would imply $x = \infty$, which would be infinitely costly for the producer.

### 1.3.3 Prevention subsidy

The previous analysis has shown that, under certain circumstances that are reasonable assumptions for agricultural markets (risk-averse producer and consumer, price elasticity of demand less than one, low income elasticity of demand), farmers may underinvest in prevention because of incomplete markets. This provides a possible rationale for governement policies in favour of prevention in the agricultural sector, such as the use of irrigation, or the development of drought-resistant seeds. Direct control of prevention by the government is possible in theory, but limited in practice. Another way of reaching the socially optimal level of prevention is to subsidize it. In many countries of the world, farmers benefit from substantial subsidization of irrigation water, either directly through a lower unitary cost of water, or indirectly through government support in initial investment in irrigation technologies. This kind of intervention is at most seen as an inefficient way of redistributing income from one category of agents to another, involving deadweight costs[6]. This assertion, which relies on a standard welfare analysis of non-stochastic economy with complete markets, is certainly realistic in this context, but can be challenged in the case of production risk, incomplete markets and a prevention technology.

We consider the case of a prevention subsidy $s \in [0, c[$ financed by the consumer-taxpayer, that lower the market price of prevention from $c$ to $c - s$. Each consumer-taxpayer pays individually $f$ to finance the programme. The economy being composed of $M$ farmers and $N$ consumers, the global cost of the programme is $Msx$, that has to be balanced by the global contribution $Nf$ from consumers. Using $\alpha = M/N$,the budget constraint is

$$\alpha s x = f \tag{1.25}$$

[6]Note that in the case of input subsidies, the winners are not necessary the producers. When the price elasticity of demand is low, consumers may globally benefit from an input subsidy through a lower food price.

A second constraint is that the consumers participation to the programme cannot exceed their own resources, i.e. $f < I$ which we can always assume to be true by choosing a sufficiently high level of income. The regulator's problem is not much different than before. Instead of having a direct control over $x$, the regulator uses $s$ to raise prevention up to its socially optimal level. With a subsidy $s$, the market equilibrium becomes $x^e(s)$. Using the prevention subsidy and redistribution, the government's programme is

$$\max_{s,T} SW(x^e(s), T) \tag{1.26}$$

Again we assume that $SW$ is concave in $(s, T)$. Under this condition, the government's optimal plan $(\hat{s}, \hat{T})$ is, as before, defined by the two first-order conditions

$$\begin{aligned}\frac{\partial SW}{\partial T} = 0 = \lambda M \left\{ p \left[ 1 + Y_1 \frac{\partial P_1}{\partial T} \right] u'(\pi_1) + (1-p) \left[ 1 + Y_2 \frac{\partial P_2}{\partial T} \right] u'(\pi_2) \right\} \\ -N \left\{ p \left[ V_I^1 - \frac{\partial P_1}{\partial T} V_P^1 \right] - (1-p) \left[ V_I^2 - \frac{\partial P_2}{\partial T} V_P^2 \right] \right\}\end{aligned} \tag{1.27}$$

$$\begin{aligned}\frac{\partial SW}{\partial s} = 0 = \lambda M x \left[ p u_1' + (1-p) u_2' \right] - N \left[ x + \hat{s} \frac{\partial x}{\partial s} \right] \left[ p V_I^1 + (1-p) V_I^2 \right] \\ + \left\{ p \frac{\partial P_1}{\partial s} \left[ \lambda M Y_1 u_1' + N V_P^1 \right] + (1-p) \frac{\partial P_2}{\partial s} \left[ \lambda M Y_2 u_2' + N V_P^2 \right] \right\} \\ + \lambda M \frac{\partial x}{\partial s} \left\{ p \left[ -P_1 L_x - (c - \hat{s}) \right] u_1' - (1-p)(c - \hat{s}) u_2' \right\} \\ + p \frac{\partial x}{\partial s} \left[ Y - L(x(\hat{s})) \right] \frac{\partial P_1}{\partial x} \left[ \lambda u' \left( \pi_1(x(\hat{s})) + \frac{\hat{T}}{\alpha} \right) - V_I \left( P_1(x(\hat{s})), I - \hat{T} \right) \right]\end{aligned} \tag{1.28}$$

The first-order condition (1.28) can be decomposed into four terms (each line of equation (1.28)) that reflect the four effects of a prevention subsidy: the term in the first line reflects the redistribution from consumers to producers that arises from a lower prevention cost, which directly benefits farmers. The terms in the second line represents the indirect redistribution of expected utility through income effect on the equilibrium state-contingent prices. Provided that the income elasticity of demand is low, this term can be considered as negligible. The term in the third line is the first-order condition of the market equilibrium (at a factor $\lambda M$), which equals zero under CARA (for the same reason as before, i.e. absent wealth effect). At last, the term in the fourth line represents the pecuniary externality, as seen in the case of direct control.

**Proposition 3.** *If $\eta = 0$ and $u$ has the CARA specification, then equation (1.28) reduces to*

$$\frac{\partial SW}{\partial s} = 0 = -Ns\frac{\partial x}{\partial s}\left[pV_I^1 + (1-p)V_I^2\right] +$$
$$p\frac{\partial x}{\partial s}\left[Y - L(x^s)\right]\frac{\partial P_1}{\partial x}\left[\lambda u'\left(\pi_1(x^e(\hat{s})) + \frac{\hat{T}}{\alpha}\right) - V_I\left(P_1(x(\hat{s})), I - \hat{T}\right)\right] \tag{1.29}$$

*Proof.* If $\eta = 0$, the state-contingent prices are unsensitive to variations in the consumers' incomes, so the partial derivatives if state prices with respect to transfers vanish. In this case, we note that the first line of equation (1.28) is equal to the RHS of equation (1.27), which is equal to zero at the optimum, plus the term $-Ns\frac{\partial x}{\partial s}\left[pV_I^1 + (1-p)V_I^2\right]$. Under CARA the term in the third line of (1.28) vanishes, hence the result. □

The conditions under which a strictly positive prevention is Pareto improving is $\frac{\partial SW}{\partial s}(s = 0) > 0$. Since at $s = 0$, prevention is equal to $x^e$ (competitive equilibrium without intervention), this can be expressed as follows

$$\frac{\partial SW}{\partial s}(s=0) = p\frac{\partial x}{\partial s}\left[Y - L(x^e)\right]\frac{\partial P_1}{\partial x}\left[\lambda u'\left(\pi_1(x^e) + \frac{\hat{T}}{\alpha}\right) - V_I\left(P_1(x^e), I - \hat{T}\right)\right] > 0 \tag{1.30}$$

Hence, the condition reduces to

$$\lambda u'\left(\pi_1(x^e) + \frac{\hat{T}}{\alpha}\right) - V_I\left(P_1(x^e), I - \hat{T}\right) < 0 \tag{1.31}$$

This condition appears to be similar to the one studied in the direct control case. However there is no presomption that $T^* = \hat{T}$, hence one cannot deduce that under conditions that ensure underprevention are exactly the same that those that ensure a strictly positive subsidy to be optimal. Since a prevention subsidy modify risk, but also redistribute income from consumers to farmers, one can suppose that redistribution is lower with a subsidy that under direct control. Hence, there may be ranges of parameters that ensure underprevention but under which a prevention subsidy is not optimal. We nevertheless shows that under incomplete markets, under certain conditions that are not much unrealistic in agricultural markets, subsidizing prevention activities may be Pareto improving. Because of incomplete markets, competitive farmers may underinvest in prevention, leading to a more risky price. Because they are risk averse, consumers dislike price volatility, and so have a propensity to pay for reducing it, i.e. they are characterized by a positive risk premium.

## 1.4 The impact of opening trade

The precedent analysis has been conducted for the case of a closed economy, where price fluctuations are pure mirrors of output shocks. In these types of models, risk is shared between producers and consumers through the price of the agricultural good. Because of incomplete markets, there is always a potential for increasing social welfare through an improvement in risk sharing through a governement intervention. Opening trade may completely remove this justification. For example, consider the same economy as before as a small open economy with a perfectly elastic (possibly stochastic) world price. In such situation, there is no link between domestic production and domestic price any more, and so no opportunity to increase efficieny through a better risk-sharing arrangement. However, one can imagine another situation. Suppose that because of comparative advantage, one country (or region) gets specialized in the production of the given agricultural good, providing it to its consumers and the rest of the world. In this case the underprevention result holds. In the following subsections we consider an intermediate case, where two identical countries of the same size are opening trade.

### 1.4.1 Two symmetric countries

Let $Y_s(x)$ denote the state-contingent output of the domestic producer in state of Nature $s$, and $Y^*_{s^*}(x^*)$ the foreign's one. More generally, all the variables and parameters with a $^*$ symbol as a superscript are related to the foreign country. The two countries are similar than the one described in the preceding section with competitive agricultural sectors. Following N-S, climate shocks are assumed to be perfectly negatively correlated across the two countries, which means that when a loss occurs in one country, no one does in the other one, and *vice versa*. Each state of Nature has the probability $p = 1/2$ to occur. The domestic producer chooses the level $x$ that maximizes his expected profit provided that the foreign one has chosen $x^*$, and vice versa. For each choice vector $(x, x^*) \in \Re^{+2}$ and each state of Nature $(s, s^*) \in \{(1; 2), (2, 1)\}$ there is a resulting state-contingent price $P(Y_{ss^*}(x, x^*))$, where $Y_{ss^*}(x, x^*) = y_s(x) + y^*_{s^*}(x^*)$ is the world production when states $s$ (domestic) and $s^*$ (foreign) occur, provided the farmers' choices $(x, x^*)$, and $P(.)$ the inverse demand function. Because shocks exhibit pure negative correlation with equal probabilities, this leads to the following values for state-contingent production

$$\begin{aligned} Y_{12}(x, x^*) &= 2Y - L(x) &(1.32)\\ Y_{21}(x, x^*) &= 2Y - L(x^*) &(1.33)\end{aligned}$$

Note that if farmers make a symmetric choice $x = x^*$, then the world production will be equal to $2Y - L(x)$ in the two states of Nature, and so the world price will be perfectly stable.

### 1.4.2 Symmetric equilibrium

We first consider the symmetric equilibrium. Let $U_P(x, x^*)$ (respectively $U^*_P(x, x^*)$) be the expected utility of profit of the domestic (respectively the foreign) farmer under the strategy $(x, x^*)$. Under symmetry, farmers' choices are identical and so the world price is perfectly stabilized. Denote $P_w$ the world price anticipated by the domestic farmer. His expected utility is thus

$$U_P(x, x^*) = pu\left((Y - L(x)P_w) - cx\right) + (1-p)u\left(YP_w - cx\right) \tag{1.34}$$

Considering interior solutions, the prevention equilibrium in free trade $x^t$ is defined by the first-order condition of the domestic (or the foreign) farmer (1.35) and the market equilbrium condition (1.36) (using isoelatic specification with $\epsilon = -1$):

$$\begin{aligned} -p\left[PwL_x + c\right]u'\left(\pi_1\right) &= (1-p)cu'\left(YP_w - cx\right) &(1.35)\\ P_w &= I\left[2Y - L(x)\right]^{-1} &(1.36)\end{aligned}$$

A simple comparative statics analysis on the effect of $\gamma$ on the market equilibrium gives the following proposition:

**Proposition 4.** *In free trade with perfectly negative correlation of climate shocks and symmetric countries, prevention increases with the farmers' risk aversion.*

This contrasts with the case of autarky, where the effect of risk aversion on prevention may be positive or negative depending on the price elasticity of demand. We want to compare the levels of prevention in autarky and free trade. We have seen that if $\epsilon = -1$, prevention in autarky is independent of the farmer's risk aversion. This leads to the following proposition:

**Proposition 5.** *Suppose that $\epsilon = -1$ and let $x^e(\gamma)$ and $x^t(\gamma)$ be the prevention demand at equilibrium, respectively in autarky and in free trade. There exists a level of risk aversion $\hat{\gamma} > 0$ such that $sign\left[\gamma - \hat{\gamma}\right] = -sign\left[x^e - x^t\right]$. If farmers are risk neutral, prevention is lower in free trade than in autarky.*

Proposition 5 illustrates the two opposite effects that trade could have on prevention. On the one hand, by smoothing climate shocks and so price variablity, trade reduces the expected benefit from prevention since farmers are deprived of rises in price when climatic conditions are bad in their country. On the other hand the trade-induced price stabilisation eliminates the natural hedge of their revenue and exposes them to output risk they can't insure because of incomplete markets. If farmers are sufficiently risk averse, opening trade will increase the global demand for prevention by exposing them to output risk. If farmers' risk aversion is low, the first effect dominates the second and opening trade leads to a reduction in the global level of prevention.

## 1.5 Conclusion

We have studied the demand for prevention in an agricultural type market when contingent claims markets are absent. We have characterized the competitive market equilibrium under rational expectations and shown that when price elasticity of demand is less than unity, prevention decreases with the farmers' risk aversion. We have characterized the socially efficient level of prevention, that internalizes the pecuniary externalities coming from the absence of state-contingent claims markets, and given sufficient conditions that lead to under-prevention at the market equilibrium and to the existence of a Pareto-improving prevention subsidy. Considering the impact of trade, we have shown that opening trade, by eliminating price unstability, leads to a lower expected benefit from prevention, but also exposes farmers to greater output risk they cannot insure because of incomplete markets. If risk aversion is sufficiently high (low), prevention increases (decreases) after trade is opened.

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## 1.6 Appendix

The link between income risk aversion and price risk aversion is recalled in this section. We follow here the expositions of Newbery and Stiglitz (1981) and Chavas (2004). Considering an indirect utility function $V(\tilde{P}, I)$ with price $\tilde{P}$ stochastic and income $I$ non-stochastic, the consumer's attitude with respect to price risk can be analyzed in a similar vein than income risk by defining the willingness to pay to stabilize the price at its mean, $B$, as follows:

$$\mathbf{E}V(\tilde{P}, I) = V(\mathbf{E}\tilde{P}, I - B)$$

Computing a second-order Taylor series approximation of the LHS at the neighbourhood of $\tilde{P}$ (respectively of the RHS at the neighbourhood of $B$), we get

$$\begin{aligned} \mathbf{E}V(\tilde{P}, I) &= \mathbf{E}\{V(\mathbf{E}\tilde{P}, I) + (\tilde{P} - \mathbf{E}\tilde{P})V_1 + 0.5(\tilde{P} - \mathbf{E}\tilde{P})^2 V_{11}\} \\ &= V(\mathbf{E}\tilde{P}, I) + 0.5V_{11}\mathbf{Var}\tilde{P} \end{aligned}$$

and

$$V(\mathbf{E}\tilde{P}, I - B) = V(\mathbf{E}\tilde{P}, I) - BV_2 \tag{1.37}$$

Hence combining these two equations we get

$$B = -0.5\mathbf{Var}\tilde{P}\frac{V_{11}}{V_2} \tag{1.38}$$

Since by assumption $V_2 > 0$ consumers benefit (lose) from stabilizing a small price risk at its meann if $V_{11} < 0$ ($> 0$), i.e. $V$ is concave (convex) in the price argument.

It is possible to go further with the analysis by approximating $B$ as a function of consumer's relative risk aversion coefficient and price and income elasticities of demand for small risks. To do so, let us differentiate the Roy's relation $Y^d = -\frac{V_P(P,I)}{V_I(P,I)}$ with respect to $\tilde{P}$ and $I$. We get respectively:

$$\begin{aligned} V_{11} &= -V_{12}Y^d - V_2\frac{\partial Y^d}{\partial \tilde{P}} \\ &= [V_{22}Y^d + V_2\frac{\partial Y^d}{\partial I}]Y^d - V_2\frac{\partial Y^d}{\partial \tilde{P}} \end{aligned}$$

and

$$V_{12} = -V_{22}Y^d - V_2\frac{\partial Y^d}{\partial I}$$

Hence we get

$$\begin{aligned} \frac{V_{11}}{V_2} &= \frac{V_{22}}{V_2}Y^{d2} + \frac{\partial Y^d}{\partial I}Y^d - \frac{\partial Y^d}{\partial P} \\ &= \frac{Y^d}{P}\left[I\frac{PY^d}{I}\frac{V_{22}}{V_2} + \frac{I}{Y^d}\frac{PY^d}{I}\frac{\partial Y^d}{\partial I} - \frac{P}{Y^d}\frac{\partial Y^d}{\partial P}\right] \\ &= \frac{Y^d}{P}\left[-\phi\frac{PY^d}{I} + \eta\frac{PY^d}{I} - \varepsilon\right] \end{aligned}$$

Thus the benefit from stabilizing $\tilde{P}$ at its mean can be approximated as follows

$$B = -0.5\mathbf{Var}\tilde{P}\frac{Y^d}{P}\left[-\phi\frac{PY^d}{I} + \eta\frac{PY^d}{I} - \varepsilon\right] \tag{1.39}$$

$B$ increases with the size of the risk $\mathbf{Var}\tilde{P}$, with the consumer's coefficient of relative risk aversion $\phi$, while it decreases with income elasticity of demand $\eta$ and price elasticity of demand $\varepsilon$ (which are respectively positive and negative).

# Chapter 2

# Raising Capital in an Insurance Oligopoly Market[1]

**Abstract**

We consider an oligopoly of firms that compete on price. Firms produce a non-stochastic output, insurance coverage, which is sold before the true cost is known. They behave as if they were risk-averse for a standard reason of costly external finance. The model consists in a two-stage game. At stage 1, each firm chooses its internal capital level. At stage 2, firms compete on price. We characterize the conditions for Nash equilibria and analyze the strategic impact of capital choice on the market. We discuss the model with regards to insurance industry specificity and regulation.

**Keywords**: Price Competition, Risk-averse Firms; Insurance Market, Capital Choice.

## 2.1 Introduction

This article presents a model of capital choice for an oligopoly of insurance firms with costly external finance. Determining the appropriate levels of capital holding and investment in risk management is a major component of insurers and reinsurers' activities, as well as a prominent regulatory issue. Due to the trend towards consolidation of the last two decades, insurance markets are far from being perfectly competitive. In the context of imperfect competition, firms' price and capital decisions can be expected to become *strategic* variables. This leads to consider the question of capital regulation with a different perspective. In a market where capital choice and solvability are crucial and where cycles linking prices and capital are observed empirically, it is useful to understand how capital decisions are impacted by imperfect competition.

There are two fundamental reasons for an insurance firm to invest in risk management and costly capital holding. The first one is the concern for quality. The nature of the insurance contract is essentially a promise to deliver indemnities ex-post in some states of Nature

[1]This chapter is coauthored with Sabine Lemoyne de Forges.

in exchange for a premium paid in advance. The credibility of such promise is a major preoccupation of policyholders. A contract with non-zero default risk has a lower value for the policyholder than a fully credible contract, so consumers have a lower propensity to pay for it. Hence profit-maximizing insurance firms have a rationale to reduce their probability of default because of consumers' concern, by investing in risk management activities, and/or holding a sufficient level of capital that plays the role of a buffer stock. This aspect refers to the solvency issue (Zanjani, 2002; Rees et al., 1999; Fagart et al., 2002). The second explanation relies on direct state-contingent costs that make the firms' payoffs becoming non-linear and so justify the use of risk management and capital holding strategies, even if shareholders-managers, considered as the same entity, are risk neutral. These non-linearities may include i. the presence of convex taxes on corporate earnings, ii. financial distress costs, iii. costly external funds due to costly state verification (Gollier, 2007; Froot et al., 1993)[2]. These explanations are not mutually exclusive, and give so many reasons for insurance and reinsurance firms to reinsure themselves, hedge, manage risks and participate in insurance pools (Froot et al., 1993), as well as to hold internal costly initial capital to reduce the cost of risk (Froot, 2007).

If such rationales for risk management and capital holding by insurers and reinsurers are well understood (at least theoretically), less is known about the way these decisions operate in the strategic context of imperfect competition. This lack of interest may come from the fact that insurance markets are usually considered to be competitive. Although this assumption is well-documented, there are also arguments in favour of imperfect competition as a more appropriate framework in the cases of specialized insurance companies (Nye and Hofflander, 1987) and the reinsurance sector (Gron, 1990). Moreover, since the insurance premiums are partly determined by the prices and capacities of reinsurance market, the degree of competition in the reinsurance sector does matter for the insurance one. Intuitively, the introduction of imperfect competition may have consequences on pricing and capital decisions: when firms compete strategically in an oligopolistic market, risk management decisions may be distorted by strategic effects. These distortions may in turn affect insurance supply decisions, that is which lines of risks to cover and at which unit price. More

[2]Note that there is also a theoretical explanation that, on the contrary, supports the assumption of *risk-loving* behavior of firms: limited liability, in a context of agency problems between creditors, who bear the cost of distress if it occurs, and owners, who get the benefits as long as they exist, but are protected by a limited liability constraint if the firm goes bankrupt.

capitalized firms would be able to accept more risks, and so capital holding could increase their market shares on lines of risks that are characterized by high aggregate uncertainty.

The purpose of this paper is to study the endogenous choice of capital holding and pricing decisions for an oligopoly of (re)insurance firms that face costly external finance. We build on Froot et al. (1993), which provides one of the canonical explanations for firms' risk management based on the assumption that internal capital is less costly than external capital. We consider a price competition setting similar to Wambach (1999). Indeed as argued by Rees et al. (1999), price competition seems more natural than quantity competition if rationing the supply is difficult once the price of the product has been posted (Vives, 1999), as it is the case in the insurance sector. In the model, the number of insurers is exogenous. Insurers cover a single line of risk which is characterized by aggregate uncertainty, i.e. uncertainty on the level of the aggregate expected loss[3]. This uncertainty may arise from correlated risks across policyholders, a typical feature of natural disaster risks, such as earthquake, drought etc. Alternatively, it may also be interpreted as knightian uncertainty; this is typically characteristic of "new technological risks", for which the probability distribution cannot be derived from past observations.

In this framework, we analyze the strategic choice of capital for insurance firms. To do so, we consider the following two-stage game: at the first stage, firms choose their level of internal capital which determines the firms' cost of risk, at the second stage, they compete on price on the output market. Under imperfect competition, holding more capital reduces the cost of risk for firms but has also consequences on competition through the firms' price-setting game. As in Wambach (1999), we obtain a continuum of Nash equilibrium prices at stage 2, allowing for positive oligopolistic rents. Under a stricter assumption of decreasing absolute risk aversion, we find that the first-stage choice of capital is strategic for the firms as playing safer on the capital market induces a harsher behavior on the product market. We underline the importance of the cost of capital in the insurance industry outcomes. Finally, we propose a different approach to the question of capital regulation, complementary to the classical quality argument (Plantin and Rochet, 2007): required levels of capital may have an impact on competition prices, and thus be beneficial in a

[3]When risks are statistically independent across policyholders, risk management and capital budgeting decisions are still an issue since the probability of default is never null, but it is clear that the problem becomes more stringent when there is aggregate uncertainty about the expected profit from a line of risk.

social welfare perspective.

**Related literature.**— Our paper is related to both the oligopoly and finance literatures. In recent years, the oligopoly literature has been extended to the case of risk-averse firms facing different sources of risk (demand, cost, rivals' characteristics). In this vein, Polborn (1998) and Wambach (1999) study an oligopoly of $n$ firms with risk-averse managers, producing a single output with constant but stochastic marginal cost. Firms commit to the price of the output before the marginal cost is revealed, and then serve the whole demand they face at the committed price, which is typically the Bertrand assumption. Such assumptions appear to fit very well with the insurance and reinsurance markets where the cost of a given line of (re)insurance is not known with certainty at the time contracts are sold, i.e. the production cycle is reversed[4]. In such setting, the authors find that the Bertrand paradox (Tirole, 1988) -i.e. the fact that at least two competitors are sufficient to restore the competitive price outcome- can be resolved in the sense that there exist Nash price equilibria above the expected marginal cost, which lead to strictly positive oligopolistic rents. There are also multiple equilibria (Wambach, 1999) due to a trade-off between expected profit and risk for each of the competing firms. Asplund (2002) generalizes the analysis to complementary or substitute strategies and takes into account the possible covariations across firms' individual risks. He also notes the importance of initial wealth and fixed cost on the resulting Nash equilibria when firms display decreasing absolute risk aversion. Duncan and Myers (2000) consider the same kind of model but allow for free entry, so the number of insurers that serve the market is endogenous and depends on their exogenous reservation utility. Because of firms' risk aversion in presence of catastrophic and correlated risks, insurance supply that emerges at the equilibrium is rationed. Powers and Shubik (1998) obtain as well an endogenous number of insurance companies in a Cournot competition framework where the scale effect is mainly a solvency effect due to the law of large numbers through the reduction of the number of customers. Froot and O'Connell (2008) also introduce imperfect Cournot competition among risk-averse reinsurers that pool insurers with correlated portfolios. They suggest that imperfect competition tends to reinforce the overpricing of correlated risks when compared to the fair price. Because we assume a price competition, our model is closely related to Polborn

[4] Other markets also have such characteristics: cost of research and development, cost of expertise among others.

(1998) and Wambach (1999), with the difference that they do not consider a capital choice stage that takes place before the pricing decision.

Our analysis can also be related to the more general oligopoly literature. Indeed, introducing risk on marginal cost and considering risk-averse firms is quite similar than assuming increasing and convex costs. After all, the cost of risk is ex-ante a production cost like other ones, which can be measured in monetary terms by the risk-premium. Since the latter is convex in the size of risk, the analogy with convex costs is quasi-direct. Price competition with a convex cost function has been studied by Vives (1999) and Weibull (2006). They show the existence of a compact set of multiple Nash equilibrium prices, some of them being above the marginal cost. The specificity of our analysis comes from the endogenous shape of the risk premium through capital choices and their wealth effect. In a certain sense, our stage 1 capital choice can be interpreted as a form of technological investment that affect the shape of the cost function, that is the risk premium in our setting. Thus the wealth effect is not only important in the pricing decision, but also at the heart of our analysis of capital choice by firms.

Another source of influence is Kreps and Scheinkman (1983). At a first sight, our two-stage game approach with a capital followed by a price decision heavily recalls their setting. But in fact our model is quite different. First, in Kreps and Scheinkman, marginal cost is constant while in our model it is not because the risk premium is convex. Secondly, our capital choice refers to a level of internal wealth that modifies the shape of the risk premium through a wealth effect, which differs from Kreps and Scheinkman that consider the first stage capital decision as a commitment to produce not more than a certain quantity in stage 2 whatever the price chosen. In other words, Kreps and Scheinkman endogenize the choice of a quantity constraint while we endogenize the choice of the shape of the cost function, measured in monetary terms by the risk premium.

A third strand of literature that appears to have some connections with our paper is the theoretical work on debt versus equity in oligopolistic settings derived from Brander and Lewis (1986), that analyze the strategic value of debt emission for firms in oligopoly markets. Brander and Lewis (1986) tackle the Modigliani-Miller neutrality result by considering that the financial structure (i.e. the repartition of debt and equity in firms 'financing choice) may have a commitment value for the stage 2 production decision. Our timing is similar, with two-stages model where financial decisions are taken at stage 1 and production decisions at stage 2. The strategic value of debt holding depends on the type of uncertainty faced by the market - demand or cost - and the type of competition (Wanzenried, 2003). We depart here from this literature as we focus on the impact of risk aversion on the choice of ex-ante equity capital, from the investor's point of view: risk aversion enhances the weight of high cost states, rendering capital level a strategic choice as it modifies the price equilibria.

The paper is organized as follow: Section 2.2 lays out the competition game; Section 2.3 and 2.4 derive the results on the impact of capital holding on the competitive structure of the market; Section 2.5 looks at the social welfare and capital regulation. Section 2.6 discusses these results in line with the insurance industry specificities and concludes.

## 2.2 The model

### 2.2.1 The oligopoly market

We consider an oligopoly of $n$ insurance firms, indexed by $i = 1...n$, that produce the same non-differentiated single good $q^i$ that can be thought of as a quantity of insurance coverage sold to a continuum of risk-averse insureds. The aggregate demand for coverage is exogenous, non-stochastic, and defined by $Q(p)$ when all insurance companies charge the same price $p$. $Q(p)$ is continuous, decreasing in $p$ and $\lim_{p\to+\infty} Q(p) = 0$.

Because of the inversion of the production cycle, insurance firms do not know ex-ante the exact cost of supplying such coverage[5]. Let us denote $\tilde{L}_i \in [0, L^{max}]$ the stochastic loss per unit of output (or coverage) $q^i$ sold by the firm $i$. We note $\bar{L}_i = \mathbf{E}\tilde{L}_i$. Cost uncertainty may be particularly relevant in (re)insurance markets where individual risks exhibit positive correlations which is a typical feature of catastrophic risks. Alternatively, cost uncertainty may also reflect the imperfect knowledge of the "true" probability distribution of the loss, due to a lack of data, a situation that is typical of new technological risks, or natural disaster risks. Because of cost uncertainty, the profit from exerting the insurance activity is stochastic. For a firm $i$ and a given price $p$, let us define $\tilde{\pi}^i(p, q^i)$ as follows

[5]This cost can be approximated by the expected loss plus a loading factor that covers a set of various transaction costs (administrative costs, ambiguity aversion, security margin and so on). Even in situations where the law of large numbers applies well, the cost of a given insured risk remains fundamentally stochastic.

$$\tilde{\pi}^i(p, q^i) = q^i(p - \tilde{L}_i) = q^i \tilde{m}_i \tag{2.1}$$

where $\tilde{m}_i = p - \tilde{L}_i$ is the stochastic unit margin. When the insurance coverage is fairly priced, i.e. $p - \bar{L}_i = 0$ and the insurance activity entails no transaction costs, the firm i's expected profit is equal to zero, as in the standard competitive model with risk neutral insurers. If, due to market power, the per unit price is strictly above the expected loss per unit, i.e. $p - \bar{L}_i > 0$, then increasing supply $q^i$ (via increasing market-share) increases the expected profit of the firm, but also makes profit riskier. This is the fundamental trade-off that will be at the heart of the following analysis. To keep things simple, we will consider that the loss $\tilde{L}$ per unit of output is the same for all insurance firms. Whether they are correlated or not is not important in our framework, since coverage is sold before the true realization of losses.

### 2.2.2 Firms' objectives

The managers are supposed to maximize the value of the firm. Following Froot, Scharfstein and Stein (Froot et al., 1993), such objective may lead to an apparent risk-averse behavior when external sources of finance are more costly than internal ones. Let us recall their model. The firm faces a two-period investment and financing choice. The investment requires an expenditure $I$ and has a net return $F(I) = f(I) - I$, where $f$ is an increasing and concave function. This investment may be financed through the firm's internal assets $w$ as well as through external capital $e$ acquired at a cost $c(e)$. The problem for firms is that there are dead weight costs of raising such external finance, due to several reasons including distress costs and informational asymmetries as argued in Froot et al. (1993). Formally, these dead weight costs are captured by the fact that $c(.)$ is convex. The solution of the investment/financing problem is given by

$$\max_I P(w) = F(I) - c(e) \tag{2.2}$$
$$\text{s.t. } I = w + e$$

The value of the firm, denoted $P(w)$ is the maximand of the programme. By analogy with the usual definition of the risk premium (Gollier, 2001), with the difference that the function $P(.)$ replaces the standard von Neumann-Morgenstern utility function $u(.)$, Let $R(W_0, \tilde{x})$ be given by

$$\mathbf{E}P(W_0 + \tilde{x}) = P[W_0 - R(W_0, \tilde{x})]$$

where $W_0$ is the level of initial wealth and $\tilde{x}$ a zero mean risk . Here, the firm $i$ is endowed with an initial level of capital $w^i$. She covers an amount of risk $q^i$ of uncertain loss $\tilde{L}$, at price $p$. Her final wealth is $\tilde{W}^i = w^i + (p - \tilde{L})q^i$. We note $\bar{W} = \mathbf{E}\tilde{W}^i$. The 0-mean risk to which it is exposed is : $(\tilde{L} - \mathbf{E}L)q^i$. For notational simplicity, we note the risk premium $R^i(\bar{W}^i, q^i)$ and we have:

$$\mathbf{E}P(\tilde{W}^i) = P[\bar{W}^i - R^i(\bar{W}^i, q^i)] \tag{2.3}$$

We make the following assumptions :

- (A1) $\quad \frac{\partial P}{\partial w} \geq 1$ and $\frac{\partial^2 P}{\partial w^2} \leq 0$
- (A2) $\quad \frac{\partial R^i}{\partial \bar{W}} \leq 0$
- (A3) $\quad$ for $m \in \{1, ..., n\}$ $\quad \frac{d}{dp}\mathbf{E}P(w^i + (p - L)Q(p)/m) \geq 0$
- $(A4)$The profit maximizing output of the firms increases when the price increases.

The following comments are in order. (A1) follows from the concavity of $f$ and convexity of $c$. This is just a consequence of the envelop theorem (Froot et al., 1993). It implies the risk averse behavior of firms, and its corollary that managing, sharing and/or reducing the risks on internal assets can increase their value. If this internal capital is stochastic, the ex-ante value of the firm, and so the objective to maximize, is given by $\mathbf{E}P(\tilde{w})$. Since $P(.)$ is concave, it is clear that the pseudo risk premium has similar characteristics as the standard risk premium. In particular, $R^i$ is increasing and convex in $q^i$. (A2) is the standard decreasing absolute risk aversion (DARA) hypothesis. (A3) states that demand is sufficiently inelastic.

### 2.2.3 Timing of the game

We consider $n$ firms endowed with a level of initial capital $w_0^i$, which can be interpreted as their past profits. The market equilibrium is modelled as a subgame perfect equilibrium (in short equilibrium) of the following two-stage game

- At stage 1: Firms choose a level of additional capital $K^i$ by issuing new shares (if $K^i \geq 0$) or by buying them back (if $K^i \leq 0$). Firm i's wealth becomes $w_1^i = w_0^i + K^i$.

- At stage 2: Each firm posts its own price and commits to sell any quantity at this price.

At stage 1, firms choose their additional capital level $K$ by maximizing the expected net value: $P(w_f^i) - (1+\tau)K^i$. The capital has an opportunity cost, $\tau K$, for the investors where $0 \leq \tau$. At stage 2, a price competition, in the same manner as in Wambach (1999), takes place between the $n$ value-maximizing firms. Firms compete on price before the true cost is revealed by Nature: the firm with the lowest price catch all the market, and must serve all the demand that it faces; if more than one firm set the same lowest price, the market is shared equally among them.

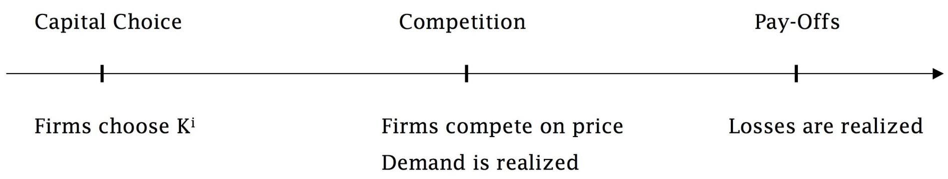


Figure 2.1: Timing of the events

Finally, the state of Nature is realized: losses are revealed. The firms realize their investments choices, raising if needed additional ex-post external capital. The game is solved backward in the two following sections.

## 2.3 Stage 2: Price competition

At stage 2, firms compete on price with the objective to maximize their expected value $\mathbf{E}P^i(\tilde{w}_f^i)$. The case of symmetric firms is first characterized, results are then extended to the case of firms endowed with different levels of internal capital.

### 2.3.1 Symmetric firms

Suppose that at the beginning of stage 2, firms have the same level of internal capital, that is for all $i, j$, $i \neq j$, $w_1^i = w_1^j$. The functions $P^i(.)$ are supposed identical and will be by now denoted $P(.)$. We have

$$\mathbf{E}P(\tilde{w}_f^i) = P\big(\overline{\pi}^i(p, q^i) - R(w_1^i + \overline{\pi}^i(p, q^i), q^i)\big) \tag{2.4}$$

where $\overline{\pi}^i(p, q^i) = q^i(p - \overline{L})$ is the expected profit of firm $i$. $p$ is a symmetric Nash equilibrium if firms can not increase their value by undercutting price. Formally

$$\mathbf{E}P\left(w_1^i + \tilde{\pi}^i\left(p, \frac{Q(p)}{n}\right)\right) \geq \mathbf{E}P\big(w_1^i + \tilde{\pi}^i(p, Q(p))\big) \tag{2.5}$$

or, using the risk premium formulation

$$\begin{aligned}\overline{\pi}^i\left(p, \frac{Q(p)}{n}\right) - R\left(w_1^i + \overline{\pi}^i\left(p, \frac{Q(p)}{n}\right), \frac{Q(p)}{n}\right) &\geq \overline{\pi}^i(p, Q(p)) \\ &-R\big(w_1^i + \overline{\pi}^i(p, Q(p)), Q(p)\big)\end{aligned} \tag{2.6}$$

Consider that firms have an outside option that gives them an expected value equal to $V^{out} \geq 0$, which is assumed exogenous.

**Definition 1.** *We note $p^{out}$ the price for which the firms are indifferent between serving 1/nth of the market or their outside option $V^{out}$*

$$\mathbf{E}P\left(w_1^i + \tilde{\pi}^i\left(p^{out}, \frac{Q(p^{out})}{n}\right)\right) = V^{out} \tag{2.7}$$

The following proposition, extending Wambach (1999)'s characterizes the Nash equilibria of the price competition

**Proposition 6.** *In the case of symmetric firms, under (A1), (A3) and (A4)*
*a) there exists a continuum $P^{NE} = [p^{out}, p^N]$ of Nash equilibrium prices $p \in P^{NE}$, where $p^N$ is defined by*

$$\mathbf{E}P\left(w_1^i + \tilde{\pi}^i\left(p^N, \frac{Q(p^N)}{n}\right)\right) = \mathbf{E}\left(w_1^i + \tilde{\pi}_i(p^N, Q(p^N))\right) \tag{2.8}$$

*b) the maximum Nash price $p^N$ is higher than the competitive price, lower than the maximum monopoly price when it exists, and provides a value of the firm higher than her outside option.*

*Proof* : see appendix. □

The fact that price competition across risk-averse firms leads to multiple equilibria has already been exhibited by Polborn (1998) and Wambach (1999). It has a strong link with the standard price competition literature when firms exhibit decreasing returns to scale[6]. When price is higher than expected cost, cutting price increases the expected profit of the firm that makes a unilateral deviation, but also exposes it to the increased cost of risk that arises from serving the whole market. For some values of price, the cost for the firms of being exposed to more risk can be greater than the expected gain from catching the whole market. In the present case, to the fundamental trade-off between expected profit and risk exposure must be added a *wealth-effect* term which comes from the fact that the cost of bearing risk itself is a function of the value of expected profit.

This three-terms trade-off can be represented graphically. To keep things simple, let us consider the case of a perfectly inelastic demand equal to $Q$. Let $s^i = q^i/Q$ denote the market share of firm $i$. Serving more customers exposes the firms to a greater share of cost uncertainty, at an increasing rate. In Figure 2.2, both expected profit and pseudo risk premium curves are drawn as a function of the market share in the case of two firms and for two (not necessarily Nash equilibria) prices: $p_0$ (thin line) and $p_1$ (thick line), with $p_0 < p_1$. There are essentially two values of interest for the market share: $Q/2$ and $Q$. For a given price $p$, the expected profit of firm $i$, $s^i Q(p - \overline{L})$, is a linear function of the market share. The certainty equivalent of firm's wealth is simply the difference between the expected profit and the risk premium, which is represented by the vertical arrows. As a preliminary, let us consider the effect of a price increase from $p_0$ to $p_1$. For all market shares, the profits will be higher for $p_1$ than for $p_0$. But the risk premium is lower because of the wealth effect: a higher expected price leads to a higher expected profit, and so a higher final wealth of the firm. Under decreasing absolute risk aversion, this tends to decrease the firm's sensitivity to risk. Hence, for a given market share, an increase in price tends to increase the difference between the expected profit and the risk premium.

Let us identify the Nash Equilibrium prices. Start at price $p_1$. At this price each firm has an incentive to slightly decreases its price in order to catch the whole market. The price cut simultaneously decreases the slope of the expected profit line and increases those of the risk premium, so the two curves are getting nearer, as a "scissor"closing movement. As the increase in expected profit more than compensates the increase in pseudo risk premium,

[6]This result has in fact an intuitive explanation: for some values of price, a slight price cut allows a firm to catch all the market, which increases its revenue. But at the same time the firm is committed to serve the whole demand (which is moreover slightly higher due to the price cut), exposing it to higher values of marginal cost and so a higher average cost of production. For low enough output price, catching the whole market could then reduce the value of the firm.

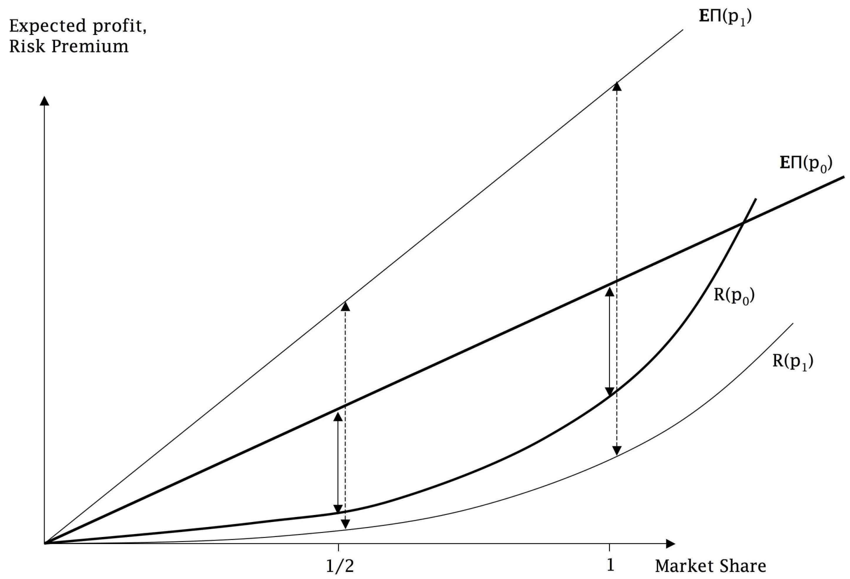


Figure 2.2: Characterization of equilibrium prices for symmetric risk-averse firms competing on price. - Case of inelastic demand.

price cutting is the optimal strategy. Symmetric firms cut prices up to a certain level. In our figure, at $p_0$, firms' value are equal at $Q/2$ and $Q$. If one firm slightly cut its price, the increase in expected profit that it would get from catching the whole market is inferior to the loss due to the increase in risk premium. So when the indifference price, $p^N$ in our formal analysis, is attained, no firm has an incentive to cut its price anymore. It is graphically straightforward that this price is not the single Nash Equilibrium. As long as firms get as much as their outside option, the firms participate to the market. Every price between the outside option price and the indifference price is a Nash equilibrium, since no firm has neither an incentive to slightly increase its price (its demand would be zero) nor to decrease it (the subsequent increase in risk would decrease the value of the firm).

To characterize how internal capital impacts the maximum Nash price, we consider here an assumption which is slightly stronger than DARA. Let us denote

$$\Delta R = R(w_1^i + \bar{\pi}(p^N, Q(p)), Q(p)) - R\left(w_1^i + \bar{\pi}\left(p, \frac{Q(p)}{n}\right), \frac{Q(p)}{n}\right)$$

and assume that

- (A5) $\quad \Delta R$ decreases in $w$.

With DARA (A2) only, the global effect of a multiplicative risk on the risk premium is ambiguous in general. This is linked to a double effect: an increase of market share corresponds to 1. An increase in endowment decreasing the risk premium through the DARA hypothesis 2. An increase in risk, increasing the risk premium through the risk aversion hypothesis. (A5) states that prices are in a region were the risk effect is amplified by the wealth effect: the more capitalised firms are less reluctant to serve higher demand - and hold more risk-. For all the following results of the paper, assumption (A5) is necessary, as it is necessary to obtain the following Lemma:

**Lemma 1.** *For symmetric firms, under (A1) and (A3) to (A5),* $\frac{\partial p^N}{\partial w_1} \leq 0$.

*Proof* : see appendix. □

Thus when the level of firms' internal capital is high, i.e. firms are less risk averse, the competitive pressure they can exert is then high, and leads to a lower the maximum Nash price.

### 2.3.2 Asymmetric firms

Let us consider the asymmetric continuation equilibrium where firms enter stage 2 with different levels of capital. It is important to consider the asymmetric equilibrium of stage 2 since capital is the strategic variable at the first stage, and we should be able to describe how unilateral deviations modify the outcome of the game. We consider the case of an oligopoly of firms $i = 1...n$: $w_1^n > w_1^i > w_1^1$. Under DARA, difference in the level of available capital lead to differences in the degree of risk aversion, which impact the price competition game. The less risk averse firm is the firm with the higher initial capital, that is firm $n$.

**Definition 2.** *We consider an oligopoly of n risk averse firms. We note* $p_{max}^{out}$ *the maximum of the prices for which the firms are indifferent between serving 1/nth of the market or their outside option* $V^{out}$

$$p_{max}^{out} = \max_{i=1..n} \left\{ p_i^{out} : \mathbf{E}P(w_1^i + \tilde{\pi}^i(p, Q(p)/n)) = V^{out} \right\} \tag{2.9}$$

Hence we can state the following proposition, focusing on n-oligopoly prices, that is the case where $p_{max}^{out} < p_{min}^N$

**Proposition 7.** *In the case of asymmetric firms, under (A1) and (A3) to (A5), if* $p_{max}^{out} < p_{min}^N$*:*

*a) There exists a continuum* $P^{NE} = [p^{out}_{max}, p^N_{min}]$ *of Nash equilibrium prices* $p \in P^{NE}$ *for the n-oligopoly, where* $p^N_{min}$ *is defined as*

$$p^N_{min} = \min_{i=1..n} \left\{ p : \mathbf{E}P(w^i_1 + \tilde{\pi}^i(p, Q(p)/n)) = \mathbf{E}P(w^i_1 + \tilde{\pi}^i(p, Q(p))) \right\} \tag{2.10}$$

*b) The maximum Nash price* $p^N_{min}$ *corresponds to the indifference price for the less risk averse firm between serving the whole market and serving 1/nth of it.* $p^N_{min}$ *is higher than the competitive price, lower than the maximum monopoly price when it exists, and provides a value of the firm higher than her outside option.*

*Proof* : see appendix. □

Note that in the case where $p^{out}_{max} > p^N_{min}$, the difference between the firms initial capital is such that the competitive pressure exerted by the less risk averse firms $i$ leads to a situation where the most risk averse firm cannot afford to stay in the market at such price. But the other firms $i$ can then still sustain the risk of all the market.

An equilibrium can be reach with asymmetrically capitalised firms. The less capitalised the firm, the less oligopolistic rent it can extract. This leads to a situation where the market is divided between less firms. Other Nash equilibria may be obtained in the case where $p^{out}_{max} < p^N_{min}$, with less than $n$ firms (see appendix).

A graphical explanation may give the intuition of the proof. For a same level of coverage of the market, the risk premium of firm i $R^i$ is higher than firm j's risk premium $R^j$. As in the symmetric case, the case of inelastic demand is considered.

As firm $i$ is more risk averse than firm $j$, $p^N_i > p^N_j$. We focus on the case where $p^{out}_{max} < p^N_{min}$. For all $p > p^N_i$, both firms prefer serving the whole market and thus may deviate from price to conquer it; $p^N_i \geq p > p^N_j$ firm j prefers the whole market and thus will lower the price to conquer it; if $p = p^N_j$, then firm j is indifferent between serving the whole market or half of it, and firm $i$ prefers serving half of it, thus $p^N_j$ is a Nash equilibrium price. Thus, with a similar argument than in the symmetric case, for $p^N_j \geq p \geq p^{out}_{max}$ there is a Nash equilibrium. Figure 2.3 illustrates this case. Both firms share the same expected profits. The risk premium curves correspond for each firm to the risk premium value for their indifference prices. Firm i's risk premium curves is always higher than firm j's. We can graphically see that the indifference price for firm i is higher than for firm j. Thus,

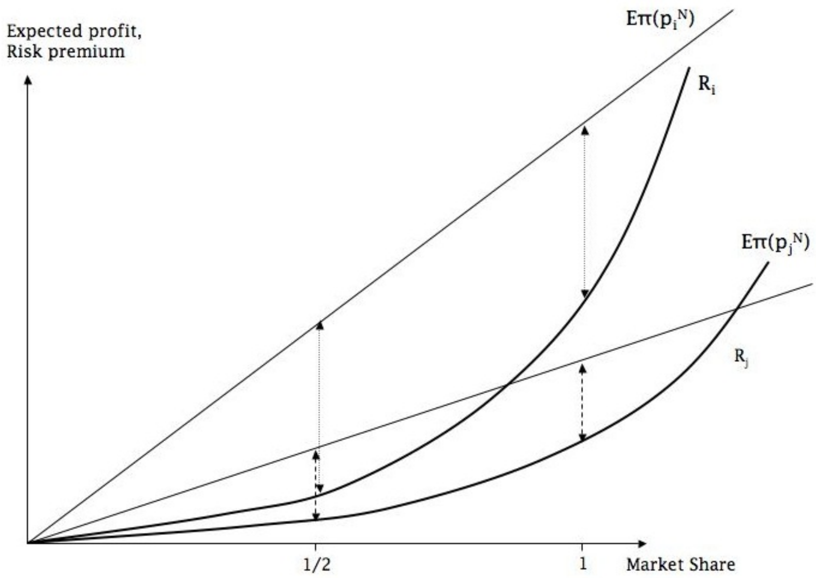


Figure 2.3: Characterization of equilibrium prices for DARA firms with different level of capital competing on price - Case of inelastic demand - $w_1^j > w_1^i$.

we have shown that in the case of a duopoly of asymmetric DARA firms, there exists a continuum of Nash equilibrium prices $p$. The higher Nash equilibrium price $p_j^N$ corresponds to the indifference price for the less risk averse firm, between serving the whole market and serving only one half of it.

### 2.3.3 Selecting a unique equilibrium price

The existence of multiple equilibrium prices raises the question of their selection. This is especially important in our two-stage setting since the anticipated Nash equilibrium price will be determinant for firms' choices of capital holding in the preceding stage. A possible argument relies on a collusion analysis[7]. Since firms do not collude in our model, it seems natural to favour the Nash equilibrium price(s) that are more robust to collusion. Let us consider a collusive group, but without punishment (short-run price competition) . For collusion to be credible in this case, all collusive equilibria should be Nash equilibria, i.e. an element of the set of Nash equilibrium prices between $[p^{out}, p^N]$ since any price higher than $p^N$ does not resist to unilateral deviation (price undercutting). Thus without punishment possibilities, the highest price of this set, $p^N$ is likely to be chosen and applied in a collusive agreement.

[7]Another kind of argument in favour of $p^N$ can also be found in the framework of evolutionary game theory, but we do not develop it in details here.

Another argument also pleads for the selection of the highest price. Intuition suggests that high equilibrium prices are more likely to deter collusion, since they let firms with high oligopolistic rents and so reduce the size of punishment if a price war occurs after some firms break the collusive agreement. Formally, let us consider a collusive price $p^C$ strictly above the maximum Nash equilibrium price, i.e. $p^C > p^N$. Suppose that the $n$ firms are identical with each firm's expected value written as $V(p,n)$ for a given price $p$ when the $n$ firms share the market equally. Let $\delta$ be the discount factor, identical among firms, and $T$ the number of periods over which collusion is supposed to take place. Under collusion, each firm gets

$$V = (1 + \delta + \delta^2 ... + \delta^T)V(p^C, n) \tag{2.11}$$

If a firm slightly undercuts the price to $p^C - \epsilon$, it get $V(p^C - \epsilon, 1)$ in the first period, which is higher than $V(p^C, n)$ for an $\epsilon$ close to zero. But such unilateral deviation triggers a price war that leads to $V(p^{NE}, n)$ in the following periods, with $p^{NE} \in P^{NE}$. Hence, firms will stick to the collusive price if

$$(1 + \delta + \delta^2 ...)V(p^C, n) \geq V(p^C - \epsilon, 1) + (\delta + \delta^2 ...)V(p^{NE}, n)$$

Strict equality defines a threshold $\delta^{lim}$ above which collusion occurs. For $T = +\infty$, this threshold is equal to

$$\delta^{lim} = \frac{V(p^C, 1) - V(p^C, n)}{V(p^C, 1) - V(p^{NE}, n)}$$

Since $V(p^{NE}, n)$ strictly increases with $p^{NE}$, $\delta^{lim}$ increases with $p^{NE}$. Hence the intuition that collusion is less likely to occur for higher equilibrium prices is verified. In this sense, the highest Nash equilibrium price $p^N$ can be selected as the more robust to collusion. In the following section, in which stage 1 choice of capital is characterized, firms will be assumed to anticipate this $p^N$ as the outcome of price competition without any uncertainty.

## 2.4 Stage 1: Capital choice

At stage 1, firms non-cooperatively determine their levels of additional capital, $K^i$. We look for the Nash equilibria, that is a set of strategies $(K^1, .., K^n)$ such that there is no profitable unilateral deviation for any firm. Since the firm(s) with the highest level of internal capital determine(s) the market price $p^N(\max[K^1,...,K^n])$[8], while the competitors take the price as given, one must distinguish price-making and price-taking firms when studying the consequences of marginal deviations. The price-making firms take into account the strategic, product-market effect of their internal capital when choosing it, while price-taking firms do not. We define the objective function of the firms below.

**Definition 3.** *The value of the firm net of capital, $V_i(.)$, is defined as follows* [9]

$$V_i : (K^1,..,K^n) \to P\big[w_1^i + \overline{\pi}\big(p^N(\overline{K})\big) - R\big(w_1^i + \overline{\pi}(p^N(\overline{K})), Q(p^N(\overline{K}))\big)\big] - (1+\tau)K^i$$

*where* $\overline{K} = \max[K^1,...,K^n]$.

Depending on the status of the firm (price taking or price making), the behaviour of the function is quite different. For a firm where $K^i = \overline{K}$ the anticipated Nash price is a function of $K^i$. Otherwise, the anticipated Nash price only depends on an exogenous $\bar{K}$. Such formal clarification being made, we are now able to study the stage 1 subgame in more depth. The first step is to characterize the behavior of $V_i(.)$, and the sign of a marginal deviation, in the symmetric case.

*a) Marginal deviation of a price-taking firm*

For a price-taking firm, $\overline{K} = \max[K^1,...,K^n] \geq K^i$. In the symmetric case, we are looking at the sign of the first order derivative of $V_i$, for an exogenous price equal to $p^N(K_i)$

$$V'_{iTaker}(K^i) = \underbrace{(1-R_1)P_w}_{MB} - \underbrace{(1+\tau)}_{MC_{direct}} \tag{2.12}$$

The first-order derivative formalizes the trade-off between the marginal cost of capital, $MC_{direct}$, and the marginal benefit of reducing the cost of risk for the firm, $MB$. If capital is not costly to hold, i.e. $\tau = 0$, the first-order derivative becomes $(1-R_1)P_w - 1$ which is always positive since by assumption $R_1 \leq 0$ and $P_w \geq 1$.

*b) Marginal deviation of a price-making firm*

For a price-making firm, $\overline{K} = \max[K^1,...,K^n] = K^i$. The first-order derivative of $V_i(K^i)$ is written as

[8] The following results are true for all anticipated strategies of equilibrium prices $p(K^1,...,K^n)$ such that $\frac{\partial p^N}{\partial w_1} \leq 0$ (Lemma 1).

[9] The ex-ante value of the firm evaluated at $p^N$ is the same for serving a part of the market or the whole market. For the sake of simplicity, we work on the "whole market" expression.

$$V'_{iLeader}(K^i) = \underbrace{(1-R_1)P_w}_{MB} - \underbrace{\left[Q'(p^N)R_2 - \frac{\partial \pi}{\partial p^N}(1-R_1)\right]\frac{\partial p^N}{\partial K^i}P_w}_{MC_{strategic}} - \underbrace{(1+\tau)}_{MC_{direct}} \tag{2.13}$$

When the firm $i$ is the most capitalized, it has to take into account the strategic effect due to product market competition $MC_{strategic}$ in addition to the direct cost-of-risk reduction incentive $MB$ and the marginal direct cost $MC_{direct}$ in its capital budgeting decision. This strategic effect represents a cost, since increasing internal capital reduces the market price set at stage 2 (Lemma 1). It is decomposed into two distinct terms that correspond to the following effects. The first one, *strategic wealth effect*, is equal to

$$MC_{stratW}(K_i) = -\frac{\partial p^N}{\partial K^i}\frac{\partial \pi}{\partial p^N}(1-R_1)P_w$$

Indeed because of increased competitive pressure, the increase in expected final wealth due to more capital is partly counterbalanced by lower expected profits. If the price-making firm $i$ chooses its capital in a naive way, i.e. without considering this effect, it would overvalue its expected final wealth, and so the real cost of risk in its capital budgeting decision. The second term that we name *strategic demand effect* is equal to

$$MC_{stratD}(K_i) = \frac{\partial p^N}{\partial K^i}Q'(p^N)R_2P_w$$

It is null when the demand is price-inelastic. By lowering the market price, a marginal increase in capital commits each firm to serve a higher demand, and so exposes them to a higher level of risk.

*c) Assumption of concavity*

The question of the sign of both marginal deviations is important to understand the trade-off of the players. We make the two following assumptions and define in the following manner the levels of external capital $K^*$ and $K^+$

- (A6a) $\quad \forall\ K^i,\ V''_{iLeader}(K) \leq 0 \quad$ and $\quad \exists K^{i*}:\ V'_{iLeader}(K^{i*}) = 0$
- (A6b) $\quad \forall\ K^i,\ V''_{iTaker}(K) \leq 0 \quad$ and $\quad \exists K^{i+}:\ V'_{iTaker}(K^{i+}) = 0$

(A6) makes the analysis tractable. $K^*$ defines the level of capital under which the price-maker firm has interest to deviate by increasing its level of capital. Whereas $K^+$ defines the level above which the price-taking firm has interest to deviate by lowering its capital. Note that $V'_{iLeader}(K^i) = V'_{iTaker}(K^i) - MC_{strategic}$. It follows directly that $K^* < K^+$.

*d) Equilibria characterisation*

Following the previous discussion, we place ourselves under assumption (A6) in the case of a symmetric oligopoly of $n$ firms, characterized by their initial wealth $w_0$. Since firms are perfectly symmetric, for all $i, j$ $K^{i*} = K^{j*} = K^*$ and $K^{i+} = K^{j+} = K^+$ . We have the following proposition

**Proposition 8.** *Under assumptions (A1) and (A3) to (A5), if $w_0^1 = ... = w_0^n = w_0$, there exists a continuum of symmetric equilibria $K_1 = ... = K_n = K$ such that $K^* \leq K \leq K^+$.*

*Proof* : see appendix. □

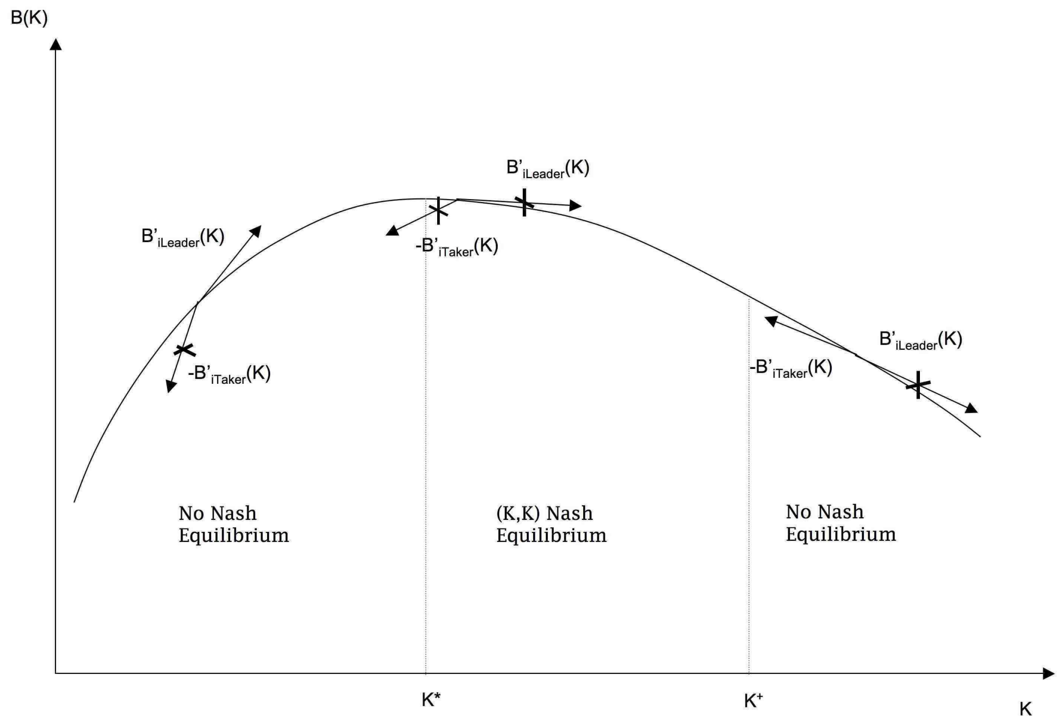


Figure 2.4: Equilibrium capital choices

Figure 2.4 provides a graphical illustration of the continuum of Nash symmetric equilibria. The curve represents the net value function $V(.)$. The right-hand arrows correspond to the marginal net value of an increase of capital for a price-making firm, whereas the left-hand arrows show the marginal net value of a decrease of capital, for price-taking firm. When $K < K^*$, a firm has no incentives to decrease capital as the marginal net value of being the follower is negative, whereas the marginal net value of increasing capital and being leader is positive. Thus it is driven to $K = K^*$. For all $K$ between $K^*$ and $K^+$, the firm has no interest in increasing nor lowering its capital level as both would induce a lower net benefit (as taker or leader). For $K$ higher than $K^+$ however, there is no incentive for the firm to increase capital, but as a follower it has an interest in lowering her capital level as marginal net value for holding one more units of capital is too low compared to the cost of holding it. This leads to a continuum of Nash Equilibrium of which one can select the set leading to the higher firm's value as in the case of the equilibrium price.

The case of asymmetric firms follows simply. To grasp the intuition of the game, consider 2 firms $l$ respectively $h$, with a low, respectively high, level of initial capital: $w_0^l < w_0^h$. First note that if assumption (A6a) holds for $V_{lLeader}$, it holds for $V_{hLeader}$ (see appendix E). The firm with the lowest level of initial capital is the more risk averse. To have the same level of risk aversion, firm $l$ has to hold much more costly capital than firm $h$. As the cost of capital is linear, they will both obtain their maximal net value for the same level of wealth $\bar{w} = w_0^l + K_l^* = w_0^h + K_h^*$. As long as firm $l$ does not have the same amount of wealth as firm $h$, it has interest to hold the same total of capital, up to $K^+$, level at which it is too costly to hold capital. This leads to the following Proposition

**Proposition 9.** *Under assumptions (A1) and (A3) to (A5), if $w_0^1 < ... < w_0^n$, there exists a continuum of Nash equilibria $(K_1, ..., K_n)$, where $\forall\ i < n$, $K^i = K_1^* + w_1 - w_i$, and $K_1^* \leq K_n \leq K_1^+$.*

*Proof* : see appendix. □

For reasons similar to those developed to select the Nash equilibrium price, we focus on the level of capital that maximizes firm's net value. Due to its implicit definition, $K^*$ depends on the initial level of capital $w^0$. Intuitively a high level of initial capital could lead to a Nash equilibrium of no additional capital. Following Proposition 8, we can show that in this case, that is when $V_i'(0) < 0$, $K = 0$ is a Nash equilibria.

*e) Analysis of the results*

The model provides a framework with an endogenous choice of capital that accounts for specificities of the insurance market. It enhances the strategic role of capital in the product market competition of insurance firms. Indeed, firms have two different ways to manage risks. The first one is by acquiring more capital at first stage to lower their risk premium. The second one is by setting a higher price everything else being equal at the second stage. Both ways to hedge interact in a price competition setting. Indeed the opportunity cost of capital limits the amount of capital an insurance company may hold before subscription. A higher level of capital however induces a decrease in insurers' cost of risk. This allows for a more aggressive attitude on the market, a decrease in their equilibrium prices and thus an increase in the quantity insurers deliver. Thus the level of capital is limited by its strategic cost in addition to the cost of holding it.
The model allows for a double set of continuum of equilibrium : continuum of equilibrium prices at a fixed capacity, and continuum of sets of capital choices, when anticipating the maximum Nash Price $p^N$. Following the arguments developed previously we focus on the equilibrium extracting the highest rents for the firms, that is the set of $K^*$ and the equilibrium price $p^N$.

**Corollary 1.** *In the preceding framework, following a symmetric negative shock on initial wealth level, prices rise and global market capacity decreases.*
*The same results hold in the case of a positive shock on the cost of capital.*

*Proof* : The concavity of function $V_i(.)$ leads to the result, derived from Proposition 8. □

This result is interesting for the study of cycles. A high cost event in an industry with uncertainty on costs leads to a decrease of the capital available. In our framework, a lower initial capital leads to a lower level of capital (initial and external) at the end of Stage 1, due to the cost of additional capital. The higher resulting price on the product market leads in the case of an elastic demand to a contraction of the industry's global capacity.
Note that in the preceding symmetric framework, a higher cost of capital leads to higher prices on the product market as capital is more costly to hold, and thus a contraction of the quantity supplied to the market in the case of elastic demand. An asymmetry in cost of capital for firms leads to interesting results. The firm with the lowest cost of capital chooses the level of capital that maximizes her net value and leads the level of price on

the market. The firms with the highest cost of capital follows her by choosing her level of capital depending on the price fixed by the other one. This result enhances the importance of the cost of capital as a *strategic* variable in the insurance industry.

An other interesting question, regarding the insurance industry, is the influence of the number of firms on capital choice and intensity of competition.

**Corollary 2.** *Consider the $n$-firms oligopoly where the maximum initial wealth of the firms is noted $w_M$. Under assumptions (A1) to (A5), $p^N$ decreases with $n$ when $w_M$ stays at the same level.*

*Proof* : see appendix. □

This result is quite intuitive. Let us first focus on the impact on the equilibrium price for a fixed level of capital $w_1$. As the number of identical, best capitalized firms increases, the trade-off between serving the whole market and a fraction $1/n$ of it is clearly modified. On the one hand, when $n$ becomes large, the risk from serving $1/n$ becomes smaller, whereas the risk associated with serving the whole market is unchanged. Thus the difference in terms of risk premium increases between the two options. This tends to incite firms to keep on serving a share $1/n$ of the market. On the other hand, from an expected profit perspective, the incentive to cut price clearly increases when $n$ increases, since expected profits are multiplied by $n$ for a firm which would follow such strategy.

Under Assumptions (A1) to (A5), this trade-off is no longer ambiguous. The graphical intuition of the result is quite intuitive. Figure 2.5 illustrates this proposition in the case of inelastic demand. An increase in the number of reinsurer, for the same price, diminishes the surplus of the firm, as the quantity of the market served by the firm is lessened (from $1/n^{th}$ to $1/n+1^{th}$). Due to the scissors effect described previously, the maximum Nash equilibrium price $p^N_{n+1}$ for a market with $n+1$ firms is below the maximum Nash equilibrium price $p^N_n$ for a market with $n$ firms. Thus, the higher the number of less risk averse firms, the lower the market price.

### *f) Monopoly case*

As an extreme case, we consider the monopoly case. At stage 2, the monopolistic firm is characterised by an initial wealth $w_0 + K$. The monopolistic price, noted $p^M$, is the

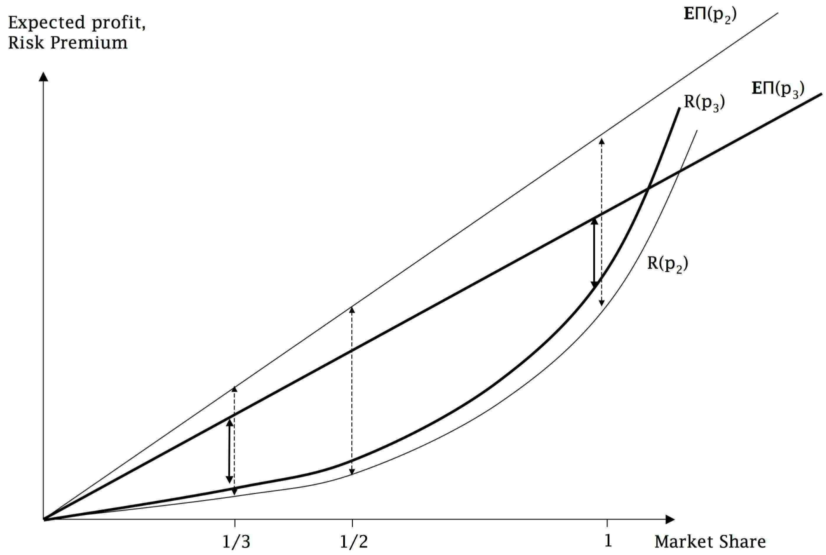


Figure 2.5: Maximum Nash prices, for a market of 2 symmetric firms and 3 symmetric firms - Case of inelastic demand.

classical solution of expected value maximization, and verifies $p^M > p^N(K)$. Note that the monopolistic price is a decreasing function of the level of initial wealth - and thus of $K$ - as a higher level of capital induces a lower risk aversion.

At stage 1, the monopolistic firm chooses its optimal level of additional capital $K^M$ by maximizing her net value $V$, anticipating the price $p^M(K)$. And we have $K^M = K^*(p^N)$.

## 2.5 Social welfare and the need for capital regulation

In the symmetric case, social welfare $SW$ is defined as the sum of consumer surplus $CS$ and firms' profits (i.e. the firms' values net of additional capital) with

$$CS(p) = \int_p^{+\infty} Q(x)dx$$

The social welfare function is thus written as

$$SW(K,p) = CS(p) + n\Big(P\big[w_0 + K + \overline{\pi} - R\big(w_0 + K + \overline{\pi}, Q(p)/n\big)\big] - (1+\tau)K^i\Big)$$

In the case of the insurance market, prices are seldom controlled except through differentiation while capital regulation is much more common[10]. We thus place ourselves in this

[10]Note that it is equivalent for the government to play on the price or on the level of capital as they both interact, when considering that firms anticipate the maximum Nash price. However in the case of a continuum of equilibria, this may have a different signification

second-best framework by supposing that government has direct control over the level of firms' capital but not on prices.

**Proposition 10.** *Under assumptions (A1) to (A5), the level of capital $K^g$ that maximises social welfare is higher than $K^*$.*

*Proof.* If the benevolent and omniscient government only control $K$, then the first order condition is

$$\underbrace{\frac{dp^N}{dK}Q'(p^N)}_{T1} + \underbrace{\frac{1}{n}\left((1-R_1)P_w - \left[\frac{Q'(p^N)}{n}R_2 - \frac{\partial \overline{\pi}}{\partial p^N}(1-R_1)\right]\frac{\partial p^N}{\partial K}P_w - (1+\tau)\right)}_{T2} = 0$$

The marginal consumer surplus (T1) is positive. The second term (T2) is equal to 0 for $K = K^*$. Thus assuming $SW$ concave leads to $K^g > K^*$. □

This result implies that imperfect competition leads to under-capitalization when compared to the social optimal capital. In our imperfect competition framework, note that higher capital requirements could lead to more competitive prices, as firms are less risk averse and potentially to a better social welfare. It is interesting to point out that this model leads to a rationale for capital regulation due to imperfect competition rather than standard solvency arguments. Note that control of capital choice reduces the interval of equilibrium prices available at the second stage of the game.

## 2.6 Concluding Remarks

The model extends Froot et al. (1993)'s framework by considering capital choices in a price competition setting for risk averse insurance firms. The principal result is the existence of a continuum of Nash equilibrium capital choices. Each level of capital leads to a continuum of Nash equilibrium prices of which we distinguish the one leading to firms' maximal value. We thus extend Wambach (1999)'s results, and provide a different analysis based on an associated risk premium: firms face the trade-off between higher expected wealth and higher risk when expending their market shares, allowing for an endogenous rationale for raising more capital. We show that the cost of capital as well as initial wealth levels of the firms have direct impacts on the market equilibrium prices. The model provides a second-best rationale for capital regulation: fixing a capital level reduces the interval of equilibrium prices available at second stage and thus may enhance social welfare. The characterisation of the dual interaction between financial and product market imperfections is particularly interesting to discuss in the case of the insurance industry.

Insofar we have considered a single strategic variable for stage two, i.e. price. One wonders if our results are robust to a change, or an enlargement of the set of available strategies. Considering alternative strategy spaces can indeed have subtle consequences on the efficiency of the market. For example, in a risk trading context, Biais et al. (1998) compare three alternative market structures - floors, dealer markets and limit order markets - and show that the efficiency of the market depends on the restrictions that are placed on the liquidity supplier, but in a non-monotonic relationship. This underlines the efficiency impacts of a change in the structure of the game. What happens if firms compete on quantities instead of prices, or on mixed price-quantity schemes? Intuitively, if we consider quantities instead of prices strategies at stage 2, the fundamental trade-off between reducing-risk and increasing competitive pressure, which determines the non cooperative capital choice by firms, is still at work. Indeed, an increase in the level of capital reduces the firms' cost of risk and allows them to supply more "quantity" of insurance at stage 2, that is in practice to sell more contracts. By increasing the aggregate supply of insurance, this leads at the market equilibrium to a lower price which can be detrimental to the insurance firms. Oligopolistic rents would still be present, as well as a strategic effect of capital at stage one. The question of the uniqueness of such an equilibrium, at both stages, is still to be thoroughly answered.
Concerning price strategies, our model assumes away the fact that firms can limit the quantity they offer once the price is posted. In the case of the insurance industry, the reinsurance (or retrocession) markets allow insurance companies to control the quantity of risk to which they are exposed. These contractual relationships between cedants and reinsurance firms aims at pooling firms' lines of risk: reinsurance contracts can enter into the set of available mixed strategies. Two distinct aspects must be considered. First, reinsurance allows firms to reduce their cost of risk through the mean of risk sharing. In this sense, it is a substitute to capital holding except that it does not modify firms' *cost* of risk but risk itself. Hence, introducing reinsurance would certainly reduce capital holding by a substitution effect. In practice, it corresponds to the dual nature of reinsurance as both a "risk management and a financing decision" (Plantin, 2006). On the one hand it allows

firms to serve a higher demand since risk is shared, but on the other hand expected profits also decrease. The second aspect is that there can also be imperfect competition at the reinsurance level, which raises the issue of the repartition of oligopoly rents at both levels. This is certainly an open question for future research.

Concerning the output price, the results are in line with the latest studies on the catastrophe reinsurance market that show that pricing far exceed competitive pricing in excess of loss contracts (Weiss and Chung, 2004; Froot, 2001; Froot and O'Connell, 2008). In our case, capital market imperfections as well as product market imperfections are integrated in the market price of risk. Furthermore, Froot and O'Connell (2008) have given evidence of the impact of the cost of capital on the pricing of risks in the reinsurance industry (489 US-contracts over the period 1970-1994).

One of the main feature of the insurance industry is its cyclical behavior, that links output price and capital depletion. In her review of insurance cycle literature, Weiss (2007) analyzes the part of literature focused on "real cycles: shock theories and explanations for crises". In the literature, two basis models are used in the classical underwriting cycle theory: capacity constraint and risky debt hypothesis. Capital constraints were at first taken as exogenous, for standard reason of regulation on the default risk - as it is the case in (Gron, 1990). Our model is related to a capacity constraint that emerges endogenously from the risk-aversion of the firms combined with costly capital and is reinforced by the typical oligopolistic structure of the market. Despite the static nature of our model, it provides an implicit dynamic interpretation of capital choice: internal capital choices of insurers at stage 1 can be interpreted as in Froot (2007) as a "long-run *target* level of capital" while ex-post stochastic acquisition of capital exhibits increasing and convex adjustment costs.

Another explanation has been proposed to understand the endogenous nature of firms' capital choice. Zanjani (2002) considers risk neutral insurance companies, that have limited liability. They face insolvency-carer consumers, and thus have incentives to hold costly capital. The firm is thus confronted with a quality/cost trade-off and diversifies between the different lines of risk. In this case, capital requirements to maintain solvency have an impact on prices. In the same vein, it could be interesting to consider in our framework multiple lines of risk and the marginal impact of each on the level of long-term capital chosen by the firm. Zanjani (2002) estimated from data over the period 1989-1998 the capital cost for insurance to be up to 13% for reinsurance lines.

Froot et al. (1993)'s framework allows for the distinction between internal and external capital. It would be interesting in our case to compare both costs. In the reinsurance industry, cost of external capital may be observed through the recourse to external capital after an important catastrophic events. Since the end of the nineties, new ways for recapitalization have emerged for this industry. Lane (2007) analyses their use by the reinsurance industry following the costly 2005 year that had seen Hurricanes Katrina, Rita, and Wilma. Total cost was estimated for the whole industry to 86,5$ bn of which 42% were supported by the reinsurance industry. During the 15 months following the hurricanes, Lane accounts for 33,5$ bn raised by reinsurance industry[11]. Costs of hybrid capital may give a proxy for the expensiveness of ex-post capital. Comparisons between recourse to external and internal capital are however not easy. In their study, Weiss and Chung (2004) use reinsurance contracts over the period 1991-1995 in the US to analyze the impact of financial quality and global capacity on reinsurance prices. The coefficients they find do not support the hypothesis that external equity is more costly than internal equity but they underline that such results are to be taken with caution because recourse to external capital much more easy to estimate than retained earnings. Further study would be needed on this point.

Finally, the impact of strategic interaction on the output market price we give is particularly interesting to discuss from a regulation perspective. Higher level of capital retention could lead to a lower price approaching pure competition and thus enhancing customer's wealth. In the case of an oligopolistic market structure, this leads to interesting conclusions in a regulatory approach. The model provides a rationale for capital regulation, that rely on other arguments than solvency issues as classically social failure costs with limited liability issues (Matutes and Vives, 2000). Each capital equilibrium leads to a continuum of Nash prices from which the maximum-value maximising price is exerted. A regulation on capital can avoid situations in which firms are under capitalised, leading to maximum Nash prices all the more high, and lower welfare. Capital regulation could then have a double impact: reduce firm insolvency as classically, but also enhance competition.

[11]This amount is split in capital raised by ancient companies (36%), and new companies (26%), through Insurance Linked Securities (19%), Sidecars (19%).

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## 2.7 Appendix

We give here the proofs of the following propositions and corollaries.

### 2.7.1 A-Proof of Proposition 6

Let us note $p^m$ the monopoly price of the symmetric firms.

**Lemma 2.** $P^{NE} \cap ]p^m, +\infty[ = \emptyset$

*Proof (Weibull provides a similar proof in the case of convex costs of production)*:
Let us suppose that all firms price at $p \in P^{NE}$, with $p > p^m$. Firm $i$ has a demand $q^i < Q(p)$. As $Q(p)$ is continuous and $\lim_{p \to +\infty} Q(p) = 0$.

$$\exists p^* > p : Q(p^*) = q^i$$

$$\mathbf{E}P(w_1^i + (p^* - \tilde{L})Q(p^*)) = \mathbf{E}P(w_1^i + (p^* - \tilde{L})q^i) > \mathbf{E}P(w_1^i + (p - \tilde{L})q^i)$$

By definition, as $p^m$ is the optimal monopoly price, $\mathbf{E}P(w_1^i + (p^m - \tilde{L})Q(p^m)) > \mathbf{E}P(w_1^i + (p^* - \tilde{L})Q(p^*))$,

$$\mathbf{E}P(w_1^i + (p^m - \tilde{L})Q(p^m)) > \mathbf{E}P(w_1^i + (p - \tilde{L})q^i)$$

As $p > p^m$, thus the firm $i$ can unilaterally deviate that enhances firm's value. Thus $p$ is not a Nash equilibrium. □

**Lemma 3.** *(Wambach): Under assumptions (A1) and (A3), if there is a price in the market such that the $n$ firms have a value equal to their outside option, the value of any firm serving the whole market at this price is strictly smaller, formally:*

$$\mathbf{E}P(w_1^i + \tilde{\pi}^i(p, Q/n)) = V^{out} \ \Rightarrow \mathbf{E}P(w_1^i + \tilde{\pi}^i(p, Q)) < V^{out}$$

*Proof:* See Wambach (1999) for Proof. □

Lemma 3 leads to $p \in P^{NE}$ if and only if $\mathbf{E}P(w_1^i + \tilde{\pi}^i(p, \frac{Q(p)}{n})) \geq \mathbf{E}P(w_1^i + \tilde{\pi}^i(p, Q(p)))$ that is equivalent to $p \in P^{NE}$ if and only if $p \in [p^{out}, p^N]$. Indeed, let us consider a deviation of firm $i$ when all firms set a common price $p \in P^{NE}$. If $i$ raises her price, then it obtains no demand, as all the residuals firms meet the demand. If $i$ lowers her price, she serves the whole market, and decreases its profit.
As $P$ is concave, we have

$$\frac{d^2}{d{q^i}^2}\mathbf{E}P(w_1^i + \tilde{\pi}^i(p, q^i)) = \mathbf{E}\Big((p - \tilde{L})^2 P_{ww}(w_1^i + \tilde{\pi}^i(p, q^i))\Big) < 0$$

As $p^N$ verifies $\mathbf{E}P\big(w_1^i+\tilde{\pi}^i(p^N,\frac{Q(p^N)}{n})\big)=\mathbf{E}P\Big(w_1^i+\tilde{\pi}^i(p^N,Q(p^N))\Big)$, a price-taker firm has an optimal output between $\frac{Q(p)}{n}$ and $Q$. From (A4), we directly obtain that the competitive price is lower than $p^N$.

Lemma 2 leads to the conclusion that $p^N$ is lower than the maximal monopoly price.

Let us consider $p\in P^{NE}$. As $p^{out}=\min(P^{NE})$, $\mathbf{E}P(w_1^i+\tilde{\pi}^i(p^{out},\frac{Q(p^{out})}{n}))=V^{out}$. From (A3), we obtain $\mathbf{E}P(w_1^i+\tilde{\pi}^i(p^N,\frac{Q(p^N)}{n}))>V^{out}$. Thus the value of the firms at $p^N$ is higher than her outside option. □

### 2.7.2 B-Proof of Lemma 1 :

Let us consider 2 firms with different levels of internal capital $w_1^j>w_1^i$. As $p_i^N$ is the indifference price for firm $i$ for serving the whole market or half of it, then $\mathbf{E}P\big(w_1^i+\tilde{\pi}_i(p^N,\frac{Q(p^N)}{n})\big)=\mathbf{E}P\big(w_1^i+\tilde{\pi}^i(p^N,Q(p^N))\big)$. As $P$ is strictly increasing, this is equivalent for $i,j$ to

$$\begin{aligned}&\bar{\pi}(p_i^N,Q(p_j^N)/2)-R(w_i+\bar{\pi}(p_i^N,Q(p_j^N)/2),Q(p_i^N)/2)\\&\quad=\bar{\pi}(p_i^N,Q(p_i^N))-R(w^i+\bar{\pi}(p_i^N,Q(p_i^N)),Q(p_i^N))\end{aligned}\tag{2.14}$$

Let us compare at price $p_i^N$ the expected value of firm $j$ for serving the whole market and half of it. Assumption (A5) leads to:

$$\begin{aligned}&R(w^j+\bar{\pi}(p_i^N,Q(p_i^N)/2),Q(p_i^N)/2)-R(w^j+\bar{\pi}(p_i^N,Q(p_i^N)),Q(p_i^N))>\\&\quad R(w^i+\bar{\pi}(p_i^N,Q(p_i^N)/2),Q(p_i^N)/2)-R(w^i+\bar{\pi}(p_i^N,Q(p_i^N)),Q(p_i^N))\end{aligned}$$

Using Equation 2.14:

$$\begin{aligned}&R(w^j+\bar{\pi}(p_i^N,Q(p_i^N)/2),Q(p_i^N)/2)-R(w^j+\bar{\pi}(p_i^N,Q(p_i^N)),Q(p_i^N))>\\&\qquad\bar{\pi}(p_i^N,Q(p_i^N)/2)-\bar{\pi}(p_i^N,Q(p_i^N))\end{aligned}$$

Thus

$$\begin{aligned}&\bar{\pi}(p_i^N,Q(p_i^N))-R(w^j+\bar{\pi}(p_i^N,Q(p_i^N)),Q(p_i^N))>\\&\quad\bar{\pi}(p_i^N,Q(p_i^N)/2)-R(w^j+\bar{\pi}(p_i^N,Q(p_i^N)/2)\end{aligned}\tag{2.15}$$

And as P is strictly increasing, the expected value to cover the whole market is higher than the expected value to cover half of it. Thus the indifference premium is lower for the less risk averse firm, that is the firm with higher level of initial capital. The proof is the same when considering a $nth$ part of the market covered.

Thus under assumptions (A1), (A2) and (A5), in the case of symmetric firms, $w_1^j > w_1^i \Rightarrow p_i^N > p_j^N$. The equation 2.14 implicitly defining $p^N$ allows for the continuity of $p^N$ compared to $w_1$. Thus $\frac{\partial p^N}{\partial w_1} \leq 0$. □

### 2.7.3 C-Proof of Proposition 7:

**Case** $p_{max}^{out} < p_{min}^N$:

In the case where $p_{max}^{out} < p_{min}^N$, Lemma 1 leads to $p \in P^{NE}$ if and only if $\mathbf{E}P(w_1^i + \tilde{\pi}^i(p, \frac{Q(p)}{n})) \geq \mathbf{E}P(w_1^i + \tilde{\pi}^i(p, Q(p)))$ that is equivalent to $p \in P^{NE}$ if and only if $p \in [p_{max}^{out}, p_{min}^N]$. Let us suppose that $p > p_{min}^N$. The firm $j$ that has the minimum Nash price $p_{min}^N$ may lower the price and then catch the whole market. Thus $p$ is not a Nash Equilibrium. Then let us consider a deviation of firm $i$ when all firms set a common price $p \in P^{NE}$. If $i$ raises her price, then it obtains no demand, as all the residuals firms meet the demand. If $i$ lowers her price, she serves the whole market, and decreases its profit. $p$ defines then a Nash equilibrium

The extension to an oligopoly of $n$ firms is immediate and when $p_{max}^{out} > p_{min}^N$. However other Nash equilibrium may exists that consider less firms. In fact, for $p < p_{max}^{out}$, only $n-1$ firms stay on the market. Let us define for the remaining firms $p_{max}^{n-1}$ the maximum of the prices for which the firms are indifferent between serving 1/n-1 th of the market or their outside option. If $p_{max}^{n-1} < p_{max}^{out}$, there still exists a continuum of equilibrium prices for a $n-1$ oligopoly.

For $m = 1..n-1$, we define for the $m$ firms remaining in the market

$$p_{max}^m = \max_{i=1..m} \left\{ p_i^{out} : \mathbf{E}P(w_1^i + \tilde{\pi}^i(p, Q(p)/m)) = \mathbf{E}P(w_1^i + \tilde{\pi}^i(p, Q(p))) \right\} \tag{2.16}$$

We note the following interval, that may be empty:

$$I^m = \left[ p_{max}^m ; \max_{i=m+1..n} \{p_{max}^m\} \right[ \tag{2.17}$$

When assumptions (A1) to (A5) hold, in the case of non-symmetric firms that differs by their risk aversion, there exist sub markets price equilibrium intervals $I^m$ for each $m$-oligopoly. □

### 2.7.4 D-Second order Derivatives of V(.):

1. *Price-Taking Firms.* For each set of strategies $(K_i)$, we consider the variation of marginal net value for the price-taking firms, at the price $p^N(K)$. We note this variation $V''_{iTaker}(K^i)$, and as marginal cost is constant, we have the following expression:

$$V''_{iTaker}(K^i) = -\Big(-R_{11}(1+\frac{\partial \bar{\pi}}{\partial K}) - R_{12}\frac{\partial Q}{\partial K}\Big)P_w + \Big(1 + \frac{(1-R_1)\partial \bar{\pi}}{\partial K} - R_2\frac{\partial Q}{\partial K}\Big)P_{ww} \quad (2.18)$$

2. *Price-Taking Firms.* For each set of strategies $(K_i)$, we consider the variation of marginal net value for the price-making firms. The second-order derivative is given by

$$\begin{aligned} V_{Leader}i''(K^i) = \Bigg[\Big(\frac{\partial^2 p^N}{\partial K^{i2}}\frac{\partial \bar{\pi}}{\partial p^N} + \frac{\partial p^N}{\partial K^i}\frac{\partial \bar{\pi}^2}{\partial p^{N2}}\Big)(1-R_1) - T\Big(TR_{11} + \frac{\partial p^N}{\partial K^i}Q'(p^N)R_{12}\Big) \\ -\Big(\frac{\partial^2 p^N}{\partial K^{i2}}Q'(p^N) + \frac{\partial p^N}{\partial K^i}Q''(p^N)\Big)R_2 \\ -\frac{\partial p^N}{\partial K^i}Q'(p^N)\Big(TR_{12} + \frac{\partial p^N}{\partial K^i}Q'(p^N)R_{22}\Big)\Bigg]P_w \\ +\big[(1-R_1) - PM(\bar{K})\big]^2 P_{ww} \end{aligned}$$

where $T = 1 + \frac{\partial p^N}{\partial K^i}\frac{\partial \bar{\pi}}{\partial p^N}$ □

### 2.7.5 E-Proof of Proposition 8

Consider an unilateral deviations of a firm $i$ in the case of an $n$ oligopoly of symmetric firms from the symmetric Nash equilibrium candidate $(\bar{K}, \bar{K})$. Under Assumption (A6) we only need to look at marginal deviations. We first note that:

$$V'_{iTaker}(K^i) = V'_{iLeader}(K^i) + MC_{stratW}(K^i) + MC_{stratD}(K^i) \quad (2.19)$$

*Increasing capital:* $K^i > \bar{K}$.
If firm $i$ chooses to increase its level of capital form the symmetric situation, it becomes the leader of the game, thus determines the market price $p^N(K^i)$. Considering Assumption (A6):

- $\forall \bar{K} < K^*$, $V'_{iLeader}(\bar{K}) > 0$. Hence $\bar{K} < K^*$ cannot be a Nash equilibrium.
- $\forall \bar{K} \geq K^*$, $V'_{iLeader}(\bar{K}) \leq 0$. Hence all $\bar{K} \geq K^*$ are candidates to be a Nash equilibrium.

*Decreasing capital:* $K^i < \bar{K}$.

If firm $i$ chooses a lower level of capital than the other firms then the market price remains equal to $p^N(\bar{K})$, which is determined by the more capitalized firms. Considering the previous discussion:

- $\forall \bar{K} < K^*,\ -V'_{iTaker}(\bar{K}) = -V'_{iLeader}(\bar{K}) - MC_{stratW}(\bar{K}) - MC_{stratD}(\bar{K}) \leq 0$, Hence a marginal decrease in capital is not profitable.

- $\forall K^+ \geq \bar{K} \geq K^*,\ -V'_{iTaker}(\bar{K}) = -MB(\bar{K}) + MC_{direct}(\bar{K}) \leq 0$ following assumption (A6b).

- $\forall K > \bar{K},\ -V'_{iTaker}(\bar{K}) = -MB(\bar{K}) + MC_{direct}(\bar{K}) \geq 0$ thus a marginal decrease of capital is unilaterally profitable.

We thus conclude that the symmetric couples of capital $(\bar{K}, \bar{K})$ are a Nash equilibrium for $K^* \leq \bar{K} \leq K^+$. □

### 2.7.6 F-Proof of Proposition 9

Consider 2 firms $l$ respectively $h$, with a low, resp. high, level of initial capital: $w_0^l < w_0^h$. If $V_{lLeader}$ follows (A6a) Assumption, then $V'_{lLeader}$ is decreasing. For all $K_l$, let us define $K_h$ such that $w_0^l + K_l = w_0^h + K_h$, $K_l < K_h$. Thus $V'_{hLeader}(K_h) = V'_{lLeader}(K_l + w_0^l - w_0^h)$, is also decreasing in $K_h$. And $V_{hLeader}$ follows assumption (A6a). Both firms rach their maximum net value (for leader) for the same level of capital $w_0^l + K_l^* = w_0^h + K_h^*$ where $K_h^* < K_l^*$.

We use the same logic as in the proof of Proposition 8. Consider firm $h$. For all $K_h \leq K_h^*$, firm $h$ when being the leading firm has the interest for increasing her level of external capital. In this situation, firm $l$ has always interest to increase as well her level of external capital up to $K_l^*$, where the Nash price is $p^N(w_0^h + K_h^*)$.

For all $K_h^* \leq K_h \leq K_h^+$, firm $^h$, as the leading firm, has no interest to increase her level of external capital, neither has she interest to lower it price-taking firm. For all $K_l^* \leq K_l \leq K_l^+$, firm $l$ as the leading firm has no interest to any deviation, when $w_0^l + K_l = w_0^h + K_h$. Let us note $K_h^M:\ w_0^l + K_l^+ = w_0^h + K_h^M$. For all $K_h > K_h^M$, firm $h$ is the leading firm, as she is less risk averse. $l$ chooses the level of external capital maximizing her net value as a follower, $K < K_h^+$, and firm $h$ thus benefits from lowering her level of capital. So for all $K_h > K_h^M$, there are no Nash equilibrium. □

### 2.7.7 G-Proof of Corollary 2:

We provide the proof of the corollary for the case of $n$ symmetric firms. We consider $n+1$ firms with the same initial wealth $w_1$ that compete on price. We note $p_n^N$ the maximum Nash price of the competition of $n$ of these firms, and $p_{n+1}^N$ the maximum Nash price for $n+1$ firms. By definition

$$\mathbf{E}P\Bigg(w_1^i + \tilde{\pi}^i(p_n^N, \frac{Q(p_n^N)}{n})\Bigg) = \mathbf{E}P\Bigg(w_1^i + \tilde{\pi}_i(p_n^N, Q)\Bigg)$$

that is $\mathbf{E}P(w_1^i + \frac{1}{n}(p_n^N - \tilde{L})Q(p_n^N)) = \mathbf{E}P(w_1^i + (p_n^N - \tilde{L})Q(p_n^N))$.
Let us consider a multiplicative factor of risk $\lambda$. $\mathbf{E}P(w_1^i + \lambda(p_n^N - \tilde{L})Q(p_n^N))$ is a concave function of $\lambda$. Then, as $\frac{1}{n+1} < \frac{1}{n} < 1$,

$$\mathbf{E}P\Bigg(w_1^i + \frac{1}{n+1}\tilde{\pi}^i(p_n^N, Q(p_n^N))\Bigg) < \mathbf{E}P\Bigg(w_1^i + \tilde{\pi}_i(p_n^N, Q(p_n^N))\Bigg)$$

Thus all firms prefer serving the whole market to $(n+1)^{th}$ of it at $p_n^N$. As all functions are continuous, a small decrease in price will not violate the condition of equilibrium for a market with $n+1$ symmetric firms that is $\mathbf{E}P\Bigg(w_1^i + \tilde{\pi}^i(p_{n+1}^N, \frac{Q(p_{n+1}^N)}{n+1})\Bigg) = \mathbf{E}P\Bigg(w_1^i + \tilde{\pi}_i(p_{n+1}^N, Q)\Bigg)$. Thus, using (A3), $p_{n+1}^N < p_n^N$. $\square$

# Chapter 3

# Crop Insurance and Pesticides in French Agriculture: an Empirical Analysis of Integrated Risk Management[1]

**Abstract**

This paper investigates the determinants of rapeseed hail insurance and pesticide decisions using individual panel data set of French farms covering the period from 1993 to 2004. Economic theory suggests that insurance and prevention decisions are not independent due to risk reduction and/or moral hazard effects. We propose a theoretical framework that integrates two statistically independent sources of risk faced by farmers of our sample –hail risk and pest risk. Statistical tests confirm that pesticide and insurance demands are endogenous to each other and simultaneously determined. An econometric model involving two simultaneous equations with mixed censored/continuous dependent variables is thus estimated for rapeseed. Estimation results show that rapeseed insurance demand has a positive and significant effect on pesticide use and vice versa. Insurance demand is also positively influenced by the yield's coefficient of variation and the loss ratio, and negatively influenced by proxies for wealth (including CAP subsidies) and activity diversification. The analysis of marginal effects shows that elasticities of insurance demand are greater for the yield's coefficient of variation (0.255), CAP subsidies (-0.192), and activity diversification variables (-0.161).

**Keywords**: Crop insurance, Pesticide use, Simultaneous equations.

## 3.1 Introduction

In recent years, agricultural risk management has become a key issue of agricultural policy reforms. The context has indeed changed deeply. Price support policies[2], which provide farmers an economic safety net in addition to income support, tend to disappear under the pressure of world trade liberalization and environmental concerns, raising the issue of price risk management in a liberalized world (World Bank, 2005). At the same time, a substantial number of production risks due to climatic and phytosanitary hazards remain

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[2]through public storage in the European Union or Target Prices in the United States

uninsurable without government support in favor of crop insurance (World Bank, 2005). Under free trade, production shocks are no longer compensated by rises in prices, a "natural hedge" of farmers' revenues that renders useless the need for crop insurance in autarky. The importance of climatic and phytosanitary risks as well as price volatility are thus calling for policy responses. The usual argument for risk policies in agriculture relies on the incompleteness of contingent claims markets that makes competitive markets inefficient in the short term. Such inefficiency provides a theoretical argument, in certain circumstances, for second-best Pareto improving government interventions that would mimic such absent contingent claims markets and restore the correct price incentives (Newbery and Stiglitz, 1981; Innes, 1990). In the long term, incomplete insurance and/or credit market lead to a too high, socially inefficient farm turnover, some viable agricultural firms being artificially unable to survive to temporary shocks (Kirwan, 2009). Despite these well-founded theoretical justifications[3], the consensus is far too be reached about the true costs and benefits of government crop insurance programmes that take place in real world. Crop insurance markets are usually plagued by various kinds of market failures, making the distinction between welfare-enhancing and redistributive objectives particularly uneasy. Since in developed countries crop insurance programmes often involve substantial financial support from governments, this raises the issue of "disguised subsidies". In addition to being highly controversial in terms of their pure risk-sharing benefits, it is frequently pointed out that government risk management programmes (in particular crop insurance ones) may have adverse environmental consequences. In particular, they would incite farmers to produce more, on more degraded lands, by using higher levels of risk-increasing inputs such as fertilizers and selecting shorter crop rotations, the same crucial critics that were already addressed to the classical, price-support based, agricultural policies of the 70's-80's .

The United States provide an interesting illustration of this debate. In this country, government crop insurance programmes constitute after nearly three decades of existence a growing component, if not one of the building block of the Farm Bill. Crop insurance programmes take the form of a public-private partnership between the Federal Government,

[3]Such normative result must be qualified. Indeed, the welfare gains, eventually losses, from risk policies have been shown to be highly sensitive to changes in parameters, especially supply and demand elasticities (Newbery and Stiglitz (1981), Innes (1990)). More profound is the critics by Dixit, who considers that welfare gains coming from government interventions may be highly overestimated because classical models implicitly assume governments to be immune to the fundamental causes that make market collapse, such as moral hazard, adverse selection or imperfect observability

through the Risk Management Agency (United States Department of Agriculture) and private primary insurers. Government support include substantial premium subsidies, Federal Reinsurance of last resort and reimbursement of primary insurers' administrative costs. In spite of such financial support, provided through various channels, farmers' participation has always been low and difficult to boost, but recent increases in premium subsidies lead to reach a participation rate of nearly 80% (Glauber, 2004). Several empirical analysis of U.S. crop insurance programmes tend to show that crop insurance programmes have negative environmental consequences through the production distortions they create (Roberts et al., 2004). Moreover, a recent paper by Kirwan (2009) shows that the farm failure rate has increased by 1.7 percentage points (30 percents) after the 1994 Crop Insurance Reform Act, that replaced ad-hoc disaster reliefs by crop insurance subsidies as the major form of government intervention. Last but not least, expanded crop insurance programmes did not succeed in eliminating Disaster Bills, i.e. ad-hoc transfers made by the Federal Government to support farmers in times of financial distresses due to adverse climate shocks.
In the European Union, growing attention is also being paid to weather risks in agriculture in a context of profound reform of the Common Agricultural Policy (hereafter CAP). The European system differs from the U.S. one. Price risks were managed at the EU level through guaranteed prices while weather risks and crop insurance programmes, when they exist, are under the responsibility of Member States. Guaranteed prices have decreased due to CAP reforms and have been replaced by decoupled agricultural subsidies to support farm revenues, with an a priori ambiguous impact in terms of farmers' risk aversion (more risk due to less price protection but less risk aversion due to a wealth effect). This has lead Member States to assess the possibility of a crop insurance programme at the E.U. level. Enlarging the perimeter of mutualization for risks that are considered as systemic at the National scale has undoubtedly some economic sense, but the lessons from the costly U.S. experience certainly incite regulators to prudence.

This paper deals with multiple risks decision making in agriculture by investigating the determinants of rapeseed hail crop insurance and pesticide use, using an individual panel data set of French farms covering the period from 1993 to 2004. We first propose a theoretical background, and then follow the reduced form approach and build an econometric model involving two simultaneous equations with a mixed censored/continuous dependent variables to account for potential endogeneity, which we estimate.

**Related literature.—** The relation between production and insurance/hedging decisions is a central aspect of the welfare and redistributive impacts of crop insurance programmes. There is a large empirical literature on farmers' choices involving risk that intend to estimate how risk preference do indeed affect farmers' production and financial choices, and how these choices interact (Just, 2000; Just and Pope, 2003). Most papers concern the U.S. case, in part because several reforms of Federal risk management programmes have stimulated empirical research on this topic. Garrido and Zilberman (2005), Ogurtsov et al. (2008) and Velandia et al. (2009) estimate the simultaneous demand for crop insurance and other risk management instruments (forward contracts, etc.) as a function of farms' characteristics. Another group of related papers focus on the relation between insurance and production choices, providing some empirical testing of the possible distorsive effects of risk management instruments (eventually magnified by public subsidies): Horowitz and Lichtenberg (1993) results suggest that crop insurance has encouraged pesticide and fertilizer input uses for corn producers in the U.S. Midwest. This contrasts with Smith and Baquet (1996), whose estimations show that fertilizer and pesticide inputs for Kansas wheat producers tend to be negatively correlated with insurance purchases. Wu (1999) is the first to extend the analysis to acreage decisions as a risk diversification tool. In his estimation of the effect of crop insurance on crop acreage allocation and pesticide use in Central Nebraska Basins, he shows that crop insurance participation encourages producers to switch to crops in higher economic values. In a more recent paper, Goodwin et al. (2004) study the acreage effects of crop insurance using the samples of corn and soybeans production in the U.S. Corn Belt and wheat and barley production in Northern Great Plains. They estimate a simultaneous equation model to take into account a larger set of endogenous risk decisions of agricultural producers to simulate the possible effects of large premium changes. Their results suggest a relatively modest acreage responses to expanded insurance subsidies. In a very recent study on insurance and acreage decisions, O'Donoghue et al. (2009) conduct an empirical analysis of the interaction between specialization and the price of crop insurance, which has been lowered through an increase in Federal premium subsidies by the Federal Crop Insurance Reform Act. They found a statistically significant but small positive relation between the degree of specialization and the level of premium subsidies.

Some general conclusions can be drawn from the existing literature. First, risk management choices are generally endogenous, suggesting possible substitutions or complementarities between risk management instruments. Second, typical explanatory variables that may influence farmers' risk aversion such as yields' coefficients of variation, financial ratios (an imperfect measure of liquidity constraint), farmers' wealth, land ownership are most of the time statistically significant. This tends to support that risk do indeed matter in farmer's production decisions. Third, although statistically significant, some variables have in some cases a small quantitative effect (O'Donoghue et al., 2009), in other cases strong quantitative effects, suggesting prudence in drawing too general policy conclusions at the national scale. Fourth, results may be qualitatively contradictory and unexpected with regards to theoretical prediction, in particular the relation between insurance and input uses. Theory suggests that the demand for risk-reducing inputs should be lower for those who buy insurance than for those who do not buy because of a standard moral hazard effect. This moral hazard argument, which has been the cornerstone of empirical studies and discussions on the subject in the U.S.A, is particularly relevant in this country because of the nature of crop insurance contracts. These contracts are *multiple peril*, which means that they provide coverage against any source of yield risk, including pest risk, which is manipulable by the farmer. Theory predicts a negative relation between the demand for insurance and the consumption of risk-reducing inputs.

Preceding empirical studies[4], mainly based on U.S. data, did not lead to clear cut conclusions concerning the sign of the correlation between pesticide and insurance decisions[5], although the fact that both decisions are made *endogenously* are rarely challenged[6]. Since many producers' decisions involve risk considerations, it is difficult to build a theoretical model that would capture an exhaustive analysis of their interactions (Goodwin et al., 2004) and yield unambiguous results, even in a static model. The classical moral hazard

[4]Another group of papers also deal with farmers' risk-taking decisions but differ in their econometric approach of the cited ones by building structural instead of reduced-form models. The advantage of such approach is to allow for simultaneous estimation of production technology parameters and risk preferences. Examples of papers fitting with this approach are Chavas and Holt (1996) and more recently and Kondouri et al. (2009) to evaluate the risk and wealth effects of agricultural policy changes towards decoupling in the European Union.

[5]Horowitz and Lichtenberg (1993) have found a positive correlation between crop insurance and chemical input use for corn producers in the U.S. Midwest. However, Smith and Goodwin (1996) demonstrated that fertilizer and chemical use for Kansas wheat producers tended to be negatively correlated with insurance purchases. Wu (1999) and Goodwin, et al. (2004) suggest no clear relationship between crop insurance demand and input use.

[6]Using Hausman-Wu test, Goodwin et al. (2004), Smith and Baquet (1996) and Wu (1999) have found that insurance, crop mix, and chemical use decisions are not exogenous and should be estimated using a simultaneous equations approach.

framework does not include multiple sources of risks, adverse selection, price risk, which may be potential explanations of these contradictory results.

The current paper contributes to the existing literature in three ways. First, instead of relying on aggregated time-series or cross-section data as in most of previous studies, we use farm-level data. This is expected to provide us with a more precise description of individual decisions. Second, the current study uses panel data, which possess several advantages over conventional cross-sectional or time-series data sets, while exploiting genuinely observed regime transitions. At last, this paper contributes to the growing literature on the empirical analysis of risk management decisions in the case of France and other European countries (Kondouri et al., 2009; Mosnier et al., 2009).

This paper is organized as follows. Some key facts concerning cereal production, weather risks and crop insurance in France are described in Section 3.2. Section 3.3 presents the theoretical background of simultaneous input and insurance decisions. In section 3.4 we present the empirical model followed by a description of the data and estimation results. We conclude in section 3.5 with a summary of our results and research perspective.

## 3.2 Policy context for crop insurance in France

### 3.2.1 The French system before 2005: duality between private and public coverage

The French agricultural sector is characterized by production diversity at the national level and a high degree of regional specialization. Most of the French farms are specialized in a narrow set of crops. The main climate risks are frost, hail and drought. Frost and hail risks mostly concern wine-growing and arboricultural, while hail and drought are the first causes of crop losses for non perennial crops (cereals essentially). Like other countries aiming at stabilizing farmers' revenues, France is doted with a specific agricultural insurance system against agricultural climate risks, which can be described as follows. First, risks are classified in two categories: insurable and uninsurable. Insurable risks are covered by private markets without any government intervention (or a very limited one) while uninsurable risks are covered by a public guarantee fund, the *Fonds National de Garantie des Calamités Agricoles* (FNGCA), created by the law of 1964. Private and public coverage thus coexist without competing with each other. The "insurability" criteria are not explicitly defined in the law of 1964, although it states that the set of insurable risks is susceptible to evolve if the private sector becomes able to develop its own supply. The fund profoundly differs from private insurance market. First it is not financed by actuarially fair premiums, but by the mix of a mandatory contribution on farmers' property/liability insurance contracts and a government subsidy, with approximately an equal sharing between the two sources (the "parity principle"). Thus premiums are not risk based and government participation implies a positive redistribution, in average, from taxpayers to the farm sector. Second, indemnifications are upper-bounded by the amount available in the funds, and so are not contractually prespecified as it is the case in a typical insurance contract. Third, the fund pools several risks (drought, hail...) for several products (wheat, maize, fruits...) which without practicing risk-based premiums is a source of cross-subsidization across farms with different specializations (between maize producers and wine-growers, for example) since mandatory contributions are not actuarially fair. The system has clearly some advantages, notably the fact that mandatory participation implies a large pooling of diversified risks, but also defaults: premiums are not functions of risks, which is a source of distortional choices, and the levels of indemnifications are low, even with the presence of a large amount of government subsidies. Hence the paradox: if redistribution from taxpayers to farmers is positive in the mean, farmers often criticize the low levels of indemnifications (around 30% of expected losses are indemnified). Moreover farmers are not free to choose between different levels of coverage if they differ in their risk preferences and their opportunities to diversify risks.

### 3.2.2 The private crop insurance market in France

Until the reform of 2005, hail was the main risk covered by a private insurance market in France, i.e. without government subsidies nor government reinsurance of last resort interventions. Hail insurance contracts are proposed by several insurance companies specialized in financial products for the agricultural sector. The proposed contracts can be described as follows. Indemnities are provided when the final yield is under a threshold value, which is freely chosen by the producer as a percentage of his reference yield. The reference yield is the mean of the five preceding years, leaving apart the higher and the lower values. When no yield data is available for an individual producer (which can occur if he has never cultivated the crop), the mean departemental yield is used as a proxy. Some standardized values of deductibles are proposed, which are typically 5%, 10% and 15% of reference yields for cereals such as wheat and maize, and 10% and 15% for rapeseed. In addition to choosing their deductible, producers are free to choose the price at which they will be indemnified, up to a maximum price fixed by the insurer. The latter provides information about prices forecast to help farmers to make their choice. In case of yield losses, indemnifications are based on plots, not on the total farm output for the given product. Thus if total farm yield per acre is higher than the yield that triggers indemnifications but lower on a given plot, indemnifications will be made for this plot (this is not the case for other risks included in the package of the reform of 2005). In order to control for potential moral hazard problems, audits are made in order to verify that appropriate agricultural practices were followed, in particular the use of phytosanitary products.

### 3.2.3 The recent reforms: towards a public-private partnership?

The system has been reformed strongly in recent years. The reform of 2005 aimed at extending the set of insurable risks, i.e. risks covered by private insurers. Before this date, mainly hail risk was insured through the private market in a sustainable way without government support. The reform of 2005 introduced for the first time large scale premium subsidies in order to stimulate farmers' demand and incite private insurers to expand their agricultural insurance supply to a larger set of risks. Subsidized contracts are targeted to cereal producers and provide coverage against multiple risks, as in the United States (twelve risks including drought, frost etc.). The basket of risks covered by these new insurance contracts can be chosen by the producer. Contrary to the traditional hail insurance contract, these contracts are now subsidized by the government at a rate of 35% of the premium. After a few years of existence, participation is not negligible but still limited. Although it seems to be inspired by the U.S. system, important differences subsist. First, premium subsidies are considered as temporary. The underlying idea is to encourage learning on both supply and demand sides: on supply side, since insurers propose new contracts that may be susceptible of high financial exposure due to correlated risks (drought in particular); on the demand side since farmers were not used to making free choices before. Second, although the debate remains open, the French government does not play the role of reinsurer of last resort as in the U.S. system. The current trend of reforms provide strong justifications for empirical analysis of the role of risk in farmers' choices and welfare in France. Unfortunately, it is too early to study the impact of the reform of 2005, since our data set goes to 2004. Moreover, the first years of application are heavily driven by learning from both sides of the market, which renders any comparison uneasy to interpret. Thus our objective here is to study the relation between insurance and input decisions in the pre-reform period.

## 3.3 Theoretical background

We focus our study on two typical risk management instruments of farmers[7]: insurance and pesticides. The direct factors that affect the demand for insurance are the farmer's coefficient of risk aversion, the cost of insurance, and the characteristics of the insured risk such as the size of the risk and other characteristics of the risk probability distribution (Henriet and Rochet, 1991; Alarie et al., 1991). The optimal insurance coverage increases with risk aversion and the size of the risk, and decreases with the cost of insurance. Other factors influence the demand for insurance indirectly through their impact on the farmers' coefficients of risk aversion: wealth, the presence of one or several background risks (Eeckhoudt and Kimball, 1991), and the presence of a liquidity constraint (Gollier, 2001). Under the reasonable assumption of decreasing absolute risk aversion (DARA), risk aversion decreases with farmers' wealth, thus so does the optimal insurance coverage. The presence of an *exogenous* background risk increases the optimal insurance coverage if the agent displays prudence in the sense of Kimball. DARA itself implies prudence. For identical reasons, all the factors cited above are also susceptible to affect the use of risk-increasing and risk-reducing inputs such as pesticides.

Analyzing the farmers' choices of insurance and input uses also requires to take into account endogeneity between insurance demand and pesticide use. In the long run, pesticide use and insurance demand are taken jointly in order to maximize the farmer's utility. Several theoretical papers examine the consequences of the introduction of a crop insurance contract on the firms' input uses (or the dual output decision). Machnes (1995), Gollier (1996) and Machnes and Wong (2003) consider a price-taking firm's simultaneous decisions of production and insurance coverage when yield is affected by a multiplicative risk, i.e.

[7]There is an absent risk management tool in our analysis. Because of unavailable data, price hedging decisions on futures markets have not been taken into account in the analysis. Since what matters to producers is income risk, and price risk is certainly not less important than production risk, incorporating price hedging into the set of risk management tools could have enriched the analysis.

proportional to the expected production; comparing the production decisions with and without insurance, they show that, under reasonable assumptions, in particular these of prudence, the optimal production level tends to increase after insurance is introduced[8]. Since multiplicative production risk is formally identical to price risk, this result recalls the traditional underproduction result of Sandmo (1971) obtained in a context of price risk. Ramaswami (1993) generalizes the analysis by considering a richer set of interactions between controllable inputs and climatic factors, considering both risk-reducing and risk-increasing inputs. He shows that the change in input use coming from the introduction of insurance can be decomposed into a *risk-reduction effect* and a *moral hazard effect*. The direction of these changes depend on the nature of the interaction between inputs and climatic factors. Hau (2006) extends the analysis by examining a single non-multiplicative risk[9]. Chambers and Quiggin (2000) propose a general state-space approach that allow for more tractable analysis of production insurance and hedging decisions under risk.

This literature shows that *gaining access* to insurance tends to modify input use but the direction of the change is ambiguous since it combines risk-reduction and moral hazard effects. Most of the U.S. empirical papers described in the introduction base their interpretation on the moral hazard effect, i.e. the fact that insurance participation tends to decrease the use of risk-decreasing inputs (pesticides). But as we have shown, qualitative results contradict each other. Moreover theoretical models of simultaneous insurance-pesticide decisions consider a single source of risk [10].

We now present the theoretical model that is the frame of our econometric estimation. The single risk framework does not fit well with the present case, since farmers of our sample face in fact not a single but two distinct risks: hail risk and pest risk, against which they

[8] Gollier (1996) provides counterexamples. Machnes and Wong (2003) show the necessity of prudence to obtain unambiguous effect of deductible insurance on production. Such assumption was unnecessary in Sandmo (1971)'s underproduction result.

[9] The traditional approach in the literature has been to use a stochastic production function of the form $f(\mathbf{x}, \mathbf{e})$, where $\mathbf{x}$ is a vector of controllable inputs (fertilizers, pesticides etc.) and $\mathbf{e}$ a vector of environmental inputs (rainfall, moisture, temperature etc.) that are stochastic when $\mathbf{x}$ is chosen by the farmer. The two most used specifications assume a single input, single risk production: the multiplicative risk model, with $f(x, \tilde{\varepsilon}) = x\tilde{\varepsilon}$ and the Just-Pope model, with $f(x, \tilde{\theta}) = f(x) + h(x)\tilde{\theta}$, with $E\tilde{\varepsilon} = \bar{\varepsilon} > 0$ and $E\tilde{\theta} = 0$, $x$ being a singleton.

[10] Moreover, this literature compares the situations "with" and "without" insurance and is therefore adapted to the analysis of an exogenous change in the insurance regime, such as the creation of a crop insurance programme by the government. The issue is however different in our region study : we analyze the simultaneous insurance and production decisions by farmers *for a given insurance regime* which has been stable during the period covered in our sample. Thus, some people insure while others do not, but everyone has access to insurance.

use two independent risk management tools: hail insurance and pesticides. In order to take into account the presence of two risks, we extend the Just-Pope production function, which considers a single risk, by adding a multiplicative climate risk.

$$y(x, \tilde{\theta}, \tilde{\varepsilon}) = [f(x) + \tilde{\theta}h(x)]\tilde{\varepsilon} \tag{3.1}$$

where $x$ is the input, $\tilde{\theta}$ the pest risk and $\tilde{\varepsilon}$ the climatic risk. These two risks are assumed to be statistically independent. This model includes the multiplicative risk model and the Just-Pope model as a special case, when $\tilde{\varepsilon} = 1$. We assume that risk $\tilde{\varepsilon}$ has a binary distribution $(q, (1-l); (1-q), 1)$ where $q$ denotes the probability of loss and $l \in [0, 1]$ is a coefficient that measures the extent of the yield loss, considered as given (i.e. non manipulable). The pest risk $\tilde{\theta}$ is characterized by $E\tilde{\theta} = 0$. It is uninsurable but can be mitigated through the use of a self-insurance input $x$, which unitary cost equals $c$. We adopt the usual assumption that pesticides are risk-reducing inputs with decreasing returns to scale, which corresponds formally to $h'(.) \leq 0$ and $h''(.) \geq 0$ respectively. The climatic risk $\tilde{\varepsilon}$ can be covered by a private insurance contract denoted $[P(\alpha, x), \alpha]$, where $\alpha \in [0, 1]$ is the coverage rate and $P(\alpha, x)$ the insurance premium as a function of coverage and input choice. Hail insurance contracts are structured as follows. A reference yield is calculated as the last years mean yield excluding the worst and best year. Thus the reference yield is equal to the expected yield $(1 - ql)f(x)$. Insurance coverage $\alpha$ is then defined as the fraction of the reference yield. An indemnity equal to $\alpha(1-ql)f(x) - (1-l)[f(x) + \theta h(x)]$ is thus paid when a hail shock occurs [11], with probability $q$. Assuming the output price $w$ non-stochastic, exogenous and normalized to unity, the insurance premium can be written as:

$$P(\alpha, x) = (1 + \lambda)q(\alpha(1 - ql) - (1 - l))f(x) \tag{3.2}$$

where $\lambda \geq 0$ is the usual loading factor, $\lambda = 0$ corresponding to the actuarially fair premium. With unit costs of input being equal to $c$ and normalizing the output price to one, the stochastic farm's profit is equal to

$$\tilde{\pi}(x, \alpha) = \begin{cases} \alpha(1 - ql)f(x) - cx - P(\alpha, x) & \text{with probability } q \\ f(x) + \tilde{\theta}h(x) - cx - P(\alpha, x) & \text{with probability } 1 - q \end{cases} \tag{3.3}$$

[11] $\theta$ is written without a tilde when it corresponds to realization of $\tilde{\theta}$

Moral hazard is not considered since it is controlled through audits. A risk-averse farmer whose preferences are characterized by the von Neumann-Morgenstern utility function $u(.)$ with the stochastic production function presented above solves the following programme:

$$\max_{\alpha,x} U(x,\alpha) = Eu[\tilde{W}_0 + \tilde{\pi}(x,\alpha)], \tag{3.4}$$

where $\tilde{W}_0$ is the initial wealth, which could also represent exogenous income or, if negative, fixed costs. The optimal choices $x^*$ and $\alpha^*$ are given by the first-order conditions for input and coverage. When $\tilde{\theta} = 0$, the problem is reduced to the multiplicative risk case studied in the literature presented before. The introduction of $\tilde{\theta}$ complicates the analysis. The combination of a risk-reducing and multiplicative model has been analyzed by Liu and Black (2004) in their two-shock model, where the multiplicative risk is assumed to represent a price risk. They show that the introduction of insurance has ambiguous effects on input use when input is risk-decreasing. However, their framework is different than ours since the insurable risk corresponds to $\tilde{\theta}$ in our model. In our case, the presence of two independent risks can lead to a non-monotonic marginal effect of $x$ on the reduction of variance. Appendix 3.6 studies this aspect in the case of mean-variance preferences.

In addition to insurance and pesticides, acreage decisions could also be considered as a risk management tool at the farm level. It is however assumed that acreage is long-term decision and so does not enter into the year-to-year multiple risk-taking decision of the farmer[12]. This can be justified on technical grounds: switching from a rotation to another can incur costs (yield losses, fixed costs) as well as time lags. Moreover, the decision to diversify can be the result of expected profit maximization due to positive production externalities between crops, as analyzed by Hennessy (2006). From an agronomic point of view, these externalities come from nitrogen carry-over effects and/or reduction of pest infestations, and can be a way to maintain or increase the soil's production potential over time. To a certain extent, crop production externalities qualify the traditional view of acreage allocation as a standard portfolio problem, and thus the role played by risk aversion[13].

[12] Our data show that the typical three years rotation rapeseed-wheat-barley is the most observed in the Meuse area. This is due to the fact that the considered area is homogeneous from the pedo-climatic conditions and that the observed rotations are a long-term choice made in the past by farmers. This justify our hypothesis that acreage choice is exogenous in our empirical application.

[13] There are other arguments for this qualification: the allocation of labor time across crops, the farmer's use of its own crop product for livestock, the impossibility to cultivate certain crops on a subset of plots

To sum up, it is generally recognized that pesticides not only reduce risk but also increase expected production, thus increasing exposure to the second, multiplicative risk. It seems to be intuitive that producers with higher expected production will tend to buy more insurance because the expected value of the output, and so the potential loss, is higher. The underlying economic mechanisms at stake in these interactions may however be quite different depending on the theoretical framework which is considered.
In the following section we estimate the reduced form relationship between demand for insurance and pesticide use with an econometric model involving simultaneous equations.

## 3.4 Empirical model

### 3.4.1 Econometric model

We now turn to the econometric model in order to examine hail insurance and pesticide use decisions. Our data set does not include insurance coverage itself but insurance expenses, for each crop. The usual way in the literature is to consider the demand for insurance as a binary variable identifying whether the farmer participates or not (Horowitz and Lichtenberg, 1993; Smith and Baquet, 1996; Wu, 1999). This is a limitation of these studies which focus on the decision of insurance purchase only and not take into account the level of coverage in the analysis. In spite of absent data, we choose to approximate the demand for insurance by the premium per unit area divided by the mean product per unit area, i.e. crop yield times crop price, calculated on the total years available. Such normalization by the mean product allows to eliminate the mechanical increase in premium coming from an increase in the value of the insured output, as shown by equation (3.2) in the case of a linear transaction cost function.
Our approach follows the empirical literature on crop insurance and production decisions, such as pesticide use (Horowitz and Lichtenberg, 1993; Smith and Baquet, 1996), cultivation practices (Goodwin et al., 2004) and cropping patterns (Wu, 1999). We thus fit into the simultaneous equation approach framework. To investigate the determinants of crop insurance demand under endogenous input use decision, we estimate our model using individual farm panel data covering the period from 1993 to 2004 instead of the usual cross sectional dataset. Our dataset allows us to capture individual farmers effects and also to follow the evolution of farmers' choices over a long period of time. Panel data, by taking

because of soil quality.

into account the inter-individual differences and intra-individual dynamics have several advantages over cross-sectional or time-series data. In our case the two most important advantages[14] are to have more accurate inference of model parameters and to control the impact of farmer's individual heterogeneity.

Following theoretical analysis and the empirical literature, we consider in this analysis that the farmers's crop insurance and pesticide input use decisions are made simultaneously. Our econometric model thus corresponds to two simultaneous equations with a mixed censored/continuous dependant variables and panel data. The simultaneous equation system can be written as follows

$$I^*_{it} = X'_{1it}\beta_1 + P_{it}\gamma_1 + w_{1it}, \tag{3.5}$$

$$P_{it} = X'_{2it}\beta_2 + I^*_{it}\gamma_2 + w_{2it}, \tag{3.6}$$

and the observed counterpart is:

$$I_{it} = \begin{cases} I^*_{it} & \text{if } I^*_{it} > 0, \\ 0 & \text{otherwise.} \end{cases}$$

where $I^*_{it}$ is the latent variable for the farmer's $i$ insurance demand at time $t$, $I_{it}$ is the observed demand insurance for the farmer $i$, $P_{it}$ is the pesticide input demand of farm $i$ at time $t$, $X'_{1it}$ and $X'_{2it}$ are vectors of explanatory variables, $\beta_1, \gamma_1, \gamma_2, \beta_2$ are parameters to be estimated,$w_{1it}$ and $w_{2it}$ are error terms, $i = 1, ...., N$ indexes the farmers and $t = 1, ..., T$ indexes time period of observation. The error term $w_{mit}$ $(m = 1, 2)$ is decomposed as

$$w_{mit} = \mu_{mi} + \varepsilon_{mit}, \qquad m = 1, 2, \quad i = 1, ...N, \quad t = 1, ...T, \tag{3.7}$$

where $\mu_{mi}$ is the individual effect for the farm $i$ and the variable of decision $m$ and $\varepsilon_{mit}$ is an i.i.d. error term for equation $m$.

We make the following distributional assumptions:

$$\mu_{mi} \hookrightarrow N(0, \sigma^2_{\mu_m}), \quad \varepsilon_{mit} \hookrightarrow N(0, \sigma^2_{\varepsilon_m}), \quad E(\mu_{mi}\varepsilon_{mit}) = 0, \quad \text{for all} \quad m = 1, 2, ..., M$$

with

[14] See Hsiao(2007) for a survey of advantages of Panel data.

$$E(\mu_{mi}\mu_{kj}) = \begin{cases} \sigma_{\mu_{mk}} & \text{if} \quad i = j, \\ 0 & \text{otherwise,} \end{cases}$$

$$E(\varepsilon_{mit}\varepsilon_{kjs}) = \begin{cases} \sigma_{\varepsilon_{mk}} & \text{if} \quad i = j \quad \text{and} \quad t = s, \\ 0 & \text{otherwise,} \end{cases}$$

for all $m, k = 1, 2, \quad i, j = 1, ...N, \quad \text{and} \quad t, s = 1, ...T.$

The model (3.5-3.6) has a mixed structure since it includes both a latent variable and its dichotomous realization. Procedures for estimating simultaneous equation models in which one or more equation contains limited dependent variable have been developed by Amemiya (1974), Amemiya (1979) and Nelson and Olson (1978). This literature shows that the FIML (Full Information Maximum Likelihood) is computationally difficult and may be infeasible. Nelson and Olson (1978) propose a simple two stage estimation procedure where endogenous variables are replaced by predicted values obtained at first stage by regression upon an instrument set. This two-step procedure has the advantage to give consistent estimates of the coefficients of the model, however Amemiya (1979) shows that this two-steps procedure misrepresents the true variances of parameters. Bootstrapping methods were proposed in the literature to estimate consistently the parameters of the matrix of variance covariance.

Following the literature, we estimate our model by a two-stage procedure (Maddala, 1983)[15]. In order to obtain consistent estimates of the parameters of the variance-covariance matrices we use bootstrap methods proposed by Efron (1979) and Efron (1987). The bootstrapping approach consists in drawing with replacement a large number of pseudo-samples of size N (which correspond to the number of observations in the observed data). For each sample the two-step procedure is applied in order to generate a distribution of consistently estimated parameters. Such an approach provides consistent variance-covariance parameter estimates that are robust to heteroscedasticity.

Since our sample consists of panel data, we have to choose between a random effect and a fixed effect specification. We assume a random effect model because the fixed effect specification suffers from the incidental parameters problem[16] in the case of Tobit model, Greene (2004) shows that the incidental parameters problem causes a downward bias in

[15] Our model corresponds to the model 2 in Maddala (1983).

[16] The incidental parameters problem of the maximum likelihood estimator in the presence of fixed effects (MLE/FE) was first analyzed by Neyman and Scott (1948) in the context of the linear regression model.

the estimated standard deviations in the Tobit model specification. Such problem might lead to erroneous conclusions concerning the statistical significance of the variables used in the regressions.

The first step of the two-stage procedure consists in estimating the reduced form of the system (3.5-3.6) which can be written as follows [17]:

$$I_{it}^{*} = X_{it}'\Pi_1 + \xi_{1it}, \tag{3.8}$$

$$P_{it} = X_{it}'\Pi_2 + \xi_{2it}, \tag{3.9}$$

where $X_{it}'$ includes all the exogenous variables in $X_{1it}'$ and $X_{2it}'$. This first step of the procedure provides us with estimates of the parameters $\Pi_1$, $\Pi_2$ as well as the matrix of variance covariance of individual effects and iid error terms. In our case, we estimate the equation in (3.8) by a random effect Tobit model and the equation in (3.9) by ML-RE model. In the second step, we estimate the equation (3.5) by RE-Tobit after substituting $\widehat{P}_{it}$ for $P_{it}$ and the equation (3.6) by RE-ML after substituting $\widehat{I}_{it}^{*}$ for $I_{it}^{*}$. This two stage procedure gives consistent estimates of the model coefficients (Maddala, 1983), but the estimates of variance of the coefficients may be inconsistent because predicted values of the endogenous variables are used in the second stage of the estimation procedure.

**Marginal effects.**— Computation of elasticity measures requires calculation of marginal effects from the RE-Tobit model[18]. Given the censored nature of insurance demand equation different marginal effects can be computed for each explanatory variable. For each explanatory variable $x_j$, we have calculated at the mean of the sample, the three elasticities[19]:

1. Conditional elasticity: which measure for each explanatory variable the elasticity of the expected insurance demand given that the farmer holds an insurance contract.

$$Ela_{conditional} = \frac{\partial \ln E(I|I>, x=\overline{x})}{\partial \ln x_j} = \beta_j \frac{x_j}{E(I|I>, x=\overline{x})} \tag{3.10}$$

[17] See the appendix 3.6.3 for more details.

[18] As proposed by Wooldridge (2002) the marginal effects were estimated by making the normalization of the individual-specific effects such as $E(\mu) = 0$.

[19] see Greene (2008).

2. Probability elasticity: which measure for each explanatory variable the elasticity of the probability that a farmer holds an insurance contract.

$$Ela_{proba} = \frac{\partial \ln Pr(I > 0|x = \overline{x})}{\partial \ln x_j} = \frac{\partial Pr(I > 0|x = \overline{x})}{\partial x_j} \frac{x_j}{Pr(I > 0)} \tag{3.11}$$

3. Unconditional elasticity: which measure for each explanatory variable the elasticity of the expected insurance demand

$$Ela_{unconditional} = \frac{\partial \ln E(I|x = \overline{x})}{\partial \ln x_j} = \beta_j \times Pr(I > 0|x = \overline{x}) \frac{x_j}{E(I|x = \overline{x})} \tag{3.12}$$

As we have

$$E(I|x = \overline{x}) = Pr[I > 0|x = \overline{x}] \times E[I|I > 0, x = \overline{x}], \tag{3.13}$$

we can easily show that for each explanatory variable, the total elasticity is the sum of the probability elasticity and the conditional elasticity:

$$Ela_{unconditional} = Ela_{conditional} + Ela_{proba} \tag{3.14}$$

### 3.4.2 Data description

The study is conducted on a sample of French farmers from the *Departement* of Meuse. Our data are provided by the Management Centre (*Centre de Gestion de la Meuse*). Our sample is an unbalanced panel observed between 1993 and 2004. We consider in this paper the most important crops in terms of cultivated area: rapeseed, wheat and barley. One interesting feature of our database is that it contains detailed information for each crop on major inputs: fertilizers ( N, P, K), pesticide inputs (herbicides, fungicides, insecticides, and growth regulators) and insurance.
As shouwn in table 3.1, approximately 88% of farmers in our sample hold a hail insurance contract . This proportion remained almost constant over the observation period 1993-2004, varying between a minimum of 81.90% in 1993 and a maximum of 91.25% in 2002.

Summary statistics presented in table 3.2 show that on average the farmers who hold a rapeseed hail insurance contract had less CAP subsidies than farmers without hail insurance contract. They are also more specialized in rapeseed production and have less animal production revenues (related to their total revenues).

Table 3.1: Farms who hold a hail insurance contract

| **Year** | **Total number of farmers** | **% of farmers who hold hail insurance contract** |
|---|---|---|
| 1993 | 442 | 81.90% |
| 1994 | 432 | 83.56% |
| 1995 | 450 | 85.33% |
| 1996 | 451 | 85.36% |
| 1997 | 483 | 87.78% |
| 1998 | 489 | 88.34% |
| 1999 | 487 | 90.14% |
| 2000 | 481 | 89.39% |
| 2001 | 459 | 89.10% |
| 2002 | 446 | 91.25% |
| 2003 | 392 | 89.79% |
| 2004 | 161 | 89.44% |
| Total | 5173 | 87.55% |

Table 3.2: Summary statistics

| **Variable** | **Definition** | Insurance=0 | Insurance=1 |
|---|---|---|---|
| | | **Mean** (std. dev.) | **Mean** (std. dev.) |
| primassph_col | premium per unit area / mean yield | 0 | 0.008 |
| | | (0) | (0.005) |
| col_pacph | CAP subsidies per ha | 4.734 | 4.672 |
| | | (0.917) | (0.788) |
| sanim_produit | share of animal revenue | 0.564 | 0.455 |
| | | (0.226) | (0.259) |
| scol_produit | share of rapeseed production | 0.246 | 0.287 |
| | | (0.099) | (0.099) |
| loss_ratio | sum of indemnities / sum of premium | 0.259 | 0.791 |
| | | (0.74) | (1.409) |
| ratio_liq | debts / assets | 0.158 | 0.183 |
| | | (0.131) | (0.138) |
| ind_ferm | =1 if land renting | 0.991 | 0.995 |
| | | (0.096) | (0.073) |
| puthf | percent of family labor | 0.933 | 0.906 |
| | | (0.132) | (0.158) |
| cvrdt_col | CV of rapeseed yield | 0.399 | 0.275 |
| | | (0.457) | (0.278) |
| col_laglnprix | log rapeseed lagged price | -3.166 | -2.447 |
| | | (4.455) | (3.309) |
| sau | Total farm area | 16593.073 | 19764.295 |
| | | (7645.564) | (9979.700) |

#### Choice of explanatory variables

According to the literature and to our theoretical discussion, the demand for crop insurance and risk-reducing input could be influenced by farms' characteristics such as farm's diversification, wealth, and liquidity constraints. We hereafter construct some proxies for these variables as explanatory variables of insurance demand.

**Diversification.**— The degree of farm's diversification is expected to have a negative effect on insurance and pesticide demands since it can be considered as a substitute to insurance as a risk management instrument. We consider two forms of farm diversification: *crop diversification* which refers to the classical rotation choice, and *activity diversification* which refers to the relative shares of crop activities taken as a whole with other sources of farms' revenues, i.e. livestock in our sample. Several index provide consistent measures of the degree of diversification, namely the Herfindahl index and Theil index of entropy. With two activities only, relative shares in the farm's total output constitute a simpler measure of diversification. Computation of these index revealed that they are highly correlated. We thus choose to restrict to a single measure. Since we have only three crops and two activities (crop and livestock), we define crop diversification as the share of rapeseed in the total crop product (*scol_produit*) and activity diversification as the share of livestock in the total farm product (*sanim_produit*). Note that since livestock activity is assumed exogenous, the activity diversification index can also be interpreted as a wealth effect.

**Wealth.**— If farmers display decreasing absolute risk aversion, then wealthier farmers may perceive less of a need to insure. There is not any real consensus in the literature in building a proxy for wealth in similar studies (farms' net present values, size index such as land area). The following proxies for farmers' wealth are included.

*Non-crop revenues.* As livestock activities provide returns that are independent to crop ones, we can interpret the activity diversification index as a proxy for wealth in addition to a diversification one.

*Farm size.* Many studies in the literature include a measure of farm size as a proxy for wealth. It also captures the effect of size economies on the demand for insurance. We thus include the agricultural area (SAU) as an explanatory variable.

*CAP income support.* Agricultural income support policies are also a major part of farmers' revenues, and can therefore be a strong component of the farmers' wealth effect. Hence CAP subsidies are also included as a proxy of farmers' wealth($col\_pacph$) as an explanatory variable.

**Financial characteristics.**— Financial characteristics of the farm such as debt and liquidity constraints are strongly expected to affect insurance and input choices through their impact on farmers' risk aversion. More liquidity constrained farmers would insure more ceteris paribus. We have built the three following ratios in order to capture such liquidity constraint: the total debt ratio, the land debt ratio and the liquidity ratio ($ratio\_liq$). These three ratios are expected to have a positive effect on insurance and input uses. For the same liquidity constraint reason, farmers who rent land are expected to buy more insurance and use more pesticides because they are more leveraged (Wu, 1999). We thus include a rent index ($ind\_ferm$).

**Loss ratio.**— The demand for insurance is expected to depend on the expected return from insurance (usually negative), which includes premiums and expected indemnities. To capture such factor, we use individual farmers' loss ratios ($loss\_ratio$), a variable that is equal to the total indemnities divided by total insurance premiums for the available years. Since our panel is unbalanced, differences due to catastrophic events that arise some years can be a source of bias between farmers (Goodwin, 1993). However, excluding these years from our analysis would also create some bias and weaken the analysis so we kept all available years in our sample. Heterogeneity in loss ratios can be due to by asymmetric information if farmers are more informed that insurers about the distribution of their yield risk. Goodwin (1993), Just et al. (1999) and more recently Goodwin et al. (2004) provided empirical evidence of the importance of such factor on the incentive to insure in the U.S. agricultural context.

**Yield variation.**— In order to catch the effect of crop risk on insurance and pesticides, we include as it is usually the case in the literature[20], the individual coefficient of variation of yield ($cvrdt\_col$). Intuitively, a high coefficient of variation reflects a higher crop risk exposure, thus an incentive to get insured.

[20] See for example Goodwin et al. (2004).

**Labor composition.**— Total labor includes hired labor and family labor. The composition of the total labor could give us an idea of the nature of farm management. We build an index, *puthf*, which is equal to the share of family labor in the total farm labor (Wu, 1999).

### 3.4.3 Estimation results

We estimate a simultaneous equation model of crop insurance demand and pesticide demand using the two-stage procedure proposed by Nelson and Olson (1978) with a bootstrapping method to estimate consistent parameters of the variance-covariance matrices. Estimations are made on rapeseed only because this crop exhibits the higher coefficients of variation than wheat and barley.

**Are insurance demand and pesticide use endogenous? The Durbin-Wu-Hausman test.**— To test the simultaneous equation specification adopted in our model, the Durbin-Wu-Hausman[21] test was performed to test the hypothesis that: (1) crop insurance decisions are exogenous to pesticide input demand and (2) pesticide input demand is exogenous to crop insurance decisions. Results of these tests are presented in table 3.3 and show that the exogeneity hypothesis is rejected for the variable pesticide input in the insurance demand equation and for the insurance demand in the pesticide input equation. These results suggest that the two variables pesticide input and insurance demand are simultaneously determined. This result shows that insurance and pesticide choices are made jointly and thus provides a strong reason for our simultaneous equation model.

Table 3.3: Durbin-Wu-Hausman test results

| Null Hypothesis | DWH statistic | DF | Test result |
|---|---|---|---|
| crop insurance demand is exogenous to pesticide use | 14.05 | 7 | Rejected at 5% level of confidence |
| pesticide use is exogenous to crop insurance demand | 19.43 | 9 | Rejected at 2% level of confidence |

**Model estimation.**— The estimation results are presented in Tables 3.4 and 3.5. Table 3.4 displays the insurance model as a function of our explanatory variables and 3.5 displays

[21] The "Durbin-Wu-Hausman" (DWH) test is numerically equivalent to the standard "Hausman test" obtained using in which both forms of the model must be estimated. Under the null hypothesis, it is distributed Chi-squared with m degrees of freedom, where m is the number of regressors specified as endogenous in the original instrumental variables regression.

the pesticide choice equation. As can be seen by inspecting the results the significant variances of individual random effects confirms the advantage of using panel data and modeling individual effects. We conclude that the classical regression model with one single constant term is inappropriate and that there exist in the data individual heterogeneity captured by individual random effects. The elasticities $Ela_{unconditional}$,$Ela_{conditional}$ and $Ela_{proba}$ (equations 3.10-3.12) are computed at the means of all variables and are presented in Table 3.6. The significant variables in Table 3.4 also have significant marginal effects (elasticities) in Table 3.6.

Concerning the parameters estimates, a first important result is that the quantity of pesticides (*col_qphytophhat*) used by farmers increases with the demand for insurance (*primassph_col*). Moreover, the demand for insurance increases with pesticides. As we have noted earlier, the empirical literature provided no consensus on the sign and magnitude of the effects on insurance on pesticide demand. Horowitz and Lichtenberg (1993) results suggest that crop insurance has encouraged the chemical input use for corn producers in the U.S. Midwest. However, Smith and Goodwin (1996) demonstrated that fertilizer and chemical use for Kansas wheat producers tended to be negatively correlated with insurance purchases. That means that the insured Kansas wheat producers tend to use less chemical input than the non-insured ones. Wu (1999)) has focused on the effect of crop insurance on crop patterns and chemical use in Central Nebraska Basins. The results show that crop insurance participation encourages producers to switch the crops in higher economic values. Thus, the expected relationship between insurance participation and input use is unclear. The results of Goodwin, et al. (2004) suggest a relatively modest acreage responses to the increases in crop insurance participation.

Our estimation results concerning the effects of diversification on insurance demand are in line with our expectations. The variable *scol_produit*, which measure the share of rapeseed in total crop production has a positive and significant effect on insurance demand. This means that farmers that planted more rapeseed are less diversified and need more crop insurance protection. In the same way, the variable *sanim_produit* which measure the share of livestock activities in the farm revenue has a negative and significant effect on insurance demand. This confirm the fact that activity diversification reduce risk aversion and so insurance demand of farmers. Wu (1999) and O'Donoghue et al. (2009) find a statistically significant negative effect of crop diversification on crop insurance demand.

Concerning activity diversification, Goodwin (1993) does not find a statistical negative relationship between the extent of diversification into livestock and the tendency to insure. Results concerning diversification must be interpreted with caution. Indeed, a negative correlation can be explained by a substitution effect between risk management tools, but a positive correlation, if arises, can be explained by heterogeneity in farmers' risk aversion: ceteris paribus, more risk averse farmers would diversify more, buy more insurance and use more risk-reducing inputs. Therefore, which of these effects dominates is likely to depend on the particular application and data set.

As expected, the CAP subsidies *col_pacph* have a negative and significant effect on the insurance demand, which can be interpreted as a wealth effect. The effect of direct payments on farmers' risk preferences has been recently estimated by Kondouri et al. (2009) using a structural model to estimate simultaneously risk preferences and technology parameters. Direct payments were shown to substantially decrease farmers' degrees of risk aversion.

Estimation results show that a higher yield coefficient of variation of rapeseed (*cvrdt_col*) appears to be positively and significantly correlated with greater demand for insurance. Such a positive relationship is conform to the intuition. However, the coefficient of variation is in part endogenous due to input uses (in particular pesticides) and crop diversification. For example, more risk averse farmers could insure more against hail risk while using more pesticides to reduce pest risk, and so exhibit a lower coefficient of variation of yield, calling for cautious interpretation.

The parameter estimate on the composition of total labor (*puthf*=family labor /professional labor) has the expected sign but is statistically insignificant at 10%. As expected, land ownership also affect farmers' insurance decisions *ind_ferm*. Farmers who rent land tend to exhibit a higher demand for insurance.

Another interesting but not surprising result is that higher loss ratio is significantly and positively correlated with greater demand for insurance. As discussed in Goodwin et al. (2004), the fact that both higher loss ratios and higher yield coefficients of variation are positively correlated with insurance demand suggest that the cost of insurance as well as size of the risk reduction do indeed matter in farmers' insurance decision. Finally, the parameter estimates of the liquidity ratio *ratio_liq* has the expected sign but is not significant.

Table 3.4: Rapeseed insurance demand

| | primassph_col |
|---|---|
| col_qphytophhat | 0.00344*** |
| | (5.34) |
| col_pacph | -0.000211* |
| | (-2.04) |
| sanim_produit | -0.00312*** |
| | (-4.13) |
| scol_produit | 0.00218* |
| | (2.32) |
| loss_ratio | 0.000664** |
| | (2.96) |
| ratio_liq | -0.000857 |
| | (-0.93) |
| ind_ferm | 0.00360*** |
| | (3.67) |
| puthf | -0.000660 |
| | (-1.31) |
| cvrdt_col | 0.00838*** |
| | (6.49) |
| _cons | -0.00348 |
| | (-1.74) |
| sigma_u | 0.00811*** |
| | (12.08) |
| sigma_e | 0.00317*** |
| | (22.85) |
| $(N \times T)$ | 5127 |

$t$ statistics in parentheses

$^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$

Table 3.5: Rapeseed pesticide use

| | col_qphytoph |
|---|---|
| primassph_colhat | 4.850* |
| | (2.00) |
| col_laglnprix | 0.0105*** |
| | (5.27) |
| sau | 0.00000445*** |
| | (5.03) |
| ann3 | -0.296*** |
| | (-15.74) |
| ann4 | -0.129*** |
| | (-7.99) |
| ann5 | 0.0220 |
| | (1.25) |
| ann6 | -0.0638*** |
| | (-4.07) |
| ann11 | 0.108*** |
| | (4.55) |
| _cons | 1.575*** |
| | (66.19) |
| $(N \times T)$ | 5127 |

$t$ statistics in parentheses

$^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$

**Marginal effects.**— We now compute elasticities to get some insight about the magnitudes of the relations between variables. The results are presented in Table 3.6. First, we note that this magnitude is quite small concerning the relation between insurance and pesticides: the probability to buy insurance increases by 0.026% when pesticide use increases by one percent. Unconditional elasticity, which sums up the probability to buy insurance with insurance demand when positive, is equal to 0.056 %. Such figures should be interpreted cautiously since they may be the result of several effects, some of them acting in opposite directions: the moral hazard effect, which predicts a negative relationship between insurance demand and pesticide use, and the risk reduction effect, which predicts a positive one. In the present region study, it seems however reasonable to think that the moral hazard effect is not very important in practice because of the presence of insurers' auditing concerning input uses. Moreover, the fact that the insured risk displays low geographical correlation at the departement level, the perceived probability of being audited by farmers may be sufficiently high to deter the moral hazard incentive. The positive, although quite modest, elasticity value of pesticide use and provides some support to the risk reduction effect of insurance.

Heterogeneity in farmers' risk aversion can also explain such positive correlation but is unobservable. In this case, a low value for elasticity could be explained by unobservable heterogeneity in pesticide productivity. Indeed, pesticides not only reduce risk but also increase expected yields. The latter motive may be predominant in farmers' pesticide use decisions, explaining low values of elasticities.

These elasticity results shed some light on the complex interaction between insurance and pesticide choices at the farm level. Although the estimated figures seem to be small, they may be the result of countervailing incentives and/or unobservable heterogeneity. Therefore making predictions about the consequences of crop insurance reforms in France on pesticide use should take these limits into consideration. During the period 1993-2004, available private insurance contracts protected against hail risk only. Other production risks such as drought were managed through the public fund FNGCA. Expanding the number of risks insured by private insurance contracts would give farmers more freedom to choose their combination of risk management tools at the farm level. This may increase the magnitude of the relation between insurance demand and pesticide use.

We now discuss the other factors affecting insurance demand. Classifying them with respect to the value of the probability elasticity and unconditional elasticity in decreasing order, we get 1. the rent index ($ind\_ferm$, 0.140 and 0.305 respectively), 2. the yield's coefficient of variation , 3. CAP subsidies per ha , and , 4. activity diversification and 5. the loss ratio.

The values of elasticities for the yield's coefficient of variation (*cvrdt_col*, 0.117 and 0.255) confirms the role of farmers' heterogeneity in risk exposure on insurance demand.

The other explanatory variables have interesting consequences for agricultural policy. First, CAP subsidies (*col_pacph*) have a negative but quite small impact on the probability to insure (-0.088), but a rather high one on total insurance demand (-0.192). This suggests that the wealth effect due to farmers' income support plays a non-negligible role in reducing the consequences of income shocks due to weather events. If such income support decreases due to forthcoming CAP reforms, farmers of our sample would be more disposed to increase their demand for risk-management tools such as insurance against weather events.

Estimated elasticities for activity diversification (*sanim_produit*) have the same order of magnitude than these for CAP subsidies (-0.074 and -0.161), suggesting that income diversification is also a substantial substitute for crop insurance in our region study.

Estimated elasticities for loss ratios ($loss\_ratio$), considered as a proxy for the cost of insurance, are rather small (0.023 and 0.049 respectively). This suggests that a crop insurance policy based on premium subsidies should not lead to strong changes in insurance demand against hail risk. These results are in line with similar studies in the United States. In this country, only large levels of premium subsidies allowed to increase the rate of penetration of insurance at the national scale. Moreover, in many cases expected indemnities are higher than premiums, rendering insurance contracts valuable even for risk-neutral producers. The situation is quite different in France, where hail insurance is a “mature” market, with a large rate of penetration rate and decades of existence without any government subsidy (the average loss ratio of our sample is 0.791). Hence it is not so surprising that the impact of a change in the cost of insurance has modest effects on insurance demand. Intuitively, such impact could be more substantial for multiple peril crop insurance contracts, introduced through a public-private partnership in France in 2005, since they provide coverage against an extended set of risks, some of them displaying strong spatial correlation, hence higher premiums. From a theoretical perspective, shows that a risk-averse individual[22] always insurance against a low probability-high loss event if he buys insurance for any other risk having the same expected loss. This suggests that crop insurance contracts extended to low frequency risks (typically drought) would always be bought by farmers who already have a hail insurance contract under identical transaction costs. However several factors are susceptible to curb insurance demand for this extended set of risks. First, these risks may not only differ in their distribution but also in their transaction costs. Insurance premiums are more difficult to calculate for less frequency risks, and spatial correlation as well as ambiguity may imply premium overloading by insurers. Second, there is substantial empirical evidence that shows individuals are reluctant to buy insurance against low probability events, or even do not consider at all risks under a certain probability threshold. At last, the insurance decision requires processing information and learning, so emerging insurance contracts may require a time lag for adaptation.

[22] In fact, any individual having preferences that display the second-order stochastic dominance property.

Table 3.6: Marginal effects: elasticities at the sample mean

| $x_j$ | $\frac{\partial \ln E(I\|x=\bar{x})}{\partial \ln x_j}$ | $\frac{\partial \ln E(I\|I>0,x=\bar{x})}{\partial \ln x_j}$ | $\frac{\partial \ln P(I>0\|x=\bar{x})}{\partial \ln x_j}$ |
|---|---|---|---|
| col_qphytophhat | 0.056** | 0.030** | 0.026** |
| | (2.36) | (2.35) | (2.36) |
| col_pacph | -0.192*** | -0.104*** | -0.088*** |
| | (-5.77) | (-5.76) | (-5.67) |
| sanim_produit | -0.161*** | -0.087*** | -0.074*** |
| | (-4.40) | (-4.43) | (-4.32) |
| scol_produit | -0.023 | -0.012 | -0.010 |
| | (-0.84) | (-0.84) | (-0.84) |
| loss_ratio | 0.049*** | 0.026*** | 0.023*** |
| | (3.75) | (3.76) | (3.71) |
| ratio_liq | 0.004 | 0.002 | 0.002 |
| | (0.35) | (0.35) | (0.35) |
| ind_ferm | 0.305** | 0.164** | 0.140** |
| | (2.29) | (2.29) | (2.29) |
| puthf | -0.079 | -0.043 | -0.037 |
| | (-1.49) | (-1.49) | (-1.49) |
| cvrdt_col | 0.255*** | 0.138*** | 0.117*** |
| | (13.34) | (13.75) | (11.81) |

$t$ statistics in parentheses
$^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$

## 3.5 Conclusion and discussion

This paper investigates the determinants of hail insurance and pesticide use decisions using an individual panel dataset of French farms covering the period 1993-2004. Statistical tests show that the pesticide use and insurance demand are endogenous to each other and simultaneously determined. An econometric model involving two simultaneous equations with a mixed censored/continuous dependent variables is then estimated.

The results of our estimation are twofold. First, it is confirmed that insurance demand has a positive effect on pesticide use and vice versa, providing empirical support for the interdependence of technical choices and insurance decisions. However, it is also shown that the magnitude of this relation, measured by elasticities, is quite small. Several explanations are proposed for this result: the presence of countervailing incentive effects of insurance (risk reduction and moral hazard), the ambiguous role of risk-decreasing inputs on the variance of yield, or the preponderance of the expected profit motive versus the risk-reducing one in pesticide use decisions by farmers. From an environmental policy perspective, this suggests that reforms aiming at facilitating the access to insurance against an expanded set of risks or reducing the cost of insurance may have positive but modest effects on pesticide use. With monoperil hail insurance contracts, moral hazard temptations concerning the use of pesticides may be more easy to control than for multiperil crop insurance contracts, for two reasons. The first one is that estimating the relative impact of pest and climate shocks on the final yield may be more difficult when multiple climate shocks enters the insurance contract. Another problem associated with multiple peril insurance contracts is that increasing the number of covered peril could possibly increase correlation across individual claims (drought), thus lower the probability of audit.

Second, the analysis of the explanatory factors of insurance demand confirm some theoretical predictions and have interesting consequences for agricultural policy analysis. CAP subsidies have been shown to have a statistically significative and negative influence on insurance demand, and in turn on pesticide use. This is in line with the assumption that farmers' preferences are characterized by decreasing absolute risk aversion, confirming results of several other studies in France and abroad. From an agricultural policy perspective, this suggests that decrease in CAP subsidies would increase the farmers' propensities to pay for risk management instruments, underlying the need for an integrated approach between income support and risk management policies in this sector. Activity diversification has also a statistically significant and negative influence on insurance demand, which confirms the assumption that whole-farm diversification is a substitute to insurance and risk-reducing inputs. More surprising is the fact that crop diversification is not statistically significant. This suggests that diversification is more an issue at the whole-farm level than at the crop acreage level. This points out interesting questions in terms of environmental policy in the agricultural sector. Indeed, our results suggest that encouraging crop rotations against monoculture would have no statistically significant impact on the intensity of pesticide use per hectare. Crop rotations thus may be chosen for other reasons than risk. They can be more profitable in expectation due to positive external effects between crops that follow each other, or be the result of other constraints such as soil qualities, which are not included in our data set. Our results show that farmers with riskier yields tend to buy more insurance, which is in line with theoretical predictions. The loss ratio, has a significant effect but of small magnitude on insurance demand, suggesting a low price elasticity of demand for insurance. Crop insurance premium subsidies could thus have small impacts on insurance demand. However, it should be noted that the insurance contracts that are analyzed in the present study are not the same than those that are actually subsidized in France, which cover multiple risks. Finally, we have shown that financial ratios are not statistically significant, which is also surprising.

**Future challenges.**— The results of this study could be enhanced and continued in several ways.

First, we do not consider price risk in our analysis. This is clearly a shortcut since theory suggests that production and insurance decisions are distorted when prices risk is introduced. Moreover, the CAP reforms of the 90's and beginning of 2000's significantly decreased price floors for major crops in the European Union, leading to a potential increase of real or perceived price risk for farmers. However, futures and forward markets were also available in France during the period covered by our sample, allowing farmers to transfer price risks to financial markets and so significantly reduce the importance of price risk. Unfortunately, farmers' positions on futures and forward markets are not available in our database, preventing us to include price hedging decisions in our analysis.

Second, our data concerning phytosanitary products are aggregate expenses, which include a set of specific inputs targeted to different sources of risks (moisture, etc.). It is possible that some producers are more exposed to some specific risks that are more costly to self-insure than others. We have assumed a continuous relation between the quantity of pesticides used (measured by the expenses) and the magnitude of loss reduction. In reality, the timing of application may be also determinant, so equal applied quantities with different fractioning can lead to different results in terms of loss reduction, but these actions are not observable. Phytosanitary (as well as fertilizer) decisions have in fact a dynamic nature, which can include observation and learning by the producer. Such ingredients would suggest a more subtle theoretical framework but is out of the scope of this paper.

Third, we foresee to carry out estimations by generalizing this exercise to the two major crops in the sample: wheat and barley, as well as considering the simultaneous demands for insurance for the three crops and including fertilizers in our analysis. This would allow to generalize our analysis of multiple risks management by farmers.

Fourth, it would be interesting to build a structural model that would allow joint estimation of technology and preferences. This requires to deepen the theoretical analysis of the joint demand for insurance and pesticides with two independent risks. This would allow us to confirm our results concerning the shape of farmers' preferences as well as making useful comparisons with results obtained elsewhere, in particular Mosnier et al. (2009) in the French case.

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## 3.6 Appendix

### 3.6.1 Theoretical model

In order to get some insights about basic intuitions concerning the role of pesticides, let us consider the case of a quadratic utility function:

$$u[\tilde{W}_0 + \tilde{\pi}(x,\alpha)] = a + b(\tilde{W}_0 + \tilde{\pi}(x,\alpha)) + 0.5\gamma(\tilde{W}_0 + \tilde{\pi}(x,\alpha))^2$$

where $a$, $b$ and $\gamma$ are parameters such that $b+\gamma(\tilde{W}_0+\tilde{\pi}(x,\alpha)) > 0$. The farmer's preferences display risk aversion if $\gamma < 0$ (respectively risk loving if $\gamma > 0$ and risk neutrality if $\gamma = 0$). Under such specification, expected utility can be written as a function of expected wealth and the variance of wealth only. Indeed,

$$\mathbf{E}u[\tilde{W}_0 + \tilde{\pi}(x,\alpha)] = a + b\mathbf{E}(\tilde{W}_0 + \tilde{\pi}(x,\alpha)) + 0.5\gamma\mathbf{E}(\tilde{W}_0 + \tilde{\pi}(x,\alpha))^2$$

i.e.

$$\mathbf{E}u[\tilde{W}_0 + \tilde{\pi}(x,\alpha)] = a + b\mathbf{E}(\tilde{W}_0 + \tilde{\pi}(x,\alpha)) + 0.5\gamma\big[(\mathbf{E}\tilde{W}_0 + \tilde{\pi}(x,\alpha)))^2 + \mathbf{Var}(\tilde{W}_0 + \tilde{\pi}(x,\alpha))\big]$$

Thus expected utility can be rewritten as a non-linear function of these two arguments, $z(.,.)$

$$\mathbf{E}u[\tilde{W}_0 + \tilde{\pi}(x,\alpha)] = z\big[\mathbf{E}(\tilde{W}_0 + \tilde{\pi}(x,\alpha)), \mathbf{Var}(\tilde{W}_0 + \tilde{\pi}(x,\alpha))\big]$$

To keep things simple, assume that $\tilde{W}_0 = 0$ and that insurance is unavailable, i.e. $\alpha = 0$. With our production function specification involving two risks, expected profit and the variance of profit can be written as, respectively,

$$\mathbf{E}y(x,\tilde{\theta},\tilde{\varepsilon}) = \bar{\varepsilon}f(x)$$

and

$$\mathbf{Var}[y(x,\tilde{\theta},\tilde{\varepsilon})] = \sigma_{\varepsilon}^2[f(x)]^2 + \sigma_{\theta}^2(\sigma_{\varepsilon}^2 + \bar{\varepsilon})[h(x)]^2$$

*Proof.*

Computing expected yield, we get

$$\begin{aligned}\mathbf{E}y(x,\tilde{\theta},\tilde{\varepsilon}) &= \bar{\varepsilon}f(x) + \mathbf{E}(\tilde{\varepsilon}\tilde{\theta})h(x)\\ &= \bar{\varepsilon}f(x) + \big(\mathbf{E}(\tilde{\varepsilon})\mathbf{E}(\tilde{\theta}) + \mathbf{Cov}(\tilde{\varepsilon},\tilde{\theta})\big)h(x) \qquad (3.15)\end{aligned}$$

Since by assumption $\mathbf{E}(\tilde{\theta}) = 0$ and $\mathbf{Cov}(\tilde{\varepsilon}, \tilde{\theta})$ ($\tilde{\varepsilon}$ and $\tilde{\theta}$ being two independent random variables), we thus get that

$$\mathbf{E}y(x, \tilde{\theta}, \tilde{\varepsilon}) = \bar{\varepsilon} f(x)$$

Turning to the variance of yield, we have

$$\begin{aligned} \mathbf{Var}[y(x, \tilde{\theta}, \tilde{\varepsilon})] &= \mathbf{Var}[\tilde{\varepsilon} f(x) + \tilde{\varepsilon}\tilde{\theta} h(x)] \\ = \mathbf{Var}(\tilde{\varepsilon} f(x)) + \mathbf{Var}(\tilde{\varepsilon}\tilde{\theta} h(x)) &+ 2\mathbf{Cov}(\tilde{\varepsilon} f(x), \tilde{\varepsilon}\tilde{\theta} h(x)) \end{aligned} \tag{3.16}$$

We consider each term of this sum:

$$\mathbf{Var}(\tilde{\varepsilon} f(x)) = \sigma_{\varepsilon}^2 [f(x)]^2 \tag{3.17}$$

$$\begin{aligned} \mathbf{Var}[\tilde{\varepsilon}\tilde{\theta} h(x)] &= \big\{\mathbf{E}(\tilde{\varepsilon}^2\tilde{\theta}^2) - [\mathbf{E}(\tilde{\varepsilon}\tilde{\theta})]^2\big\}[h(x)]^2 \\ = \big\{\mathbf{E}(\tilde{\varepsilon}^2)\mathbf{E}(\tilde{\theta}^2) + \mathbf{Cov}(\tilde{\varepsilon}^2, \tilde{\theta}^2) &- [\mathbf{E}(\tilde{\varepsilon})\mathbf{E}(\tilde{\theta}) + \mathbf{Cov}(\tilde{\varepsilon}, \tilde{\theta})]^2\big\}[h(x)]^2 \end{aligned} \tag{3.18}$$

We know that $\mathbf{E}(\tilde{\theta}) = 0$. Moreover, the fact that $\tilde{\varepsilon}$ and $\tilde{\theta}$ being two independent random variables implies that $\mathbf{Cov}(\tilde{\varepsilon}, \tilde{\theta}) = 0$ and $\mathbf{Cov}(\tilde{\varepsilon}^2, \tilde{\theta}^2) = 0$. Hence this expression reduces to

$$\begin{aligned} \mathbf{Var}[\tilde{\varepsilon}\tilde{\theta} h(x)] &= \mathbf{E}(\tilde{\varepsilon}^2)\mathbf{E}(\tilde{\theta}^2)[h(x)]^2 \\ &= \sigma_{\theta}^2(\sigma_{\varepsilon}^2 + \bar{\varepsilon})[h(x)]^2 \end{aligned} \tag{3.19}$$

Hence we get

$$\mathbf{Var}[y(x, \tilde{\theta}, \tilde{\varepsilon})] = \sigma_{\varepsilon}^2 [f(x)]^2 + \sigma_{\theta}^2(\sigma_{\varepsilon}^2 + \bar{\varepsilon})[h(x)]^2 \tag{3.20}$$

*End of proof.*

The farmer's input choice is thus given by the following programme:

$$\max_x U(x, 0) = z\big[\bar{\varepsilon} f(x) - cx, \sigma_{\varepsilon}^2 [f(x)]^2 + \sigma_{\theta}^2(\sigma_{\varepsilon}^2 + \bar{\varepsilon}^2)[h(x)]^2\big] \tag{3.21}$$

Assuming an interior solution, the optimal choice of input use, $x^*$ is given by the first-order condition

$$\bar{\varepsilon}f'(x^*)z_1 - \left\{\sigma_\varepsilon^2 f'(x^*)f(x^*) + \sigma_\theta^2(\sigma_\varepsilon^2 + \bar{\varepsilon}^2)h'(x^*)h(x^*)\right\}z_2 = c \tag{3.22}$$

Looking at the first-order condition, we see the double impact of a marginal increase in $x$ on the variance of yield. On the one hand, since by assumption $h'(.) \leq 0$ it reduces the farmer's exposure to risk $\tilde{\theta}$ (risk-decreasing input). On the other hand it increases the exposure to the other risk, $\tilde{\varepsilon}$. Without further specifications of $f$ and $h$ and imposing conditions on the values of the parameters $\sigma_\varepsilon^2$ , $\sigma_\varepsilon^2$ and $\bar{\varepsilon}^2$, there is no clear cut conclusion on the fact that a marginal increase in $x$ increases or reduces the variance of yield. For some values of parameters, the variance of yield can be a non-monotonic function of $x$. For small $x$, the variance decreases, and up to a certain level of $x$, it increases. This is explained by the relative strengths of the risk-reduction effect of $x$ on $\tilde{\theta}$ and its risk-increasing effect on $\tilde{\varepsilon}$. To see this, consider the following specifications: $f(x) = k_1\sqrt{x}$ and $h(x) = \frac{1}{1+k_2 x}$ where $k_1$ and $k_2$ are two positive parameters. Computing the variance as a function of $x$, we obtain:

$$\mathbf{Var}[y(x,\tilde{\theta},\tilde{\varepsilon})] = \sigma_\varepsilon^2 k_1^2 x + \sigma_\theta^2(\sigma_\varepsilon^2 + \bar{\varepsilon})\frac{1}{(1+k_2x)^2}$$

Thus we get

$$\frac{\partial \mathbf{Var}[y(x,\tilde{\theta},\tilde{\varepsilon})]}{\partial x} = \sigma_\varepsilon^2 k_1^2 - \frac{k_2\sigma_\theta^2(\sigma_\varepsilon^2 + \bar{\varepsilon})}{(1+k_2x)^3}$$

and

$$\frac{\partial^2 \mathbf{Var}[y(x,\tilde{\theta},\tilde{\varepsilon})]}{\partial x^2} = \frac{3k_2^2\sigma_\theta^2(\sigma_\varepsilon^2 + \bar{\varepsilon})}{(1+k_2x)^3} \geq 0$$

Hence the variance is convex in $x$. The sense of variation depends on the values of parameters. More precisely, if $\sigma_\varepsilon^2 k_1^2 - k_2\sigma_\theta^2(\sigma_\varepsilon^2 + \bar{\varepsilon}) \geq 0$, then the variance is increasing with on the interval $[0, +\infty[$. If $\sigma_\varepsilon^2 k_1^2 - k_2\sigma_\theta^2(\sigma_\varepsilon^2 + \bar{\varepsilon}) < 0$, the variance is decreasing on the interval $[0, \sigma_\varepsilon^2 k_1^2 - k_2\sigma_\theta^2(\sigma_\varepsilon^2 + \bar{\varepsilon})[$ and increasing on the interval $[\sigma_\varepsilon^2 k_1^2 - k_2\sigma_\theta^2(\sigma_\varepsilon^2 + \bar{\varepsilon}), +\infty[$. In the latter case, for small values of $x$, the ris-reduction effect dominates while for higher values the risk-increasing effect dominates due to the fact that $x$ increases the production scale. Thus the effect of $x$ on the variance of yield is non-monotonic.

### 3.6.2 Review of empirical results: synthesis

**Part 1**

| Study | Assumptions | Region/Data | Main results |
|---|---|---|---|
| Horowitz and Lichtenberg (1993) | • “Moral hazard”<br>• “Pesticides can be strongly risk-increasing”<br>• “Crop insurance decision made before input use decision” | U.S. Midwest | • “Producers who purchased insurance applied 20% more N per acre and spent 22% more on pesticides” |
| Smith and Goodwin (1996) | • “Moral hazard”<br>• “Crop insurance decision made simultaneously with input use decisions” | Kansas (dryland wheat farmers)/ Farm-level data | • “Crop insurance reduces input use”<br>• “Each dollar spent on chemical inputs lowers the probability of insurance purchases by about 1%.” |
| Wu (1999) | • Substitution between risk management tools<br>• Moral hazard | Nebraska/farm-level data | • “Farmers grow more corn and soybeans and less hay and pasture.”<br>• “Crop mix changes lead to to 20% increase in N use, 33% increase in P use, and 22% increase in atrazine use.” |

**Part 2**

| | | | |
|---|---|---|---|
| Keeton et al. (1999) | - | "U.S., crop reporting district data" | • "45 million acres brought into production (including 30 million CRP acres)<br>• "No environmental measures" |
| Nimon and Mishra (2001) | • "Moral hazard"<br>• "Crop insurance decision made simultaneously with input use decision" | 17 U.S. states, Agricultural Resource Management Study 1998 data/Individual data | • "Crop insurance increases pesticide use"<br>• "Crop insurance reduces fertilzer use" |
| Goodwin et al. (2004) | Crop insurance influences acreage decisions | U.S. Corn Belt (corn and soybean) and Upper Great Plains (wheat and barley)/Farm level data | • A 30 % decreases in premiums increases acreage by 0.2-1.1 %. Significant but small impact. |

### 3.6.3 Econometric model

$$
\begin{aligned}
I^*_{it} &= X'_{1it}\beta_1 + P_{it}\gamma_1 + w_{1it}, && (3.23)\\
P_{it} &= X'_{2it}\beta_2 + I^*_{it}\gamma_2 + w_{2it}, && (3.24)
\end{aligned}
$$

Then,

$$
\begin{aligned}
I^*_{it} &= X'_{1it}\beta_1 + (X'_{2it}\beta_2 + I^*_{it}\gamma_2 + w_{2it})\gamma_1 + w_{1it} && (3.25)\\
P_{it} &= X'_{2it}\beta_2 + (X'_{1it}\beta_1 + P_{it}\gamma_1 + w_{1it})\gamma_2 + w_{2it}, && (3.26)
\end{aligned}
$$

$$
\begin{aligned}
I^*_{it} &= X'_{1it}\widetilde{\beta}_1 + X'_{2it}\widetilde{\beta}_2\gamma_1 + w_{2it}\widetilde{\gamma}_1 + \widetilde{w_{1it}} && (3.27)\\
P_{it} &= X'_{2it}\widetilde{\beta}_2 + X'_{1it}\widetilde{\beta}_1\gamma_2 + w_{1it}\widetilde{\gamma}_2 + \widetilde{w_{2it}}, && (3.28)
\end{aligned}
$$

where $\widetilde{\beta_k} = \frac{\beta_k}{1-\gamma_1\gamma_2}$ and $\widetilde{w_{1it}} = \frac{w_{kit}}{1-\gamma_1\gamma_2}$, for $k = 1, 2$.

# Chapter 4

# Inequity Aversion, The Samaritan's Dilemma and Risk Prevention

**Abstract**

We reconsider the Samaritan's dilemma game in the case of a prevention activity against risk. Agents are risk-neutral and inequity averse in the sense of Fehr and Schmidt (1999). They choose a level of prevention that reduces the probability of wealth loss. Once the state of Nature is realized, individual outputs are mutually observable inequity averse agents make transfers to the unlucky. In contrast to the previous literature on the Samaritan's Dilemma which mainly assumes pure altruism preferences, we show that inequity aversion may lead to multiple prevention equilibria. We also discuss the traditional normative conclusion concerning the welfare-enhancing role of in-kind transfer of prevention.

**Keywords**: Inequity aversion, the Samaritan's Dilemma, risk prevention

## 4.1 Introduction

Understanding people's motivations to buy insurance and invest in prevention activities is a major issue for insurance practitioners, policy makers and researchers. From a public policy perspective, two fundamental issues arise: are natural-related risks efficiently allocated across people under the current institutional arrangements? Do people face the appropriate incentives to undertake prevention and mitigation measures, at both individual and collective levels? The two issues are closely related since a good allocation of risks implies fair pricing that internalizes the true cost of risk into individual decisions (Picard, 2008)[1]. There is however some empirical evidence showing that insurance and prevention cannot be explained by the canonical model of expected utility maximization alone. In particular, a significant fraction of people tends to forgo any of these forms of risk coping. Several explanations have been proposed in the literature to solve this puzzle. A first one relies on the

[1] In this case, the insurance industry provides the good price signals to risky individuals. Since fair pricing can hurt individuals that are characterized by a high cost of prevention, some form of redistribution by the governement can cope with the equity issue (Picard, 2008).

lack of information. Potential insurees/prevention buyers are expected utility maximizers but poorly informed about the nature and the precise quantification of the risks they face. Moreover information is costly to acquire and is itself subject to some form of cost-benefit analysis. If it can be diffused without restrictions, information has the characteristics of a public good, and therefore is likely to be undersupplied. A second explanation relies on psychological grounds. People tend to distort probabilities, putting more or less weight on some states of Nature. For example, people may consider probabilities as being equal to zero under a given (small) probability threshold (Kunreuther and Pauly, 2006). Therefore, for low probability risks, the fraction of uninsured and underprotected individuals could be explained by the heterogeneity of such threshold in the population, or even the perception of it.

A third explanation may also explain underprevention and underinsurance that is observed in several risk and prevention markets: social preferences. Although several definitions and formalizations are possible, the notion of social preferences broadly refers to the fact that the individuals' utilities are interrelated. Social preferences may have important economic consequences, in particular the incentive to redistribute goods or wealth to needy people. This incentive may in turn modify the economic environment in which individuals take decisions, and thus have consequences on both social efficiceny and wealth redistribution. At first sight one may be tempted to think that social preferences have in most cases a positive effect on economic decisions, at worst a neutral one. But this is not necessarily the case. Perhaps the most known story of a negative role of social preferences is the *Samaritan's dilemma*. It tells that altruism, by providing agents free mutual help through financial charity tranfers in cases of need, reduces their incentives to invest in prevention, insurance and savings, or incites them to overinvest in too risky projects. The problem with altruistic agents is their inherent inability to commit to not help when other agents of the groups they belong to are in need. Being aware of this lack of commitment power, some agents have an implicit incentive to free-ride on the Samaritan's social concern.

We examine this argument in the case of risk prevention. We consider a two-stage game between two risk neutral agents that display inequity aversion in the sense of Fehr and Schmidt (1999) and produce a risky output. There are two states of Nature: a high output state and a low ouput one. At the first stage, agents choose or not to invest in a costly risk-prevention technology that reduces the probability of the low output state. At the second stage, the state of Nature is realized, agents mutually observe their outputs at no cost, and choose a level of solidarity transfer to the unlucky driven by their inequity aversion preferences.

**Related literature.**— A growing body of litterature intents to study and incorporate social preferences into economic models . Moral sentiments –the term used by Adam Smith– such as altruism, fairness, or conformism are by now considered by economic analysis as an important component of individuals' well-being, and therefore a potentially important driver of individuals' choices in certain contexts, such as teamwork, finance, industrial organization, public goods, and externalities (Sobel, 2005). Once it is recognized that social preferences may matter for economic decisions, it is thus useful to improve our understanding on the way they interplay with pure economic incentives, in theory and in practice, and *in fine* to analyze their consequences on economic outcomes and social efficiency.

The story of the Samaritan's dilemma has been first told by James Buchanan. It has been later formalized in a game-theoretic framework in several papers. Lindbeck and Weibull (1988) consider a two-agent, two-periods game where mutually altruistic agents make a saving decision in the first period and provide charity transfers in the second period, if they wish to do so. Characterizing the subgame perfect equilibria of this game, they show that undersaving is likely to occur in terms of Pareto efficiency. Kotlikoff (1987) considers a similar problem and suggests that the inefficiency result provides a rationale for public provision of social security. Bruce and Waldman (1991) study a close model of saving/investment but with one-sided altruism only. The Pareto inefficiency result still holds, and the authors also suggest that in-kind transfers of saving and/or productive investment can be a solution to overcome the lack of commitment of the altruist. Coate (1995) also assumes one-sided altruism but reconsiders the problem in a context of uncertainty and redistribution. A poor individual make insurance and prevention choices instead of saving/investment, and can be helped by two rich who want to redistribute a part of their wealth to the poor. The fundamental logic of the Samaritan's Dilemma remains: instead of anticipating to free-ride in the future, agents anticipate to benefit from an implicit safety in bad states of Nature. In addition to the ex-ante inefficiency due to forgoing insurance, Coate (1995) also considers ex-post inefficiency, i.e. the too low levels of charity transfers that are frequently observed in real life. This is due to the fact that charity transfers are decentralized actions of rich altruist, thus subject to free-riding. For example, in an international context, when a shock occurs in a given country, the different countries that provide relief may not be able to coordinate themselves on the socially optimal (from their point of view) level of aid, leading to underprovision. Hence, not only charity deters insurance, which is ex-ante inefficient, but it also provides an inefficent safety net instead. This justifies on Pareto efficiency grounds in-kind redistribution of insurance and prevention (eventually a package including both instruments) from the rich to the poor. It is often used as a metaphor for describing a variety of real-life situations at very different scales, such as mutual help in communities, national solidarity between citizens, international aid and so on[2].

In all these cases, unconditional altruism generates social inefficiency in a strategic contexts. The Samaritan's dilemma has strong normative implications in terms of public economics, calling for government intervention to restore Pareto efficiency. The most direct response is indeed to force free-riding agents to undertake the socially optimal choices, which necessary involves the intervention of a third party having enforcement power. This constitutes a potential rationale for government mandatory insurance, prevention, savings programmes, and social security *on efficiency ground*. Government intervention can also include subsidies in favour of prevention and insurance, as well as taxation of risky activities[3].

Despite its implacable logic, the inefficiency result of the Samaritan's dilemma calls for scrutiny. In particular, its normative implications, when taken literally –mandatory savings, investments, insurance etc.–, seem "too strong to be realistic" as a policy advice. This would require a very large intervention of the State in the economy, which could itself create new sources of inefficiency (Lindbeck and Weibull, 1988). Recently, several papers have enriched the traditional framework in different ways and suggest that the inefficiency result may not be as robust as it appears. Lagerlöf (2004) considers the case of asymmetric information and signalling in a two-period model of savings similar to Bruce and

[2] Lindbeck and Weibull (1988) note that it is also a way to interpret the "soft budget constraint" problem of Kornai.

[3] In the international aid context, in the absence of a central government, a potential solution is the delegation of the provision of aid to an independent agency with more commitment power ex-post (for example a less altruistic third party). See Svensson (2000) and Hagen (2006) for such analysis. But this does not necessary eliminates the commitment problem. Moreover this can create other sources of inefficiency.

Waldman (1991). He assumes that selfish recipient has private information concerning his discount factor. Because the altruistic transfers increases with the discount factor, the selfish agent has incentive to signal a high discount factor through his first-period saving decision. This tends to countervail the typical undersaving effect. In a different vein, Ghosh and Karaivanov (2008) reconsiders the dilemma in a trilateral relationship between a principal, an agent, and an altruist and show that effort undeprovision is mitigated. Another recent result by Alger and Weibull (2008) tackles the puzzle of mutual altruism, i.e. the surprising result that people that count for each other can finish worse off than selfish agents. They consider the case of two mutually altruistic agents that face uncertain output and can invest in prevention that reduces the probability of low output. Altruism generates ex-post transfers from the lucky to the unlucky, which allows implicit risk sharing across agents (positive effect), but also free-riding on the prevention effort (negative effect). They show that, for certain values of altruism, the free-riding effect is countervailed by an *empathy effect*, due to the fact that each agents want to be able to help the other one if the latter gets a low output. Furthermore, an evolutionary analysis shows that altruism can be sustainable at intermediate levels.

These recent studies call for investigating further refinements of the "standard" (if it exists such one) model. The fact that close but different models yield different results calls for studying diverse strategic settings, but also different specifications of social preferences. The objective of this paper is to propose another look at the Samaritan's dilemma problem by considering the impact of an alternative specification of social preferences. To our knowlege, almost all models of Samaritan's dilemma assume pure altruism for modelling social preferences. Pure altruism refers to utility functions of the form $U_i(u_i, u_j)$, where the utility of agent $i$ is a function of his own material utility $u_i$ and the material utility of the other agent $u_j$[4]. The pure altruism assumption for social preferences has however been criticized over the last decades (Sobel, 2005). Several authors have thus proposed alternative models of social preferences, which put the emphasis on *relative payoffs* between agents. Perhaps the two most known models of such type are the Fehr-Schmidt model of inequality aversion (Fehr and Schmidt, 1999) and the Bolton and Ockenfels' model of equity, reciprocity and cooperation (Bolton and Ockenfels, 2000). These models have their origin in the field of experimental economics. The objective was to find a common

[4]Many papers assume separability, i.e. the utility function takes the form $U_i = f(u_i) + \delta g(u_j)$.

framework for explaining a recurrent pattern of observed behaviors in standard experiments such as the dictator game or the ultimatum game (Fehr and Fischbacher, 2002). Another strand of literature, the economics of happyness, also stresses the importance of relative wealth in individuals' well-being (Clark et al., 2008). The objective of this chapter is thus to reconsider the Samaritan's dilemma in the case of inequity averse preferences in the context of risk prevention.

The paper is organized as follows. In section 2 the game is presented, in section 3. it is solved and analyzed. Section 4 concludes.

## 4.2 The model

Consider an economy composed by two risk-neutral agents, producing a single good $y$. Production is risky, with two possible states of Nature, a low output state where production is equal to $y^L$ and a high output state where it is equal to $y^H > y^L$. Let us denote $\Delta = y^H - y^L$ the difference of production levels across the two states of Nature. Agents can invest in a costly prevention technology that increases the probability that the good state occurs. Formally, denote $p_i(e_i)$ (respectively $1-p_i(e_i)$) the probability of a low output $y^L$ (respectively a high output $y^N$) for a given agent $i$, where $e_i \in E_i$. More effort reduces the probability of low output, that is for all $e_i^1 \leq e_i^2$ with $(e_i^1, e_i^2) \in E_i^2$, $p_i(e_i^1) \geq p_i(e_i^2)$.

Agents are assumed to be risk-neutral over their private consumption and to have social preferences formalized by the non-linear version of the Fehr and Schmidt's model of inequity aversion. Formally, if one considers a group of $N$ agents with a consumption vector denoted $\mathbf{w} = (w_1, ..., w_i, ...w_N)$, the utility of agent $i$ is defined as follows

$$u_i(\mathbf{w}) = w_i - \sum_{j \neq i} \frac{1}{N-1} v_i\big(w_i - w_j\big) \tag{4.1}$$

where for all $i$ $v_i(0) = 0$ and for all $z \in \Re$, $v_i(z) \geq 0$, $v_i(.)$ is assumed to be twice differentiable, with $v_i'(z) \geq 0$ (respectively $\leq 0$) for $z \geq 0$ (respectively for $z \leq 0$), $v_i''(.) \geq 0$. In this model, an agent's overall utility is defined as the sum of his own consumption $w_i$ and a term that reflects the average degree of consumption inequalities between him and the $N-1$ other agents. In contrast to pure altruism, inequity aversion is a self-centered concept based on interpersonal comparisons of consumption levels. Because $v_i$ is convex, the disutility arising from consumption inequalities exhibits decreasing returns to scale.

That is the marginal disutility from inequality increases as the gap between consumption levels increases. Agents are assumed to dislike both favourable (they are richer than their fellows) or unfavorable (they are poorer than them) inequity but some kind of asymmetry between these two types of inequalities are possible. To capture this in a simple manner we introduce the following specification as a special case:

$$v_i(z) = \begin{cases} \alpha_i v(z) \text{ if } z < 0 \\ \beta_i v(z) \text{ if } z > 0 \\ 0 \text{ if } z = 0 \end{cases}$$

and $v$ exhibits the same properties than $v_i$. Parameters $\alpha_i \geq 0$ and $\beta_i \geq 0$ measure the disutility from, respectively, favorable and unfavorable inequity for agent $i$. This quasi-linear specification generalizes the model of Fehr and Schmidt, which corresponds to the case $v(z) = z$. Considering non-linear inequity aversion has ever been proposed by these authors as a natural generalization of their piecewise-linear initial formulation[5]. It is however crucial in our context since it allows for eventual transfers between agents. Convexity has already been assumed in a contract theory context by Englmaier and Wambach (2005), and the subject of an axiomatic analysis by Neilson (2006). It has also consequences in terms of risk preferences toward social outcomes $\mathbf{y}$: agents not only dislike inequitable outcomes ex-post, but are in addition averse to inequitable outcomes ex-ante. That is, between two lotteries that yield the same level of expected inequity, the agent prefers the less inequity variability, in the sense that they have a positive willingness to pay ex-ante to reduce the risk of inequitable outcomes ex-post.
We consider the following two-stage game:

- At stage 1, each agent chooses a level of investment in costly prevention,
- At stage 2, the state of Nature is revealed. Agents observe each other payoffs and choose a level of transfers to make to the other agents.

We make the following assumptions:

- (A1) Outputs $y_i$ are perfectly and commonly observable by the two agents.
- (A2) The cost of prevention is not included in the inequity aversion function.

The following section characterizes the subgame perfect equilibrium of the game.

[5] The Fehr-Schmidt model is written as $u_i(\mathbf{w}) = w_i - \sum_{j \neq i} \alpha_i \{ \max[0, w_j - w_i] + \beta_i \max[0, w_i - w_j] \}$.

## 4.3 Equilibria characterization

### 4.3.1 Stage 2: transfers

Looking at the second stage transfer game, I denote $y_i$ and $y_j$ the respective output of agents $i$ and $j$ before transfers between agents are made and $T_{ij}$ the net transfer from agent $i$ to agent $j$. Suppose that agent $i$ has produced more than agent $j$, i.e. $y_i > y_j$. The optimal transfer from $i$ to $j$, $T_{ij}$, maximizes the utility of $i$, thus the following programme

$$u_i(w_i, w_j) = w_i - \beta_i v\big(w_i - w_j\big) - c_i(e_i) \tag{4.2}$$

$$\text{s.t. } w_i = y_i - T_{ij} \tag{4.3}$$

$$w_j = y_j + T_{ij} \tag{4.4}$$

In case of interior solution, the optimal transfer from $i$ and $j$ is thus defined by the first-order condition

$$1 = 2\beta_i v'(y_i - y_j - 2T^*_{ij}) \tag{4.5}$$

The optimal net transfer equalizes the cost of giving, equal to one, with the marginal gain of inequity reduction. In case of corner solution, the marginal cost of giving is always higher than the marginal gain from inequity reduction and we have $T_{ij} = 0$. In sum the optimal transfer from $i$ to $j$ can be explicitely written as

$$T^*_{ij}(\beta_i) = \frac{1}{2}\max\Big[0, y_i - y_j - \gamma_i\Big] \tag{4.6}$$

with

$$\gamma_i = v'^{-1}\left(\frac{1}{2\beta_i}\right) \tag{4.7}$$

Inequity aversion lead to a strictly positive transfer if the income gap between the two agents is greater than $\gamma_i$. A certain degree of tolerance towards favourable inequity is thus acceptable, and this is measured by the term $\gamma_i = v'^{-1}\big(\frac{1}{2\beta_i}\big)$ which is increasing with the inequity aversion parameter $\beta_i$. Using the insurance vocabulary, $\gamma_i$ is a kind of "inequity deductible". When realized output are such that a positive net transfer from $i$ to $j$, the indivuals' final wealths, $w_i$ and $w_j$ are equal to, respectively

$$w_i = y_i + T^*_{ji} = \frac{y_i + y_j}{2} + \frac{\gamma_i}{2} \tag{4.8}$$

$$w_j = y_j - T^*_{ji} = \frac{y_i + y_j}{2} - \frac{\gamma_i}{2} \tag{4.9}$$

The final consumptions are the the sum of two terms: the equally shared output of the group and a term that depends on $\beta_i$ only. Because $v$ is increasing and concave, for $\beta_i \to +\infty$, $w_i = w_j = \frac{y_i+y_j}{2}$, i.e. there is equal sharing of outputs. For lower values of $\beta_i$, inequity aversion only leads to incomplete sharing. This in in line with Englmaier and Wambach (2005) who show that in a principal agent model convex inequity aversion leads to proportional contracts with slope $1/2$ between the principal and the agent. The following proposition defines the final wealth of agent $i$ once transfers are made.

**Proposition 11.** *The final wealth of agent $i$ after transfers, $\tilde{w}_i$ is defined as follows*

$$\tilde{w}_i(e_i, e_j) = \begin{cases} \frac{\tilde{y}_i(e_i)+\tilde{y}_j(e_j)}{2} - \frac{\gamma_j}{2} & \text{if } \tilde{y}_i(e_i) < \tilde{y}_j(e_j) - \gamma_j \\ \tilde{y}_i(e_i) & \text{if } \tilde{y}_i(e_i) \in [\tilde{y}_j(e_j) - \gamma_j, \tilde{y}_j(e_j) + \gamma_i] \\ \frac{\tilde{y}_i(e_i)+\tilde{y}_j(e_j)}{2} + \frac{\gamma_i}{2} & \text{if } \tilde{y}_i(e_i) > \tilde{y}_j(e_j) + \gamma_i \end{cases}$$

Transfers driven by inequity aversion provide an implicit safety net to agents. However this safety net is itself risky because a transfer from $i$ to $j$ is activated only when agent $i$ gets a high level of output. If all agents are hurt by a production shock that leaves them with a low, identical disposable income, no transfers will arise. The safety net can only be active when some agents within the group have a sufficiently high level of disposable income.

### 4.3.2 The full game

At the first stage, agents choose their levels of prevention in order to maximize their expected utility, which is equal to their expected private wealth (including net transfers) minus the expected disutility from inequality aversion. We assume a Nash behavior, i.e. they take as given the level of prevention of the other individual. The programme of individual $i$ is thus

$$\max_{e_i} U_i(e_i, e_j) = \mathbf{E}\big[\tilde{w}_i(e_i, e_j) - v_i\big(\tilde{w}_i(e_i, e_j) - \tilde{w}_j(e_i, e_j)\big)\big] - c_i(e_i) \tag{4.10}$$

Let us consider a binary prevention choice $e_i \in \{0,1\}$. Investing in prevention reduces the probability of loss. Formally $p(1) = \theta p \leq p(0) = p$, with $\theta \in [0,1[$ being an efficiency parameter of the prevention technology. The lower $\theta$ is, the most efficient prevention is.

**Selfish agents —.** As a benchmark, suppose that both agents are selfish, i.e. $\alpha_i = \alpha_j = \beta_i = \beta_j = 0$, Then the individual $i$ choice is $e_i^s = 1$ (respectively $e_i^s = 0$) if

$$(1-\theta)p\Delta - c_i \geq \text{(respectively <) } 0 \tag{4.11}$$

**Inequity averse, symmetric agents —.** Now consider the case of inequity averse agents. Assume that $\alpha_i = \alpha_j = \alpha \geq 0$ and $\beta_i = \beta_j = \beta > 0$, identical technologies $\theta_i = \theta_j = \theta$ and unitary cost of prevention $c_i = c_j = c$, and that $\Delta > \gamma = v'^{-1}\left(\frac{1}{2\beta}\right)$, which simply means that gaps in final output are sufficiently high to always induce transfers when one indivual succeeds (gets $y^H$) and the other fails (gets $y^L$). Let us denote $(e_i^*, e_j^*)$ a pure Nash equilibrium of the stage 1 prevention game. With a binary prevention choice, there are four Nash equilibrium candidates: $(0,0)$, $(0,1)$, $(1,0)$ and $(1,1)$. The following proposition characterizes the Nash equilibria as a function of the parameters' values:

**Proposition 12.** *Let us define $\delta(z,\alpha,\beta)$ as follows:*

$$\delta(z,\alpha,\beta) = \frac{\Delta + \gamma_j}{2} + \frac{\gamma_i - \gamma_j}{2} zp - zp\beta v(\gamma_i) + (1-zp)\alpha v(\gamma_j) \tag{4.12}$$

*In the symmetric equilibrium,*

1. *If $\delta(\theta,\alpha,\beta) < \frac{c}{(1-\theta)p}$, then there is a unique Nash equilibrium $(0,0)$*

2. *If $\delta(1,\alpha,\beta) < \frac{c}{(1-\theta)p} < \delta(\theta,\alpha,\beta)$, then both equilibria coexist: $(0,0)$ and $(1,1)$*

3. *If $\frac{c}{(1-\theta)p} < \delta(1,\alpha,\beta)$, then there is a unique Nash equilibrium $(1,1)$*

*Proof.* To characterize the Nash equilibria of this game, we study the incentives for $i$ to deviate given $j$'s choice. The incentives to invest in prevention for $i$ given $e_j = 1$ and $e_j = 0$ are given by, respectively

$$U_i(1,1) - U_i(0,1) = (1-\theta)p\delta(\theta,\alpha,\beta) - c_i \tag{4.13}$$

$$U_i(1,0) - U_i(0,0) = (1-\theta)p\delta(1,\alpha,\beta) - c_i \tag{4.14}$$

Simple computation gives

$$U_i(1,1) - U_i(0,1) - [U_i(1,0) - U_i(0,0)] = (1-\theta)p(\gamma_i - \gamma_j) + p(1-\theta)\alpha_i v(\gamma_i) + (1-\theta)p\beta_i v(\gamma_j)$$

Assuming identical preferences, this expression reduces to $(1-\theta)p(\alpha+\beta)v(\gamma) > 0$ which is strictly positive for $\alpha + \beta > 0$. Thus $U_i : E1 \times E2 \to R$ has strictly increasing differences in $(e_i, e_j)$ so the game is supermodular. □

The prevention decision is driven by two disctinct although interrelated incentives: the free-riding incentive due to output sharing, and the desire to minimize the expected disutility arising from inequity. The free-riding incentive is captured by the two first terms of 4.12. Indeed, since by assumption $\gamma_i \in [0, \Delta[$ we have

$$\frac{\Delta}{2} \leq \frac{\Delta + \gamma_j}{2} < \Delta$$

So the difference between outputs in the two states of Nature, $\frac{\Delta+\gamma_j}{2}$ is always lower with social preferences than without, $\Delta$. Moreover, since $\gamma_j$ decreases with $\beta$, $\frac{\Delta+\gamma_j}{2}$ decreases with $\beta_i$, which reflects the intensity of free-riding as a function of the aversion to favourable inequity. The third and fourth terms of 4.12 correspond to the expected disutility of agents from residual inequity (i.e. following transfers). The fact that multiple equilibria may arise for intermediate cost parameters is due to the nature of inequity aversion preferences and can be explained as follows. If one individual increases the probability to produce a high output, the others are incited to do as well. Inequity aversion over wealth generates some form of conformism in prevention choices. Inequity aversion thus makes prevention choices strategic complements, generating a standard coordination problem between agents. Therefore two Nash equilibria can coexist for a given subset of parameters[6].

In order to analyze in more depth the role of social preferences on prevention equilibrium determination, we study the equilibria in the space $(c, \alpha)$ (4.1).

[6]It may be also linked to the fixed cost nature of the prevention technology. We are not ensured that multiple equilibria arise for all specifications of the prevention technology and cost function. Intuitively, S-shape prevention functions or fixed cost may favorize the existence of muliple equilibria (see Appendix 4.5)

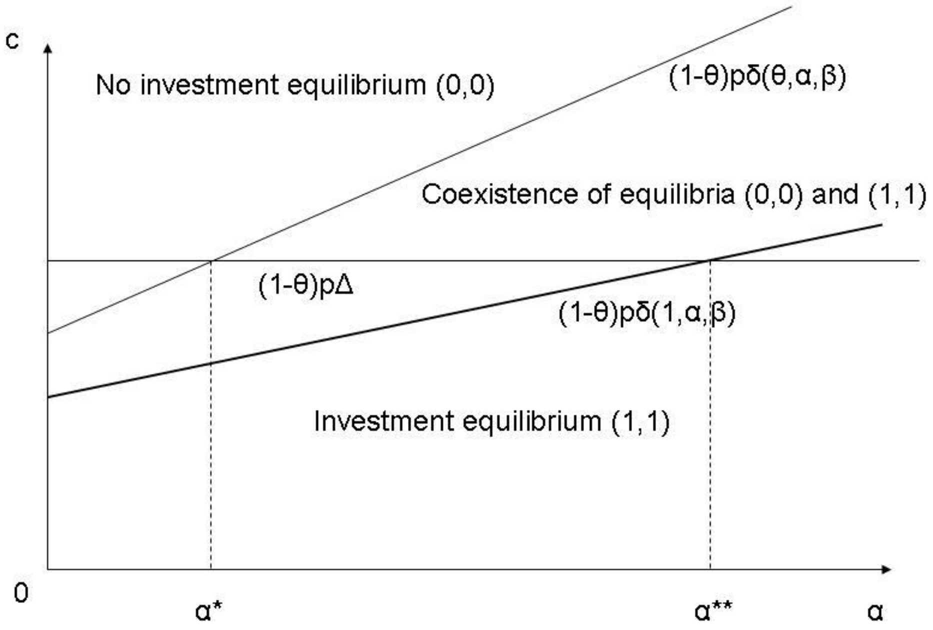


Figure 4.1: Equilibrium determination the $(c, \alpha)$ space

The two increasing and linear curves are graphical representations of the equilibrium conditions exposed in proposition 12 for a given value of $\beta$. Above the thin curve, there is a single no investment equilbrium. Between the thin curve and the thick curve, we are in the presence of multiple equilibria. Below the thick curve, there is a single equilibrium with positive investment in prevention. The horizontal line represents the investment condition in the absence of social preferences, which by definition is independent of $\alpha$. This figure clearly shows that aversion to unfavourable inequity, measured by $\alpha$ increases the likelihood of risk prevention investment, and thus mitigate the underinvestment result by reducing the maximal cost at which investment (thick curve) or multiple equilibria (thin curve) arise. For $\alpha = 0$, the thin curve is below the horizontal line, which illustrates the classical underinvestment result of the Samaritan's Dilemma for any value of $\beta$ such that $\Delta > \gamma = v'^{-1}\left(\frac{1}{2\beta}\right)$. For $\alpha \in [0, \alpha *[$, inequity aversion leads to underinvestment. For $\alpha \in [\alpha^*, \alpha^{**}[$, both equilibria arise. Finally, for $\alpha \in [\alpha^{**}, +\infty[$, there is no underinvestment compared to the case without social preferences.

### 4.3.3 Welfare analysis

We now consider the optimal prevention choice from a social welfare point of view. We have seen that three situations can arise: a no-investment equilibrium, an investment equilibrium, and a case where the equilibrium is undeterminated. To examine the social value of risk prevention in the case of identical agents, we compute the difference in expected utility between the two situations "the two agents invest" and "none of the agents invest" for symmetric agents. After simple computation, we obtain the following result.

$$U(1,1) - U(0,0) = (1-\theta)p\Delta - \big[\theta p(1-\theta p) - p(1-p)\big](\alpha+\beta)v(\gamma) \qquad (4.15)$$

$p(1-p)$ reaches a maximum for $p = 1/2$. Since $\theta \in ]0,1]$, if $p \leq 1/2$ (which is the most natural case), then $\theta p(1-\theta p) - p(1-p) \leq 0$. Hence $U(1,1) - U(0,0) > (1-\theta)p\Delta$. In other words, it is always socially optimal to invest in risk prevention with social preferences, i.e. $\alpha > 0$ and/or $\beta > 0$ when it is optimal to invest without, i.e. $\alpha = 0$ and $\beta = 0$. The first term of equation (4.15) represents the expected material wealth of each individual. The second term represents the expected disutility from inequity, which is reduced by prevention. Hence with inequity averse preferences, investing in prevention is not only driven by expected wealth but also by the desire to reduce the expected disutility from inequity.

**Mandatory prevention fund.**— Comparing social welfare with the outcome of the game, it is straightforward that there exists some ranges of parameters $\alpha$ and $\beta$ for which there is no investment in risk prevention although it is socially optimal to do so. Following Lindbeck and Weibull (1988) and Coate (1995), this may be solved by a social planner through the mean of a mandatory prevention fund. This would consist in subsidizing prevention at a certain fraction $s$ using a contribution $t < y^L$ from each individual. Hence equation 4.12 would remain unchanged, while the cost of prevention payed by individual would become equal to $(1-s)c$, with the budget constraint $t = (1-s)c$. Starting from a situation where there is a single equilibrium $(0,0)$, a prevention subsidy such that

$$\delta(1,\alpha,\beta) < \frac{(1-s)c}{(1-\theta)p} < \delta(\theta,\alpha,\beta)$$

allows to reach the case where both equilibria coexist, while a prevention subsidy characterized by

$$\frac{(1-s)c}{(1-\theta)p} < \delta(1,\alpha,\beta)$$

ensure a positive investment in risk prevention by agents.

## 4.4 Conclusion

We have reconsidered the Samaritan's dilemma in a context of risk prevention with mutual inequity aversion. Because inequity aversion captures a form of reciprocal behavior, it generates conformism in agents' choices, which gives rise to the possibility of multiple equilibria. In the case of a discrete prevention choice, positive investment can occur even in the presence of the free-riding effect due to the countervailing incentive driven by unfavourable inequity aversion. The usual argument for in-kind redistribution of prevention to solve the commitment problem remains valid, and can take the form of a mandatory prevention fund. The usual criticisms also apply, namely the fact that subsidies can create other forms of inefficiency, or may be difficult to calibrate under private information.

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## 4.5 Appendix

### 4.5.1 Continuous prevention choices

Let us consider the case of continuous prevention choices. The probability function $p_i(.)$ is assumed to have the following properties: $p_i'(.) \leq 0$, $\lim_{e_i \to +\infty} p_i(e_i) = \underline{p}$, $p(0) = \overline{p}$, and $\overline{p} > \underline{p}$. The cost of self-protection is denoted by $c_i(e_i)$, $c$ being characterized by $c_i'(.) \geq 0$. Given $e_j$, agent $i$ maximizes

$$\begin{aligned} U_i(e_i, e_j) = [1 - p(e_i)][1 - p_j(e_j)]y^H + p_i(e_i)p_j(e_j)y^L \\ +[1 - p(e_i)]p_j(e_j)\left(\frac{y^L + y^H}{2} + \frac{\gamma_i}{2}\right) \\ +p_i(e_i)[1 - p_j(e_j)]\left(\frac{y^L + y^H}{2} - \frac{\gamma_j}{2}\right) \\ -[1 - p_i(e_i)]p_j(e_j)\beta_i v(\gamma_i) \\ -p_i(e_i)[1 - p_j(e_j)]\alpha_i v(\gamma_j) \\ -c_i(e_i) \end{aligned} \tag{4.16}$$

The first-order condition is

$$-p_i'(e_i)\left[\frac{\Delta}{2} + \frac{\gamma_j}{2} + \frac{\gamma_i - \gamma_j}{2}p_j(e_j) - [\beta_i v(\gamma_i) + \alpha_i v(\gamma_j)]p_j(e_j)\right] = c_i'(e_i) \tag{4.17}$$

With symmetric agents this reduces to

$$-p_i'(e_i)\left[\frac{\Delta}{2} + \frac{\gamma_j}{2} - (\alpha + \beta)v(\gamma)p_j(e_j)\right] = c_i'(e_i) \tag{4.18}$$

Under continuous prevention efforts strategic complementarity still holds: if $p(.)$ and $c(.)$ are convex, then prevention efforts are strategic complements. Indeed, differentiating the first-order condition with respect to $e_j$, we get

$$\begin{aligned} -e_i^{*'}(e_j)p_i''(e_i^{*'}(e_j))\left[\frac{\Delta}{2} + \frac{\gamma_j}{2} - (\alpha + \beta)v(\gamma)p_j(e_j)\right] \\ +p_i'(e_i^{*'}(e_j))p_j'(e_j)\big(\alpha + \beta\big)v(\gamma) - e_i^{*'}(e_j)c_i''(e_i^{*}(e_j)) = 0 \end{aligned} \tag{4.19}$$

Rearranging terms,

$$e_i^{*'}(e_j) = \frac{p_i'(e_i^{*'}(e_j))p_j'(e_j)\big(\alpha+\beta\big)v(\gamma)}{c_i''(e_i^*(e_j)) + p_i''(e_i^{*'}(e_j))\left[\frac{\Delta}{2}+\frac{\gamma_j}{2}-(\alpha+\beta)v(\gamma)p_j(e_j)\right]} > 0 \tag{4.20}$$

It is not ensured however that multiple equilibria arise. In particular, for linear probabilities and quadratic cost, it is not the case.

# General Conclusion

This thesis has analyzed several aspects of the economics of insurance and prevention markets and the role of public policy.

Chapter 1 has considered the problem of optimal risk prevention in agricultural markets. Following the literature on agricultural policy analysis under incomplete markets, we have considered a closed economy with two exchanged goods, food and the numeraire, and a competitive farm sector and a representative consumer-taxpayer. Farmers face a systemic risk they can reduce through a prevention technology available at an exogenous unitary price. We have shown that at the market equilibirum, risk prevention decreases with the representative farmer's coefficient of risk aversion. This is in line with the idea of natural hedge: price shocks compensate yield losses and thus protect the farmer's revenue. For a price-inelastic demand, income risk increases with prevention for a price-taker farmer. We have also characterized the socially efficient level of prevention and compared it with the market outcome. We have shown that underprevention is likely to occur in conditions that are typical of agricultural markets, i.e. low price and income elasticities of demand, risk averse farmers and risk-averse consumers. We have also shown the existence of a Pareto improving prevention subsidy financed by the representative consumer-taxpayer. With such a programme, yield risk, thus price risk are reduced at the socially optimal levels. Because he is risk-averse, the consumer-taxpayer has a propensity to pay for reducing price risk. Similarly, the risk-averse farmer also benefits from risk reduction. The programme has redistributive consequences that are managed by the government through lump-sum transfers. At last, we have discussed the consequences of opening trade on risk prevention choices in the case of symmetric countries, and shown two countervailing effects: on the one hand, opening trade reduces the expected profit from prevention, on the other hand it eliminates the natural hedge and so exposes farmers to production risk, inciting them to invest more in prevention.

# GENERAL CONCLUSION

Chapter 2 has dealt with pricing and capital choices of re(insurance) firms in the oligopoly context. Considering a line of risk displaying aggregate risk and risk-averse insurers due to costly external finance, we have built a two-stage game to analyze the strategic choices of price and capital. At the first stage, (re)insurance firms choose their levels of internal capital, at the second stage they compete in price. Having characterized the subgame-perfect equilibria of this game, we have demonstrated the existence of multiple capital equilibria. Moreover, we have shown that each capital level leads to multiple price equilibria. We have analyzed this multiplicity, which finds its origin in the reluctance of risk-averse firms to catch a whole market that is characterized by aggregate risk. This prevent firms to cut price for the set of price equilibria, each firm having a greater value equal market sharing than under monopoly. For a given anticipated second-stage equilbrium price, the first stage capital choice results from a trade-off that includes three terms: the marginal direct benefit from reducing the cost of risk, the marginal cost of capital, and a strategic term. We have shown that this strategic term is itself the sum of two terms: the strategic wealth effect and the strategic demand effect. This can be explained as follows. By increasing its level of internal capital, a deviant firm commits to be able to catch to whole market for a lower price, i.e. to be more agressive at the second stage. A lower price means lower expected profit, which decreases the value of the firm (strategic demand effect) and increases the firm's cost of risk because of a wealth effect (strategic wealth effect). Analyzing this three terms trade-off, we have shown that multiple capital equilibria arise. For each of this equilibrium, a positive deviation is not profitable because the marginal strategic and direct costs of capital more than offset the marginal direct benefit from reducing the cost of a risk. A negative deviation is not profitable because the marginal direct benefit from risk reduction is greater than the marginal cost of capital. Finally, we have characterized the second-best (without price control) socially optimal level of capital, and have shown that undercapitalization may occur. We have thus proposed an alternative view for capital regulation on competition grounds. Capital regulation can increase social welfare, in particular consumers' welfare through its impact on price competition.

In chapter 3 we have conducted an empirical investigation of the determinants of insurance demand and pesticides use for a sample of French farmers. We have underlined the importance of understanding farmers' risk management decisions in the current context of agricultural policy reforms and trade liberalization. First, because of policy reforms the need for insurance may increase in the future, raising the issue of insurability for several climatic risks in the sector. Second, insurance, as well as other risk management tools (futures markets, savings), can interact with farmers' production decisions that often include risk management motives: crop diversification, the use of risk-reducing inputs (pesticides, irrigation water, drought-resistant seeds etc.) and have in turn impact on agricultural markets and the environment. In this chapter we tackle these issues by the mean of an empirical analysis that focus on two important risk management tools in our region study: insurance and pesticides. We have first recalled some theoretical predictions concerning the factors influencing insurance demand and the mechanisms which make insurance and pesticides use decisions interdependent. Several results emerge from the empirical analysis. First statistical tests have shown that insurance demand and pesticides use are simultaneouly determined. We have thus estimated an econometric model involving two simultaneous equations with mixed censored/continuous dependent variables for rapeseed. Estimation results have shown that the relation between insurance demand and pesticides is positive, but has a rather small magnitude. We have also characterized the statistically significant variables that influence insurance demand and evaluated their magnitude by computing elasticities. We have found them in line with theoretical predictions for the statistically significant variables: insurance demand decreases with CAP subsidies (wealth effect), activity diversification (diversification effect), increases with yield risk and the loss ratio. The two first variables exhibit the highest values for elasticity (respectively -0.192 and -0.161). This has interesting implications for agricultural policy, although one should be cautious in the interpretation of our results. First, CAP subsidies seem to decrease insurance demand, supporting the view that crop insurance programmes and agricultural income support should not be analyzed separately. Second, our results suggest that less diversified and more risky farms should be more concerned by crop insurance programmes. Other aspects of our results concern environmental policy. We have found a positive and significant but rather modest relation between insurance demand and pesticide use. This suggests that environmental policies aiming at limiting pesticide use should to a certain extent interact with crop insurance programmes.

Chapter 4 has analyzed the role of inequity aversion on prevention decisions. Following the growing strand literature that intents to incorporate social preferences into economic models, we have reconsidered the Samaritan's Dilemma game in the case of inequity averse preferences. We have thus considered an economy composed by two symmetric risk-neutral, inequity-averse agents that produce a risky output, with a costly prevention activity that increases the probability of high output. We have analyzed the following two-stage game: at the first stage each agent chooses a level of prevention, at the second stage, transfers driven by inequity aversion are made from the lucky to the unlucky. Our results are twofold. First we have shown that for intermediate prevention costs, multiple equilibria may arise. This is explained by the nature of inequity aversion preferences, that makes prevention choices strategic complements. Second, the usual underprevention result may occur for a given set of parameters, but can be mitigated by aversion to unfavourable inequity. Finally, we have discussed the potential role of a mandatory prevention fund that would increase social welfare.

These chapters have shed some new light on several issues of insurance and prevention markets, and suggest research extensions. Chapter 1 could be extended by a more profound analysis of risk prevention choices in the context of trade, in particular the determination of optimal government policies in a context of free trade. Chapter 2 could also be extended in several ways. First, it could be interesting to include several lines of risks instead of a single one, and take into account correlations across lines. Second, including reinsurance contracts as an alternative way to cope with risk would also enrich the analysis. Chapter 3 has raised important issues for agricultural and environmental policy making. A first natural extension of this analysis could consist in building a structural model in order to reach a simultaneous estimation of technology and preferences. This would facilitate the comparison with other studies based on structural models. A second extension would be to include a larger set of risk management decisions. In addition to pesticide use and insurance for all crops, acreage decisions could be included as a choice variable. Chapter 4 could be deepened in several ways: considering more general technologies, including asymmetric information between individuals, and correlated risks.

# Résumé

This thesis consists in four independent essays on insurance, prevention and public policy. Chapter 1 investigates the issue of prevention in a partial equilibrium, competitive agricultural economy with incomplete state-contingent claims markets. Under typical assumptions for agricultural markets (low price and revenue elasticities, risk aversion), it is shown that underprevention is likely to occur at the market equilibrium and can be corrected through a government prevention subsidy. Chapter 2 analyzes prices and internal capital choices of insurance firms in an oligopoly context. Considering a two-stage game with capital choice followed by price competition, it is shown that capital has a strategic cost for firms, leading to an equilibrium level of capital that is lower that the social optimum. The rationale for capital regulation is discussed in this imperfect competition context. Chapter 3 is an econometric analysis of insurance demand and pesticide use based on an original panel dataset of French farms of Meuse covering the period from 1993 to 2004. Results show that insurance and pesticide decisions are simultaneously determined and allow to characterize the explanatory variables that drive these choices. These results are put into perspective in the context of current agricultural policy reforms. Chapter 4 studies the influence of social preferences on prevention choices using a Samaritan's dilemma model in the case of mutually inequity averse agents.
Keywords : Prevention, Insurance, Public Policy.

Cette thèse propose quatre chapitres indépendants sur l'assurance, la prévention des risques, et les politiques publiques associées à ces marchés. Le chapitre 1 s'intéresse au choix de prévention dans un marché agricole en équilibre partiel dans un contexte de marchés contingents incomplets. Sous des hypothèses typiques de ces marchés (faibles élasticités prix et revenu, aversion au risque), il est montré que l'équilibre concurrentiel se caractérise par un niveau de prévention inférieur à l'optimum social. Cette sous-prévention peut être corrigé par une aide publique à la prévention. Le chapitre 2 analyse les choix de prix et de capital interne des firmes d'assurance dans un contexte d'oligopole. Considérant un jeu à deux étapes avec choix de capital puis concurrence en prix, il est montré que le capital interne a un coût stratégique pour les firmes, ce qui conduit à un niveau de capital à l'équilibre inférieur à l'optimum social. La régulation publique du capital est rediscutée dans ce contexte de concurrence imparfaite. Le chapitre 3 est une analyse économétrique de la demande d'assurance et de pesticides menée sur un panel non cylindré d'exploitations agricoles françaises de la Meuse sur la période 1993-2004. Les résultats mettent en évidence la simultanéité des choix d'assurance et de pesticides et permettent de caractériser les variables explicatives de ces choix. Ces résultats sont mis en perspective dans le contexte actuel des réformes des politiques agricoles. Le chapitre 4 s'intéresse à l'influence des préférences sociales sur les choix de prévention dans le cadre d'un modèle de dilemme de Samaritain sous l'hypothèse spécifique d'agents présentant une aversion mutuelle à l'inégalité.
Mots-clés : Prévention, Assurance, Politiques Publiques.