Insurability

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Abstract

The events of September 11 have raised again the questions of the limits of insurability by the market and of the importance of insurance for the efficient functioning of our economies. In this paper, we examine the sources of the uninsurability problem in general and in particular for the so-called "new risks", and we make policy recommandations for public intervention.

1 Introduction

The possibility to share risk is a cornerstone of our modern economies. Because risk-sharing allows for risk-washing through diversification, it is useful for risk-averse consumers. It is also essential for entrepreneurship. Without risk transfers, who could have borne alone the risk to build skycrapers and airplanes, to invest in R&D, or to drive a car? Historians have well documented the role of private risk sharing devices in the development of trade in the middle ages, in particular in the case of sea transport. The successes of the Netherland in the seventeenth century and of the England in the eighteenth century are strongly correlated with the emergence of financial markets and insurance companies in those countries. The prohibition of insurance companies in France during the same period is one of the explanations for the late starting of the industrial revolution there.[1] The importance of risk-sharing has recently been restated when insurance markets have been on the verge of collapsing after the events of September 11.

The adverse consequences of the limits to insurability are overwhelmingly underestimated. The management of risks and the management of production cannot be disentangled. It forces small entrepreneurs to bear the risk linked to their investment. It yields a reduction in investment, employment and growth. In addition, the inability of our economies to efficiently transfer risks affecting human capital forces households to bear a larger risk over their lifetime. Given risk aversion, it has a sizeable adverse effect on welfare. This provides an alternative view to the conclusion reached by Lucas (1987) that if society allocates risk efficiently, the social cost of risk is negligible.

There are several ways to share risk in Society. Historically, before the emergence of a market economy, risk were shared within families or small rural communities. This is still the case in various developing countries, as documented by Townsend (1994), Ogaki and Zhang (2001) and Attanassio (2001)). Private contracts usually entails several risk-sharing clauses. The most obvious one is limited liability. Long-term labor contracts, cost-plus industrial contracts and fixed-rate credit contracts are a few examples of such risk-sharing devices. Stocks and bonds are the tradable version of them. But the insurance contract is the one for which the transfer of risk is the essence

[1] See Bernstein (1997) and Baskin and Mirandi (1997) for a short description. Le Goff (1956) gives more details.

of the exchange.

The standard economic model of risk exchanges predicts that competition on insurance markets leads to a Pareto-efficient allocation of risks in the economy. In particular, it states that all diversifiable risks in the economy will be washed away through mutual risk-sharing arrangements. All risks will be pooled in financial and insurance markets. Moreover, the residual systematic risk in the economy will be borne by the agents who have a comparative advantage in risk management, as insurers and investors. In short, it means that all individual risks are insured. This prediction is obviously contradicted by casual observations. Many diversifiable risks are still borne by individuals. Indeed, individual consumption levels are not perfectly correlated in the population, i.e., for every shock in the economy, they are "winners" and "losers". This is the expression of an inefficient risk sharing ex ante. To illustrate, most of the risks related to human capital, as long-term unemployment and fluctuations to labor incomes, cannot be insured. Many environmental, catastrophic and technological risks are not covered by an insurance contract. Risks linked to terrorism may be difficult to insure.

The possibility to transfer a risk to the market place is contingent upon whether the buyer is ready to pay a larger price than the minimum price at which the seller is ready to sell. Consequently, the concept of a limit to insurability cannot be defined only on the basis of the distributional characteristics of the risk, but it should also take into account the economic environment. Berliner (1982) enumerates the criteria to define insurability. The actuarial view on this problem is usually summarized by stating that a risk is insurable if the Law of Large Numbers may be applied. It means that the maximum potential loss may not be infinite, or very large. Similarly, risks should not be too much positively correlated. In addition, the risk must exist: a realized risk cannot be insured. The legal environment must be stable, or predictable. Finally, an objective distribution function should be subject to quantification.

This definition is not entirely satisfactory. The actuarial view on the limits of insurability appears to be too narrow. After all, the Lloyd's accepted to underwrite the risk of the capture of the monster of Loch Ness, and more standard insurance companies cover the risk of failure of Ariane V, the new European satellite launcher on which no data is available. Moreover, many risks on which the Law of Large Numbers could be used are beyond the limits of insurability. One cannot find insurers that would accept the risk of the absence of promotion, or of divorce.

As said before, a transaction on the market is possible if the two parties are willing to transfer the underlying "good" against a specific price. This joint willingness can exist only if the seller and the buyer find it advantageous to exchange. We define a risk as being uninsurable if, given the economic environment, no mutually advantageous risk transfer can be exploited by the consumer and the suppliers of insurance. Partial uninsurability occurs when the parties can exploit only part of the mutually advantageous transfer of risk. Whether there exists a mutually advantageous risk exchange between the two parties is an interesting question that has been examined by several authors as Arrow (1965), Borch (1962) and Raviv (1979). The basic model is a perfect competitive insurance market in which it clearly appears that indeed the Law of Large Numbers plays an important role to evaluate the social surplus of the transfer of risks. But, contrary to the standard actuarial view, the maximum potential loss and the probability of loss have an ambiguous effect on the size of the transfer of risk at equilibrium. In addition some factors as the degree of risk aversion of the agent , or her degree of optimism, are crucial in the insurability of risks in the economy.

The objective of this paper is to provide some insights on the recent developments on the economic analysis of the limits of insurability. There is no unified theory for it. Rather, there are a large set of economic reasonings explaining why some risks cannot be insured on the marketplace. All of them are related to a modification of one of the assumption in the Arrow-Borch standard model of perfect competition on insurance markets. Perfect competition is indeed a poor assumption for describing the insurance sector. First, it has long been recognized that the existence of asymmetric information is central to its functioning. Adverse selection and moral hazard can explain why competitive insurance markets fail to provide an efficient level of insurance. Specialists in this field focused their research in the recent years to the problem of insurance fraud, a special case of moral hazard. The risk of fraud is another explanation for the reluctance of insurers to provide coverage for some risks. The effects of asymmetric information on the functioning of insurance markets are examined and measured in Dionne (2000). We also examine the limited liability rule which introduces another distortion in the form of negative externalities to victims.

We provide some insights about the well-known uninsurability problem due to the fact that some risks may not have an objective probability distribution. The ambiguity of the distribution seems to be the rule rather than the exception in our fast-moving, heterogeneous world. We also look at the dynamic aspects of insurance contracts.

2 The economics of diversifiable risk sharing

2.1 The mutuality principle

Consider a static exchange economy of n agents. They are assumed to be strongly averse to risk, i.e., that they dislike mean-preserving spreads in the distribution of their final wealth. Uncertainty is characterized by S states of nature indexed by $s = 1, ..., S$. At this stage, we assume that there is an agreed-upon probability distribution over the possible states of nature. Let p_s denote the probability of state s. Let also ω_{is} denote the endowment of the single consumption good of agent i in state s. Total wealth in state s is denoted $\omega_s = \sum_{i=1}^{n} \omega_{is}$. An allocation of risk is defined as a matrix

$$(c_{is})_{\substack{i=1,...,n \\ s=1,...,S}}$$

where c_{is} is the consumption of agent i in state s. It is feasible if $\Sigma_{i=1}^{n}(c_{is} - \omega_{is}) = 0$ for all s. A feasible allocation of risk is efficient if there is no other feasible allocation that makes at least one agent better off without making the others worse off.

We now prove the following Proposition, which is known as the mutuality principle.

Proposition 1 *Any efficient allocation of risk is such that if they are two states (s, s') such that $\omega_s = \omega_{s'}$, then $c_{is} = c_{is'}$ for all $i = 1, ..., n$.*

Proof: To keep the notation simple, let us suppose here that $n = 2$. Suppose by contradiction that they are two states (s, s') such that $\omega_s = \omega_{s'}$, $c_{1s} = c_{1s'} + \delta$, with $\delta > 0$. This implies that $c_{2s} = c_{2s'} - \delta$. Consider an alternative allocation $(\widehat{c})$ such that, for $i = 1, 2$,

$$\widehat{c}_{it} = c_{it} \text{ for all } t \neq s, s'$$

$$\widehat{c}_{is} = \widehat{c}_{is'} = \frac{p_s c_{is} + p_{s'} c_{is'}}{p_s + p_{s'}}.$$

Obviously, this alternative allocation is feasible, and it provides the same expected wealth levels than in the initial allocation. Moreover, the alternative allocation is less risky than the initial one, as it yields a mean-preserving contraction of final wealth levels in the sense of Rothschild and Stiglitz (1970) for the two agents. Thus, the initial allocation may not be efficient. ■

If there are two states with the same stock of the good in the economy, each agent consumes the same amount of it in these two states. Under the mutuality principle, all resources are mutualized in a common pool, and the allocation of consumption in a given state depends only upon what is available in the pool in that state, not upon the distribution of the contributions to the pool in that state. The proof of the mutuality principle is self-explanatory and intuitive. The mutual agreement organizes the diversification of all diversifiable risks.

All states with the same average wealth leads to the same allocation of consumption. In a decentralized economy, competition on Arrow-Debreu markets generates this allocation by yielding actuarially fair prices to transfer wealth from state s to state s'. As is well-known, competitive financial markets do not generate any positive expected excess return for risky assets that can diversified in individual portfolios. That implies in particular that competitive insurers actuarially price those risks. It implies in turn that all risk-averse consumers will fully insure their specific individual risk. In short, the above Proposition means that all diversifiable risk are washed away at equilibrium.

Notice that up to now we did not make any assumption on preferences, except that people dislike mean-preserving spreads in the distribution of their final wealth. A special case is expected utility with a concave utility function.

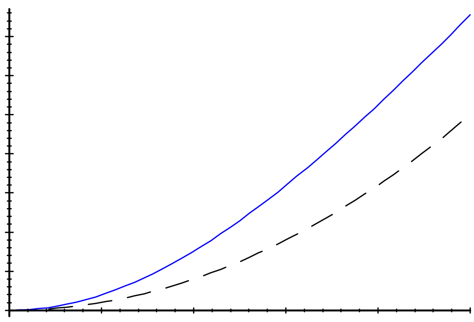
There is no doubt that this principle is violated in the real world. Most people bear risks that could be diversified in the economy. For example, real wages are not indexed on the GDP, and it is difficult to insure this risk, either on financial markets, or on insurance markets. Townsend (1994) tried to test whether the mutuality principle holds in three poor, high risk villages in Southern India. He used panel data of individual consumptions. Without surprise, he rejected the model of efficient risk sharing in the economy as a whole, but he found that individual consumptions comove positively with village average consumption. More significantly, he found that individual consumptions are not much influenced by individual-specific events like sickness and unemployment. This indicates that some forms of Pareto-improving risk-sharing is organized inside each village.

2.2 The social cost of uninsured risks

In order to measure the social cost of the inefficient allocation of diversifiable risks, let us consider the following simple numerical example. Consumers are identical and are expected-utility maximizers with a CRRA utility function $u(c) = c^{1-\gamma}/(1-\gamma)$. They face an idiosyncratic risk of losing or gaining k percents of their wealth with equal probabilities. Assuming that the size n of the population is large and invoking the Law of Large Numbers, these risks are diversifiable through mutualization. Suppose that, for some reasons that will be examined latter in this paper, individual risks cannot be transferred to the market. In such a situation the social cost per capita for this uninsurability problem can be measured by the risk premium $\pi(k,\gamma)$ associated to this risk. It is implicitly characterized by the following formula:

$$0.5u(1-k) + 0.5u(1+k) = u(1-\pi),$$

where initial wealth has been normalized to unity. In Figure 1, we draw π as a function of the size of risk k for constant relative risk aversion $\gamma = 2$ and $\gamma = 4$, which are within the range of acceptable values of risk aversion.



The social cost of risk of size k, in percent of the GDP per capita. The upper (lower) curve is for $\gamma = 4$ ($\gamma = 1$).

What can we learn from this exercise? If we take an idiosyncratic risk of losing or gaining 25% of the GDP per capita with equal probabilities, the social cost of having this risk uninsured is π =6.25% of GDP/cap if $\gamma = 2$, and π =11.47% if $\gamma = 4$. Notice also that the social cost of uninsurability is convex in the size of risk. As is well-known from the Arrow-Pratt approximation, it tends to zero with k as k^2. This means that risk aversion is a second-order phenomenon, as defined by Segal and Spivak (1990). The absence of insurance really matters only for large risks at the individual level, as long-term unemployment, chronic diseases, professional liability, and so on.

2.3 Transaction costs

Contrary to what we assumed above, providing insurance is a costly activity. The insurer, public or private, must cover administrative costs linked to the monitoring of individual insurance policies. It must control for ex ante and ex post moral hazard. That entails in particular expensive audits of large claims. In addition, private insurers face the problem of adverse selection. They must invest in costly efforts to screen their customers. On their side, public insurance programs face the social cost of public funds induced by the distorting effect of taxes. It is commonly suggested that all this yields a 30% loading factor for insurance pricing. In other words, insurers must have a loss-to-premium ratio that does not exceed 0.7 in order to break even on average.

When insurance is costly, the choice of the level of coverage is not a simple matter. Arrow (1963) and Mossin (1968) were the first to examine this question in a simple static model. Mossin (1968) showed that it is never optimal to purchase full insurance when insurance policies are not actuarially priced. Consider an agent who purchased a full insurance contract and who contemplates the possibility to switch to a policy yielding a small retention. The benefit of switching comes from the reduction of the deadweight insurance cost. The cost of switching comes from the risk premium linked to the retained risk. As seen in Figure 1, the risk premium increases from zero as the square of the size of the retained risk. Thus, the marginal cost of retaining a small share of the insurable risk is zero. In consequence, given the positive marginal benefit of risk retention, no expected-utility-maximizer consumer should purchase full insurance.

Arrow (1963), showed that the optimal form of risk retention is given by a straight deductible. The optimality of a straight deductible is the expression of the relevance of insurance for large risks. Small risks, i.e. risks whose largest potential loss is less than the optimal deductible should not be insured. I am willing to purchase insurance against the important risk for my kids and unemployed wife in case of my premature death. I am willing to purchase insurance for my house, which is my largest asset at this time. Given the cost of insurance, I am not willing to purchase insurance against the risk of broken glasses, or even against damages to my old car. I would be ready to bear the risk of paying for standard medical care, but I would like to get a large indemnity from my insurer in case of a costly surgical procedure. This is exactly what a policy with straight deductible provides! Drèze (1981) estimated the optimal level of deductible in insurance. It is a decreasing function of risk aversion. If we accept a range $[1, 4]$ for relative risk aversion, Drèze concluded that the optimal level of deductible should be somewhere between 6% and 23% of the wealth of the policyholder.

2.4 Adverse selection

In the classical model, it is assumed that all agents share the same information about the likelihood of the various states. This allows for an heterogeneous population as long as the characteristics of the risk borne by each agent is common knowledge. For example, the fact that women are safer drivers than men is compatible with full insurance of every driver at the competitive equilibrium with a risk-neutral insurance industry. The premium rate for every category of risk will be fair, thereby inducing each individual to purchase full insurance at the optimum.

A problem arises when the population is heterogeneous, but the observable characteristic of the agents are not perfectly correlated to the intensity of their risk. The adverse selection problem initially pointed out by Rothschild and Stiglitz (1986) originates from the observation that if insurance companies calculate the premium rate on the basis of the average probability distribution in the population, the less risky agents will purchase less insurance than riskier agents. In the extreme case, the low-risk agent will find the premium rate too large with respect to their actual probability of loss. They will prefer not to insure their risk. Insurers will anticipate this reaction, and they will increase the premium rate to break even only on the population of high-risk policyholders.[2] The presence of high-risk agents generates a neg-

[2]The litterature on adverse selection is devoted to characterizing an equilibrium. In-

ative externality to lower-risk agents who are unable to find an insurance premium at an acceptable premium rate. To illustrate, this is probably why the proportion of households that purchase life insurance is so small, despite the potential severity of the risk. People have private information about their health status that cannot be observed by insurance companies. Then, only those with the lowest life expectancy purchase life insurance. Finkelstein and Poterba (2000) provided evidence on the importance of adverse selection in the insurance markets for annuity policies. More specifically, they showed that policyholders who purchase policy with a payment from the annuity that rise over time are less likely to die early.[3]

The policy recommendation that is relevant to reduce adverse selection is to make public all relevant information about risks. For example, insurers should be allowed to know whether the potential policyholder has some severe illness. They should also be allowed to use genetic testing. Insurance companies should also be allowed to pool their information. In France, genetic testing has been prohibited by the pool of insurance companies. Asking questions related to AIDS is prohibited by law, together with pooling information with other insurance companies or banks. Clearly, there are ethical reasons for that. Another standard argument is that if this type of information is public information, then high-risk individuals would face an insurability problem. The above analysis shows why this argument is wrong. Indeed, this is not because the premium rate is high that the risk is not insurable. As long as the premium rate corresponds to the intensity of the risk, there is room for insurance. Quite to the contrary, by prohibiting discrimination or public information, one artificially increases the premium rate of lower-risk agents, thereby introducing an insurability problem of the type described above for low risks.

There is a European syndrome for forcing the insurance sector to redistribute wealth among different categories of risk through the prohibition of discrimination. This is particularly obvious for risks related to human capital (unemployment, health, life). This is also true for natural disasters (uniform

surers will use the fact that low-risk agents and high-risk agents behave differently in the face of a large set of insurance contracts. In particular, low-risk agents could credibly signal their type by selecting a contract with a large deductible, something that high-risk agents dislike.

[3] Chiappori and Salanié (2000) did not find evidence of adverse selection in the automobile insurance market.

pricing in France), automobile, environmental risks,.... Our claim is that the regulator has underestimated the cost generated by the adverse selection problem that this policy induces.

2.5 Ex ante moral hazard

The population of risks can be heterogeneous not only because agents bear intrinsically different risks, but also because they do not invest the same amount of their energy, wealth, or time to risk prevention. In particular, it has long been recognized that individuals that are better covered by insurance invest less in risk prevention if the link between the premium rate and the size of these investments is weak. It will be the case if insurers are not in a position to observe the investment in risk prevention by the insuree. In that case, the premium rate is not sensitive to the effort made by the policyholder to prevent losses. Obviously, contrary to the result of the classical model, there will be an inverse relationship between risk prevention and insurance coverage. The level of risk prevention will be inefficient. This is ex ante moral hazard. Anticipating this low degree of prevention and the higher frequency of losses that it entails, insurers will raise their premium rate. Full insurance will not be optimal for agents. At the limit, no insurance can be an equilibrium.[4] To illustrate, this is why it is not possible to insure against promotion at work, about failure at school or university, about the lack of demand for a new product, or about divorce. In some extends, this is also why it is hard to insure against unemployment, or against environmental and technological risks.

The policy recommendation to fight against ex ante moral hazard is the enforcement of norms for risk prevention. This is the case for environmental risks in which ships transporting chemical products have to satisfy several safety requirements that are imposed by regulatory agencies. Automobile driving norms are also standard, as speed limits, alcohol-free driving,.... Why these norms are mostly organized by a regulatory agency rather than by insurers is not completely clear. One reason is due to the combination of negative externalities and limited liability. If they are more than one principal supervising the implementation of norms, the information among the

[4] Holmstrom (1979) characterized the equilibrium insurance contract with ex-ante moral hazard.

different principals should be pooled to save on monitoring costs. For example, auto insurers should be allowed to get the information about driver fines by the police. This is not allowed in France.

Another policy recommendation is to allow insurers to discriminate prices among different policyholders. Allowing for discrimination is a way to provide incentive to policyholders to invest in risk-reducing activities. In France again, insurers are not allowed to discriminate premium rate for natural risks. The consequence are by now obvious: many households built their house in areas that were secularly known to be flooded periodically. The absence of actuarial insurance pricing was supposed to be counterbalanced by the imposition of strict norms for where to build houses. But these norms have never been written...

2.6 Ex post moral hazard

Ex post moral hazard relates to the risk of fraudulent claims. We assumed in the classical model that the size of the loss was observable. There are many instances in which this is at best a crude approximation of the real world. Contracts can be made contingent only upon observable events. The problem here is to give the good incentives to the policyholder to report her actual loss. The inability for insurers to verify claims is at the origin of why it is not possible to insure against loss of happiness, or against some forms of sufferings that cannot be measured by physicians. Weisberg and Derrig (1991) and Dionne and Gagné (2000) measure the intensity of fraud in automobile insurance.

There exist other types of risk for which outcomes can be observed by the insurer only at a relatively high auditing cost. Townsend (1979), Mookherjee and Png (1989), Picard (1996, 1998) and others analyzed the optimal risk-sharing scheme in this case. If there is no limit on the penalty that can be imposed to policyholders that do not declare the actual level of their loss, the first-best solution can be attained. Indeed, insurers should announce that they will audit claims with some probability p that is very low. If the insuree made a fraudulent claim, a $+\infty$ penalty ("death penalty") is imposed to him. This is enough to give the good incentive not to fraud on the insurance contract, even if p is very small. In this case, the fact that there is costly claim verification is not detrimental to welfare, and the risk is insurable in full.

But there are several reasons to believe that an infinite penalty in case of a fraudulent claim is not a realistic assumption. There are ethical reasons why an infinite penalty is not acceptable by Society. Also, there is limited liability. Finally, insurers and third parties may often observe the size of the loss only with an error when auditing. The risk of error could well induce the insurer to punish a policyholder who reported his loss correctly. Ex ante, it is then Pareto-efficient to limit the size of the penalty. In order to report her loss correctly, the insurer will have to audit claim at a high frequency. This entails additional costs on the insurance contract. If the auditing cost is high, or if the frequency of audit necessary to give the good incentive for the policyholder to reveal the truth is too high, consumers would be better off by not insuring the risk. Notice that another way to reduce the willingness to submit a fraudulent claim is to limit the indemnity. The maximal indemnity that is compatible with truth-telling is an increasing function of the penalty and of the probability of audit. Consumers would like to announce ex ante that they will not submit fraudulent claims ex post. That would allow insurers to save the audit cost, thereby reducing the equilibrium premium rate, but the announcement is not credible.

Is ex post moral hazard an important problem? It is often suggested that the cost of fraudulent claims may well amount up to 10% of premiums paid for some insurance lines as automobile insurance or homeowner insurance. This estimation is just about paying unjustified indemnities to policyholders, not the auditing cost to fight against fraud. This percentage is comparable to the rate of transaction costs, whose effects on insurability has been previously examined.

The policy recommendation is clear from the discussion above: one should impose larger penalty to policyholders that have been convicted of a fraudulent claim. Several countries in Europe have been weak in this area, recognizing fraud as a "national sport" that should be forgiven. By doing so, the legal system imposes a large cost to Society in terms of a loss of insurability. This weakness has been particularly clear for insurance lines where the indemnity payer does not have the good incentives to be though on fraud. For example, one may question about whether European social security organizations are fighting fraudulent claim efficiently. This yields a general distrust to the system, which is detrimental to unemployed themselves. Also, successive governments in France publicly ordered insurance companies to be "generous" with their policyholders every time a natural disaster occurred.

The same effect is also apparent about agricultural mutuals, funded by the taxpayers in France, to provide indemnities without audit. The capture of the regulator in charge of indemnifying victims generates an important loss of efficiency in the allocation of risks.

2.7 Limited liability

An individual can cause a damage to others, either in the course of his/her profession (medicine, surgery, house-building,...) or because of other activities (e.g. driving a car). The same kind of external random effect occurs for firms. In most countries, the agent found liable to a damage to others must indemnify them accordingly. This is done to force decision makers to internalize all costs generated by their choice. However, indemnification is possible only up to the decision maker's financial capacity. Limited liability is a way to protect risk-takers against an excessive financial distress. But it has long been recognized that limited liability distorts the decision of the risk-taker in a way that is socially inefficient. The US Saving and Loans crisis is often explained by the fact that "zombie" S. and Ls adopted in the early eighties a very risky attitude in an attempt to "bet for resurrection" after some blows on their portfolio of (real estate) assets. This is because limited liability gives the agent the equivalent of a free put option. Put it in simpler terms, under limited liability, an insolvent agent can only benefit from taking more risk, because he does not bear the burden of losses. Therefore, if he is risk-neutral, he will seek to maximize the expectation of a convex function of his wealth. As a result, he will systematically exhibit a risk-loving behavior, and adopt a very risky attitude. This is a kind of moral hazard problem. Risk aversion mitigates this result, but only for agents who are well capitalized, as shown by Gollier, Koehl and Rochet (1996).

The effect of limited liability of the policyholder on his demand for insurance is thus unambiguous: if he is risk-neutral, it is never optimal to cover a risk of loss, even in the most favorable case where the premium rate is fair. Insuring the risk would yield a sure reduction in wealth equaling the expected loss. Not insuring the risk would yield an expected reduction of wealth that is less than it, since the agent bears only part of the risk of loss. Another way of looking at this problem is that the insurance contract create a "deep pocket" where victims can find compensation for their losses. This kind of problem is particularly crucial when examining the demand of insurance by firms for environmental risks. Limited liability on the part of the insurer also reduces the demand of insurance, since it makes the indemnity dependent to the its solvency.

Limited liability thus raises several important questions. How to organize compensation for those who bear the negative externalities? How to build an incentive-compatible mechanism that increases loss prevention by decision makers with limited liability? How to solve the market failure of liability insurance markets? How to force firms not to under-capitalize their subsidiaries which are in charge of managing the riskiest part of the business? Two routes have been used. The first one is compulsory insurance. This solves the misallocation of risk in the economy and the organization of a system to compensate the victims. But, most of the time, compulsory insurance has been funded by a flat, non-discriminatory, non-incentive-compatible insurance tariff. The policyholder's investment in loss prevention is not observed by the fund, either because it is difficult to get information on it, or because the fund did not get the good incentive to organize an incentive-compatible system.

The second route has been to organize "deep pocket" for decision makers. It means for example that the hospital who employs an uninsured physician will be made liable in case of the physician's insolvency. Under the US CERCLA, when a bank has been relatively closely involved in the monitoring of a firm's activities, it may be considered by the courts as liable for cleaning up the environmental damages generated by the insolvent firm. The objective of this strategy is to force risk-takers to internalize the full cost of potential losses: the hospital will reduce the income of the careless physician, and banks will increase the loan rate of riskier firms. If there is no asymmetric information between the principal (the hospital, the bank) and the agent (the physician, the firm), the agent will select the socially efficient level of care and insurance. There would be no more insurability problem. But, as observed by Boyer and Laffont (1995), there is no reason to believe that the principal can monitor the agent at no cost. The CERCLA legislation, for example, introduces more asymmetric information on credit markets. Consequently, there will be more credit rationing, the cost of capital will be larger, and the structure of banking contracts for firms will be affected. Is insurability worth this cost?

2.8 Realized risks

In many circumstances, risks borne by agents are not independent through time. For example, my health status tomorrow is affected by my health status today. Thus, health insurance will be more expensive for people with a poor current health. The extreme form of this is a "realized risk" in which the evolution of the random variable in the future became deterministic, given the current situation. Obviously, there exists no mutually advantageous risk transfer in this case. In short, one cannot insure a risk ex-post.

External information on the scale of a risk can yield the same effect. Genetic testing will soon inform us about the evolution of our health. If this information is made available to the market, the scope of insurance will be much reduced. Hirshleifer (1971) already noticed that more information can have a negative value for Society. Early information on risks will make these risks uninsurable. This so-called "Hirshleifer effect" may be escaped if insurance could be organized prior to the revelation of the information. Whether the outcome of genetic tests will be insurable in the future is central for the future of life and health insurance systems. In France, the prohibition of genetic information revelation to insurers is considered by the legislator. This would for sure have a dramatic consequence for insurance markets, because it would introduce an incredible amount of adverse selection in them. Only those with a bad genetic profile will be willing to purchase insurance, raising the break-even premium rate, thereby excluding good risks from the market. The same kind of problem will occur if one improves our ability to forecast future earthquakes, or other natural disasters.

This phenomenon indicates the importance for insurance markets to establish long-term relationships between the buyer and the seller of a risk. Health insurance would have a much smaller value if, at any time, one party could renege the contract. This links this discussion to the assumption made in the classical model that there exist insurance markets for future risks. The problem here is our inability to insure future generations against future risks. There are simply not present on markets to purchase insurance contracts. This is a particularly important problem for environmental and technological risks.

2.9 Implicit risk-sharing versus insurance

A substitute for market insurance is to organize an implicit or explicit system of solidarity for the unlucky citizens through an indemnity financed by the taxpayers. Social security is the most obvious example. The decision of the US government to compensate the relatives of the victims of September 11 and the shareholders of airline companies is another example. France is the prefect example of a country that established an implicit system of solidarity for unlucky citizens. Farmers and truck drivers for example can rely on the state to get compensations for adverse shocks to their profits. Victims of floods may expect to get indemnities that depend upon the power of their local representatives at the Parliament.

The solidarity system yields problems that are similar to those of the market insurance: adverse selection, moral hazard and fraud. Moreover, if the system is implicit, it generates some uncertainty about the level of the indemnity, because of the political nature of the intervention. But the most important difficulty is related to the non-stability of the coexistence of the solidarity system and the solidarity system. If citizens believe that the state will compensate them for their damages, they will prefer not to insure the risk. Ex-post, the absence of insurance coverage forces the state to intervene. This is a case of self-fulfilling prophecy. One can mitigate this problem by asking the state to specify explicitly the conditions and the limits of national solidarity. However, such a commitment may be difficult. Ex-post, the social pressure for the public indemnification of the uninsured victims of a much publicized catastrophe will be strong. Solidarity kills market insurance. This problem can also be mitigated by offering public indemnities that are not contingent to the existence of an insurance contract covering the victim's loss. For example, it would be a bad idea to deduce the insurance indemnity (for those who have one) from the public compensation paid to the victims of September 11.

3 About the insurance of the so-called "new risks"

During the last two decades, we have experienced the emergence of new risks as those related to super-terrorism, global warming, genetic manipulations, the "mad cow" disease, and so on. These new risks share in various degrees the following two characteristics: First, they cannot be diversified by mutualization. Second, the probability distribution of losses is not perfectly known. These two characteristics may generate some problems for the insurance market, as we see now.

3.1 Sharing catastrophic risks

We have seen in section 2.1 how society can mutualize idiosyncratic risks in order to eliminate them. However, many individual risks are not idiosyncratic. Earthquake, global warming, super-terrorism and GMO create individual risks that are correlated across agents. This generates an undiversifiable risk at the macroeconomic level. This risk must be allocated to the consumers.

To determine the efficient allocations of risk, let us go back to the model presented in section 2.1. We assume here that the preferences of agent i is represented by a von-Neumann-Morgenstern utility function u_i, which is increasing and concave. An efficient allocation is obtained by solving the following program:

$$\max_c \sum_{i=1}^{n} \lambda_i \sum_{s=1}^{S} p_s u_i(c_{is})$$

$$s.t. \quad \sum_{i=1}^{n} c_{is} = \omega_s = \sum_{i=1}^{n} \omega_{is} \quad \text{for } s = 1,..,S,$$

where $(\lambda_1, ..., \lambda_n)$ are the positive individual weights in the social welfare function. Gollier (2001, chapter 21) derives the properties of the solution to this program. They may be summarized as follows. First, the mutuality principle holds:

$$c_{is} = C_i(\omega_s).$$

It states that individual consumptions depends upon the state only through the total wealth available in that state. This means that all diversifiable risks have been eliminated. Second, it must be that the share of the macroeconomic risk borne by agent i be proportional to his/her degree of absolute risk tolerance defined by $T_i(c) = -u_i'(c)/u_i''(c)$:

$$\frac{dC_i}{d\omega} = \frac{T_i(C_i)}{\sum_{j=1}^{n} T_j(C_j)}. \tag{1}$$

This has several important implications. For example, this means that no agent should be left without participating to the sharing of this undiversifiable risk. Also, under the reasonable assumption of decreasing risk aversion, wealthier people should bear a larger share of the systematic risk.

If markets are complete and perfect, the competitive allocation of risk is Pareto-efficient. Individual consumers are willing to retain some of the systematic risk in their portfolio because of the equity/risk premium associated to assets whose returns are positively correlated to it. So are financial assets with a positive beta, or individual risks generated by super-terrorism or earthquakes for example. Thus, the presence of a relatively large deductible of catastrophic insurance schemes does not per se imply that the allocation is inefficient.

3.2 The social cost of catastrophic risks

How much society would be ready to pay for the full elimination of the systematic risk? This question has first been raised by Lucas (1987). Suppose that all agents have the same attitude towards risk ($u_i \equiv u$) and that there is no wealth inequality. This implies that the competitive allocation will be symmetric: $C_i(\omega) = \omega/n$. Every agent will consume the GDP per capita in every state of nature. They will therefore be ready to pay π per capita to get rid of the systematic risk, where π is defined as

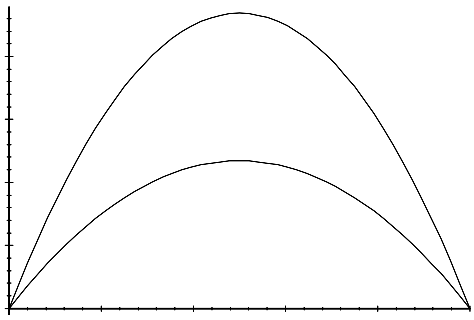
$$Eu\left(\frac{\widetilde{\omega}}{n}\right) = u\left(\frac{E\widetilde{\omega}}{n} - \pi\right).$$

Lucas calibrated the model on the U.S. data. He obtained that the social cost of the systematic risk is less than one-tenth of a percent of the annual growth rate of the economy! In fact, the volatility of the U.S. growth during the last century has been relatively small. If we combine this with the observation that risk aversion is a second-order phenomenon, we obtain a simple intuition for why the systematic risk is not essential.

Let us illustrate this point by another simple numerical exercise based on the events of September 11. The total loss has been estimated to 48 billion dollars, to be compared to the \$41.000 billion World GDP[5] and 6 billion

[5]This is an estimate of J. Bradford DeLong, available at www://www.j-bradford-delong.net/.

inhabitants. Per capita, the loss equals 8 dollars, for a net yearly income of 6833 dollars. Suppose that such an event can occur with probability p each year. In Figure 2, we draw the risk premium associated to this risk, as a function of p. We see that the risk premium never exceeds half of a cent.



The risk premium (in U.S. dollar) associated to an event similar to Sept 11 occuring with probability p per year. The lower (upper) curve is for a constant relative risk aversion $\gamma = 2$ ($\gamma = 4$).

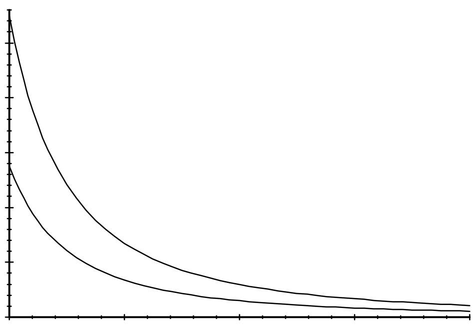
If markets are efficient, each (representative) agent on the earth should reduce her consumption by 8 dollars each time there is a catastrophe costing 48 billion dollars. In particular, this implies that the socially efficient deductible for such risk should not exceed 8 dollars. The small individual contribution with respect to the level of consumption cannot justify a sizeable risk premium attached to such an insurance contract.[6] In turn, it cannot explain the decision of many consumers and corporations to self-insure these risks.

Many explanations can be given to solve the paradox. An unsatisfactory one is based on the large wealth inequality on the earth. For a large fringe of the population in the Third World, a contribution of 8 dollars is unbearable, and would lead to a much larger risk premium. This argument is not acceptable, because the socially efficient share of the catastrophic risk borne by these poor people would be much smaller than that, given equation (1)

[6] As is well-known, the equilibrium price of risk is not governed by the global risk premium π defied by (??), but rather by the premium associated to the marginal risk, which is given by $P = E\widetilde{\omega}u'(\widetilde{\omega})/Eu'(\widetilde{\omega})$. Eeckhoudt and Gollier (2001) show that the equilibrium price P is larger than π.

and decreasing risk aversion. On the contrary, wealthier people will want to retain a much larger share of the risk. Gollier (2001) shows that wealth inequality has absolutely no effect on the equilibrium price of risks when relative risk aversion is constant.

A better explanation comes from the limited participation to financial markets due to various participation costs. Given that many people do not hold any asset portfolio, they do not hold shares of (re)insurance companies that are considering covering catastrophic risks. The remaining shareholders will require a larger risk premium to participate, because of the larger size of the risk. Since the risk premium increases as the square of the size of the risk, this can generate a sizeable effect on the risk premium, and in turn on the insurability problem. If m denotes the participation rate, each shareholder will incur a loss of $8/m$ in case of a catastrophe. Let us consider the worse case where the probability of a catastrophe is $p = 0.5$. In Figure 3, we depicted the risk premium as a function of m. We see that the risk premium is dramatically impacted by the participation rate. For example, for $\gamma = 4$, the risk premium goes from half a cent when the 6 billion inhabitants participate to 49 dollars when only 1% of them participate.



The risk premium as a function of the participation rate m to financial markets. The lower (upper) curve is for a constant relative risk aversion $\gamma = 2$ ($\gamma = 4$).

Another argument is based on the international diversification puzzle, as stated by French and Porterba (991), and Baxter and Jermann (1997). They reported that US investors hold around 94% of their financial assets in the form of US securities. In Japan, the United Kingdom and Germany, the portfolio share of domestic assets exceeds 85% in each case. Whereas this effect is mitigated by the existence of international reinsurance treaty, it shows that catastrophic risks are not as much geographically disseminated as suggested by the theory. A possible explanation for the home bias of individual portfolios comes from various tax incentives for retirement funds to invest within the country. We believe that relaxing these investment constraints would alleviate the insurability problem for catastrophic risks by reducing the risk premium requested by shareholders of (re)insurance company to bear them.

We endorse the proposal of Robert Shiller (1993) to create new markets for claims on various indexes related to national incomes, or to these so-called new risks for which the current allocation is obviously inefficient. For example, an international mutualization of the risk of climate change would be very helpful, as we believe that most of it can be diversified away. Such an international risk-sharing can be attained either through a formal risk-sharing treaty among different countries, or through the creation of claims on regional indexes of damages generated by climate changes. Super-terrorism could be treated in a similar manner. A difficulty of the system comes from the moral hazard problem that risk-sharing generates. Another difficulty, which is specific to the international treaty system, is due to the long-term commitment that such sharing device requires.

3.3 Time diversification and catastrophe loan programs

Risks can be transferred between individuals, but it can also be transferred through time via the credit markets. Economic agents can forearm themselves in the face of uncertainty by building financial reserves. In the face of random shocks on their future revenues, they can reduce the volatility of their consumption by reducing their reserves in case of an adverse shocks, and by increasing their reserves in the absence of catastrophes. This buffer stocks strategy has been examined by Yaari (1976), Deaton (1991), Carroll (1997) and Gollier (2002a) for consumers in a life-cycle model. Yaari (1976) showed that an agent with an infinite time horizon and with risks that are independent through time would "time-diversify" his risks by an efficient borrowing-lending strategy that perfectly smooths his consumption through time. No costly insurance would be necessary in this case.

The "time-diversification" strategy is actually not a perfect substitute to insurance because agents have a finite lifetime, and because consumers face borrowing constraints. In particular, they cannot borrow in case of an "early hit" of damages that dries up their initial financial reserve. A standard governmental policy in situations where a large population hit by a catastrophe faces a borrowing constraint is to provide a simplified access to governmental loans.

Gollier (1994, 2002b) examines considers a standard lifecycle model that can be used to measure the benefit of relaxing borrowing constraints. The representative consumer has a constant flow of labor incomes that is normalized to unity, but there is 10 percent chance to lose 75% percent of the yearly income each year. He has a power utility function with a constant relative risk aversion equaling γ =2 . We examine four different market structures. In the benchmark structure, consumers live in autarchy. They are forced to consume each year their realized income that year. There is no bank and no insurance. In that case, the certainty equivalent consumption is 77% of the yearly income. Suppose alternatively that there is now a spot insurance market with a 30% loading factor. In such a situation, there is an optimal deductible of 12% of the yearly income y. The certainty equivalent consumption equals 90.4 % of y, which confirms the importance of insurance for welfare.

Up to now, we did not allow agents to borrow (in case of a loss) and lend. This simulates the inefficiency of credit markets. Suppose that we open a credit market where agents can borrow and save at a risk-free rate of 1%, but they must maintain a positive net balance of financial reserves. Agents select the consumption policy the buffer stock strategy, and the spot insurance policy that maximize their lifetime expected discounted utility. The optimal strategy in our example is to have a target financial reserve of 272% of yearly incomes y. The average buffer stock equals 159% of y. The mean optimal deductible goes up to 63% of y, which shows the power of time diversification. The certainty equivalent consumption goes up to 91.2% of y, to be compared to the 90.4% when no such governmental loan program is available. The marginal benefit of governmental loan program is thus marginal when an efficient insurance market exists.

The last market structure that we examined is when the risk is uninsurable, but there is an efficient access to the credit market to time diversify individual risks. In such a situation, consumers will have a target for their financial reserves up to 313% of y. The certainty equivalent consumption equals 90.6%. When compared to the 77% in the case of autarchy, and to the 90.4% of the "insurance only" case, we see that easing borrowing constraints when risks are difficult to insure may have a large effect on welfare that can even dominate the effect of insurance. Table 1 summarizes the main results of this calibration exercise.

	Mean deductible	certainty equivalent consumption	target buffer stock
autarchy	...	0.769	...
with insurance only	0.126	0.904	...
with insurance and loans	0.627	0.912	2.723
with loans only	...	0.906	3.127

Table 1: The interaction between insurance demand and the credit market

This model can be reinterpreted for insurance companies determining their strategies of capital accumulation and reinsurance. A starting insurance company has a low capacity to retain risks. It is thus forced to reinsure a large part of their business. If it is not caught by an "early hit" of catastrophic indemnities, its capacity to retain risk will grow. This will increase the capacity of the market. The ability of insurance companies to transfer wealth through time is thus central for organizing time diversification of catastrophic risks. But the modern theory of corporate finance indicates that managers in firms with a large financial reserve will be less efficient than managers in less capitalized firms where their job is at stake. Managerial inefficiencies open the door to raiders who could use the cash reserve of the insurance company for his own purpose. The bottom line is that it can be hard for insurance companies to accumulate financial reserves. This has an adverse effect on the capacity of the insurance market.

The bottom line is that when catastrophic risks are difficult to insure, time diversification may provide a good substitute. Because consumers and insurance companies may face difficulties to smooth shocks through buffer stocks and borrowing, the state may be in a better situation to organize time diversification. The state has the credit worthiness and the long time horizon that are necessary to implement time diversification efficiently. The best way to do this would be to ask the state to play the role of reinsurer of last resort, a backstop, by offering reinsurance contracts with a deductible corresponding to the capacity of the insurance market. The moral hazard problem that it generates should be mitigated by the usual methods (experience rating, norms of prevention,...).

3.4 Ambiguity

There are many instances in which the random variable describing the risk has no objective probability distribution. This can be due to the absence of historical data. Or because of our imperfect scientific knowledge, for those who believe in a deterministic nature. To illustrate, who knows the actual probability of, for example,

- a major leak in some specific type of nuclear plan,
- the transmission to the human being of the so-called "mad cow" disease,
- a large terrorist attack on the US territory next year,
- a failure of the new European satellite launcher Ariane V,
- or the average temperature on earth to increase by more than 4 degree Celsius in the next century?

Ambiguous probabilities can also be due to a volatile environment, as is the case for future liability rules of environmental policies.

The ambiguity about the probability distribution raises several questions. How to calculate a fair insurance premium? How to evaluate the benefits of an insurance contract for the insuree? What would be an efficient allocation of risks in the economy? To keep it simple, suppose that there are two possible states of nature, a loss state and a no-loss state. The probability p of loss is unknown. Using all available information gives us an interval of confidence $[p_{\min}, p_{\max}]$, with a mean $\overline{p}$. Following the terminology of insurers, we are in a situation where there is no credible actuarial estimates of the risk, which "implies" that the risk cannot be priced, and that the risk is not insurable.[7] Let us try to understand this explanation of the limits of insurability. Keynes (1921) distinguished between probabilities and the weight of evidence. Probabilities represent the balance of evidence in favor of a particular event, whereas the weight of evidence represents the quantity of evidence supporting that balance. He then raised the following question: "If two probabilities are equal in degree, ought we, in choosing our course of action, to prefer that one which is based on a greater body of knowledge?"

[7] The ambiguous probability cannot explain alone the uninsurability problem. Borch (1989) reports the Lloyd's insuring the risk of discovering the monster of Loch Ness.

The defenders of the orthodox theory claim that ambiguity is no problem. Following Savage (1954), people should behave as if there would be no uncertainty on probabilities. More precisely, they should use $\overline{p}$, i.e. the best probability estimate, to compute their expected utility. Ambiguity on probabilities should not play any role neither on welfare nor on behavior. In particular, it should not affect the demand and supply of insurance. Whereas this theory has a strong normative contain, it cannot explain various observations. Daniel Ellsberg (1961) showed in a well-known experiment that some people do not behave as Savagian agents. They don't behave in the same way in the face of two uncertain environments with the same probabilities, but with different weights of evidence. More precisely, they are ready to pay more to get rid of a more ambiguous risk. In the Keynes-Ellsberg's "two-color" problem, there are two urns each containing red and black balls. Urn 1 contains 50 red balls and 50 black balls, whereas urn 2 contains 100 red and black balls in an unknown proportion. A ball is drawn at random from an urn and one receives 100 euros or nothing depending on the color of the ball. The fact that people are indifferent to bet on red or black if urn 2 is used indicates that their subjective probability for each color is 0.5, as in urn 1. If they would be SEU maximizers, they should thus be indifferent to using urn 1 or urn 2 for gambling. However, most people prefer to gamble with the unambiguous urn 1, where the "weight of evidence" is larger.

The concept of ambiguity aversion has received a precise theoretical content by the works of Gilboa and Schmeidler (1989). Ambiguity aversion means that economic agents do use some probability p smaller than $\overline{p}$ to measure their welfare in the face of uncertainty. Pessimism is another word for ambiguity aversion. People may have different degrees of ambiguity aversion, as they may have different degrees of risk aversion. Notice that if both the policyholder and the insurer have the same degree of ambiguity aversion, they should use the same p to compute expected utility on one side, and the actuarial value of the policy on the other side. This should not introduce any specific insurability problem. The ambiguity raises the premium required by the insurer to accept to cover the risk, but it also raises the policyholder's willingness to pay for insurance. An insurability problem may occur only if insurers are systematically more ambiguity-averse than consumers. Kunreuther, Hogarth and Meszaros (1993) conducted a series of studies to determine the degree of ambiguity aversion of insurers. They showed that many of them may exhibit quite a large degree of such an aversion.[8] For which reasons this is the case remains an open question. This could for example come from an incentive problem. Underwriters are usually much more penalized when it happens ex-post that they "underestimated" the risk of loss than when they "overestimated" it. Underestimation leads to the much visible problem for the company to face a loss ratio much larger than unity (asbestos in the US, transfused blood scandal in France,...). Overestimation yields unearned potential profits that are usually not even mentioned by the principal. Thus, underwriters would not be genetically more ambiguity-averse. Rather, they react to biased incentives. Solving this uninsurability problem requires a modification of incentive schemes for underwriters.

4 Conclusion: Terrorism coverage

After September 11, the risk of terrorism attacks became at the same time more difficult to measure and less easy to diversify because of its catastrophic component. We have shown why this may imply an insurability problem that can have an important adverse effect on welfare. We pointed out three problems.

First, financial markets and their financial intermediaries do not currently allocate risks efficiently in our globalized and decentralized economy. The low rate of participation to financial markets and the low level of international diversification of investors' portfolios imply an inefficiently large risk premium for this type of risks. This in turn induces more reluctance to insure them. This may have various policy implications, as the creation of a new markets for terrorism-related claims, or the establishment of international risk-sharing treaties.

Second, a substitute for the missing/inefficient insurance markets is to plan to offer a privileged access to the credit markets for the victims and for the insurance companies. Allowing them to borrow in the short run to compensate the uncovered loss provides a second-best for the absence of insurance (time diversification). Repayable loans backed by a government

[8] Viscusi and Chesson (1999), using a sample of 266 business owners facing risks from climate change, show evidence of both ambiguity-seeking behavior and ambiguity-averse behavior. More precisely, people seem to exhibit fears effect of ambiguity for small probabilities of suffering a loss, and hope effects for large probabilities.

guarantee should be proposed. Due to its natural creditworthiness and its long time horizon, the state is better shaped than insurance companies to smooth shocks over time. One should create a state-owned reinsurer of last resort that would reinsure risks above an upper limit retained by the market.

Finally, the existence of some degree of uncertainty on the size of the risk generates an incentive problem on the supply side of insurance. Because underwriters are more penalized for having underestimated a risk than for having overestimated it, they are induced to be pessimist, a form of ambiguity aversion. This generates an uninsurability problem in periods of high uncertainty. This problem should be mitigated by rethinking how insurers reward their underwriters and actuaries after the facts.

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