Risk allocation: The Double Face of Financial Derivatives

Abstract. Financial markets, insurance contracts and financial innovations share the goal of efficiently allocate risk. In the last two decades derivatives have been the primary tool employed for risk-management and risk-sharing activities. However, owing to the 2007-2008 crisis, financial derivatives have received, partly for good reason, an increasingly bad press. The main purpose of this paper is to to spell out in detail, within a stylized portfolio choice model, the various effects derivatives can have on the efficient allocation of risk. Given a suitably defined notion of systemic risk, we define an allocation to be efficient if it allows to finance the maximum amount of productive investments while minimizing the overall the systemic risk of the economy. We say that a derivative is socially enhancing or cooperative if it leads to a more efficient allocation of risk, thus producing positive externalities for the economy. We then apply of our model in two case studies: asset backed securities and credit default-swaps.

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1. Introduction and Motivation

Insurance contracting and financial markets share the vital goal for the economic system of efficiently allocate the unavoidable risk generated by the business activity of the economic subjects. Insurance companies and other financial risk-bearing entities may enter into various kinds of formal risk-sharing agreements for a variety of reasons, the most important of which is the simultaneous reduction of risk for all participants. In fact, an enhanced risk allocation results in real economic benefits for the whole society: as Irving Fisher wrote in 1906: *Risk is one of the direst economic evils, and all of the devices which aid in overcoming it – whether increased guarantees, safeguards, foresight, insurance or legitimate speculation – represent a great boon to humanity*[22].

In the theoretical actuarial literature the determination of optimal rules for sharing risks and constructing reinsurance has a long history: already in Thirties Medolaghi [25], de Finetti [17], and Ottaviani [26] developed the first linear reciprocal reinsurance models by minimizing individual and aggregate variance of risk. Later, in a series of studies Borch [8], [9] has considered the problem of introducing a utility function into actuarial theory. In the framework of a neoclassical perfect market, he sets up a n-person cooperative game and derives the condition for a Pareto-optimal risk exchanges in a reinsurance market. By means of the claim distribution for the risks insured during an insurance year, the best reinsurances, i.e. the one reaching Pareto-optimality, can be obtained.

In practice, the way risk allocation is performed by the financial system has rapidly evolved in the last decades, and especially in recent years, due to sheer increased in financial innovations. A lot of efforts have been devoted to the design of institutions and products which allow individuals to efficiently share risks (see, e.g., [3], which also discusses a basic theory of risk sharing in an economy with incomplete markets, and [20]). Most notably, innovations in the fields of derivative products have significantly increased both efficiency and the complexity of the allocation of risk. Market-based allocation of risk is primarily accomplished through the use of derivative products and *it is not an exaggeration to state that a considerable portion of financial innovation over the last 30 years has come from the emergence of derivative markets* (see [1]). Derivatives are risk management devices which, according to the theoretical literature, are introduced in order to complete the market.

In addition, derivatives are considered to have a beneficial impact on markets because of reductions in transaction costs and enhanced informational efficiencies (see [18]).

For at least two decades the benefits of derivatives and of the associated market-based risk sharing model seemed to be abundant: in a nutshell they appeared to allow for a more efficient risk management, they have an important informative role since they can be used as price discovery tools and finally they also seemed to provide more liquidity to the markets and also to the general economy. For example banks and other lenders often transfer credit risk to liberate capital for further loan intermediation. The trend in risk allocation was therefore marked by the "marketization" and the securitization of risk: various types of risks were originated, securitised, rated and allocated by various actors in the financial market; i.e. risk were transferred from regulated sector to unregulated sector. Institutional supervisors welcomed this risk marketization that appeared to distribute risks away from small number of large and systematically important actors to a large number of investors. Insurance firms too increasingly manage underwriting risks not only by the common approaches of reinsurance, coinsurance, and geographic/product diversification, but, like any other financial and non-financial firms, by the use of derivatives to hedge investment risks and risks associated with insurance products. However, the global financial crisis of 2007-2008 raised a number of serious issues on the use of derivative products by various agents: paradigmatic was not only the instability of markets following the failure of Lehman Brothers, but the need of a bailout of AIG, at that time the largest insurance company of the United States [28].

The reality is that markets can and sometimes do fail to provide the expected risk management performances and the associated desirable social outcomes. Indeed, it is widely agreed among authoritative commentators [15, 27, 30] that the recent global economic and financial crisis is a direct consequence of failures of the risk marketization process. Many analyses connect causally the financial crisis to the unmanageable systemic risk produced by increasingly sophisticated financial derivatives products. Moreover, many recent empirical studies find either no relation or negative relation between derivative usage and firm value. For instance, [21] finds that in firms with greater agency and monitoring problems derivatives usage has a significantly negative impact on firm value measured by their Tobin's Q.

As a consequence, financial derivatives have been put under the spotlight as the main culprits of the recent financial crisis by having decisively contributed in increasing the systemic risk of the economy. The importance of the role of the systemic risk in financial crisis, is gaining increasingly recognition. Several definitions and several measures of systemic risk in the finance and insurance sectors have been proposed (see, e.g., [2, 7, 6, 14]), many of them based on the statistical properties of market data (stock returns, the prices of various kinds of derivatives, etc). These have the advantage that they should incorporate the most current information and expectations, since market returns reflect information and update more rapidly than accounting variables. On the other hand, accounting measures provide unique insights (see, e.g., [23]) and are less subject to behavioural biases.

Given their capital base and risk management policies, individuals choose their desired level of market risk. However, in setting their level of market risk it is doubtful that individuals internalize the systemic implications of the failure of their firms or the public cost associated with any implicit government safety net. The theoretical relationships and institutional mechanisms[1] which connect liquidity and leverage with correlation, connectivity and ultimately lead to domino effects which can exasperate systemic risk are still far from being fully understood. Certainly the use of leverage, establishing positions which are often considerably larger than the amount of collateral posted to support those positions, combined with sampling or model errors in estimates of expected returns, correlations and risk of investments, can determine an explosive mix. When unexpected (but not necessarily unprecedented...) adverse market conditions reduce the value of the collateral, investors must meet margin calls and they are sometimes forced to liquidate large positions quite rapidly. This is made in order to reduce leverage and risk, but it can enhance systemic risk, especially when these forced liquidations are made in relatively illiquid markets which cannot easily absorb the price impact of the forced liquidations

In this work we take a different perspective respect to the standard actuarial literature on optimal risk sharing by differently defining the concept of efficient allocation of risk, in a way which takes in to account the ability of the market to fund productive but risky projects without increasing the systemic risk of the whole financial system. Capital, in fact, is a

[1] The possibility to encourage regulatory arbitrage should always be kept in mind, see e.g. [4]

limited resource and so is the capital available for covering risky investments. It therefore has to be allocated e ciently toward the highest risk-adjusted return opportunities. From this perspective, not all risk equally deserve to be diversi ed and spread across the economy, being the ones more related to productive investments to be preferred to the ones having lower or zero return opportunities.

Moreover, we explicitly model the systemic e ects induced by the imprecise estimation of risk made by the individuals. Financial innovations can greatly change the precision of the estimation of risk which, in turns, have key implications for risk allocations.

In our theoretical framework we de ne an allocation to be e cient if it allows to nance the maximum amount of productive investments while minimizing the overall aggregate risk of the system (the systemic risk). This approach permits to take in to accounts many important factors in the evaluation of the e ciency of a risk allocation: the quality of the diversi cation achieved by the individuals, the amount of funding of productive investments, the precision in the estimation of the risk, the degree of leverage, the dependence among the risk positions of the individuals.

This theoretical framework allow as to identify and evaluate the e ects of di erent type of derivatives on the e cient allocation of risk. We say that a derivative is socially enhancing or cooperative if it leads to a more e cient allocation of risk, thus producing a positive externality, while it produces a negative externality for the economy if it leads to a suboptimal risk allocation. Our goal is to spell out in detail the various channels through which a individual decides, on the basis of his own preferences, how much to invest of his initial capital in the market portfolio of risky assets, i.e. by linearly combining the tangent portfolio with the risk-free asset (the so called capital market line) he will be able to obtain the desired degree of leverage according to his risk preferences. The two funds separation theorem assumes that the choice of how much individuals leverage their positions does not affect the joint distribution of the returns project in the economy. However, at the aggregate level, different degree of leverage, and hence different amount of aggregate investment, can affect the return distribution of the economy through various ways (possibly including risk externalities stemming from the size of institutions [31]): not constant return to scale of the projects, not constant correlation to scale and, more importantly, different level of credit risk which also induces different level of systemic risk. Taking into account these macroeconomic effects has important consequences on the mean-variance allocation theory. For instance, for each level of systemic risk there exists a different curve for the mean-variance efficient frontier. Hence, even in this simplified case, a capital market line can not be drawn anymore and the standard Markovitz two-dimensional mean-variance plane has to be augmented by a third dimension representing the total amount of systemic risk reached as a consequence of the positions chosen by the individuals. For the moment we abstract from these effects defining our model in the standard framework of the separation theorem, differing the discussion of the important consequences of these considerations for systemic risk to a subsequent section.

Let's start considering an economy characterized by a collection of M risky investment projects and a group of individuals $i = 1, \ldots, N$ endowed with a given amount of initial ($equity$) capital C_i. Each individual constructs his own portfolio of risky assets and decide how much to invest on it. Let's define r_i the gross return per unit of capital invested in the portfolio chosen by agent i (ROI) and I_i the amount agent i chose to invest in the portfolio of risky assets. We assume that an individual i will default when the loss on his risky asset position will exceed his initial capital C_i, which can then be interpreted as the risk capacity of agent i. Thus, the probability of default (PD) of agent i is given by

$$PD = P(I_i r_i < \quad C_i).$$

A convenient measure that emerged as the industry standard for estimating and evaluating the default risk in credit risk modelling (Moody's KMV model) is the so called Distance to Default (DD) that in our setting becomes:[2]

$$DD_i = \frac{C_i}{I_i \sigma_i} \tag{1}$$

where σ_i is the standard deviation of the return r_i. It is customary among practitioners to interpret DD as the "number of standard deviations a company is away from its default threshold". Obviously, the larger is DD the smaller is the probability of default. The DD measure does not include the contribution of the mean of r_i being typically negligible on short-medium horizon and very difficult to estimate; more importantly, it does not consider the effects of the higher order moments of the distribution of r_i (this point will be discussed more later). It is clear that the larger is the investment I_i the smaller will be DD and hence greater the risk of default. On the other hand, the Return On Equity (ROE) is given by $I_i \mu_i / C_i$, where μ_i is the expected value of r_i, thus it is an increasing function of the amount invested.

In accordance with the two funds separation theorem, each individual, after having selected the desired portfolio, decides how much leverage his positions on the basis of his own risk preferences. We assume that each agent maximizes a Constant Absolute Risk Aversion (CARA) utility function[3] with absolute risk aversion parameter λ_i. Assuming for simplicity a zero risk free rate, each individual i then maximizes,

$$\max_{I_i} \; I_i \mu_i - \frac{\lambda_i}{2} I_i^2 \sigma_i^2 . \tag{2}$$

The first-order-condition for this utility maximization is

$$\mu_i - \lambda_i I_i \sigma_i^2 = 0 \tag{3}$$

so that the optimal level of investment for individual i, I_i^* becomes

$$I_i^* = \frac{\mu_i}{\lambda_i \sigma_i^2} \tag{4}$$

In practice, however, the true value of the portfolio expected return μ_i and risk σ_i are not known. Let's call ^ the estimates made by agent i of the unknown expected return

[2] Notice that in a Gaussian world with $r_i \sim N(\mu_i, \sigma_i^2)$ the return obtained by investing I_i in such a portfolio is distributed as $I_i r_i \sim N(I_i \mu_i, I_i^2 \sigma_i^2)$, and therefore the true probability of default is $P(I_i r_i < -C_i) = 1 - \Phi\left(\frac{C + I_i \mu_i}{I_i \sigma_i}\right) \simeq 1 - \Phi\left(\frac{C}{I_i \sigma_i}\right)$, i.e. a decreasing function of $\frac{C}{I_i \sigma_i}$.

[3] Hence a negative exponential utility function $U(X) = a - b e^{-\lambda X}$.

and $\hat{}_i$ the estimates of the unknown risk $\ _i$. Hence, the desired level of investment can be written as

$$\hat{I}_i = \frac{\hat{}_i}{_i \hat{}^2_i} = I_i \frac{^2_i}{\hat{}^2_i} \frac{\hat{}_i}{\hat{}_i} = I_i e_i$$

where $e_i = \frac{\sigma^2_i}{\hat{\sigma}^2_i} \frac{\hat{\mu}^2_i}{\hat{\mu}^2_i}$ is the estimation error of the agent i in evaluating the expected mean and risk of his position.

Then taking in to account estimation errors, the \actual" or \realized" DD of individual i becomes:

$$DD_i = \frac{C_i}{\hat{I}_i \ _i} = \frac{C_i}{I_i e_i \ _i} = (\ _i \ \ _i \ e_i)^{\ 1} \tag{5}$$

where $\ _i = I_i = C_i$ is the leverage of the position chosen by agent i.

Hence, DD is then made of three components: the true riskiness of the portfolio $\ _i$, the degree of leverage $\ _i$, and the risk estimation error e_i. Being a decreasing function of DD, the probability of default then increases with the true riskiness of the portfolio $\ _i$, the degree of leverage $\ _i$ and the underestimation of risk ($\hat{}_i < \ _i \ ) \ e_i > 1$) or overestimation of the expected return ($\ _i < \hat{}_i \ ) \ e_i > 1$).

We then de ne the aggregate Systemic Risk (SR) as the probability of the Number of Defaults (ND) in the whole economy exceeding a certain threshold n

$$SR_n = P(ND > n):$$

Hence, ceteris paribus SR is an increasing function of the individual values $\ _i$ and $\ _i$. Concerning the estimation error components e_i it is, in general, reasonable to assume that individuals error are uncorrelated and hence their estimation errors tend to average out, i.e. $E[e] = 1$. However, at the aggregate level the variance of the estimation error $Var[e]$ starts to play an important role, since the higher the variance of e the higher will be the probability of having more than n defaults[4] and hence the greater the SR of the economy. Finally, SR will also be an increasing function of the average correlation (or more generally dependence) among the individual probabilities of default that we denote with .

Lets now denote

$$Y = \sum_{i=1}^{N} I_i r_i$$

[4]assuming $n < N/2$

to be the total gross return of the whole economy.

We define an allocation to be *socially efficient* if for any given level of $E[Y]$ minimizes the SR,

$$\min SR \quad \text{subject to} \quad E[Y] = E[Y_0];$$

or if for any given level of SR, maximizes the expected value of $E[Y]$, i.e.

$$\max \mathbb{E}[Y] \quad \text{subject to} \quad SR = SR_0;$$

Hence, the socially efficient frontier will be a curve in the plane SR–$E[Y]$ which maximizes $E[Y]$ for any level of SR or, alternatively, which minimizes SR for any level of $E[Y]$.

In this economy an efficient allocation is reached when both the idiosyncratic risks of the single projects are optimally diversified (reducing $_i$'s) and the remaining non–diversifiable risk is optimally estimated (minimum $Var(e)$ and $E(e) = 1$) and optimally shared among the investors according to their risk capacities (minimization of the aggregate leverage of the economy). This definition of an efficient risk allocation makes also clear that only those risks which directly or indirectly contribute to elevate $E[Y]$ should be born by the society, the others, by only increasing SR but not $E[Y]$ leads to a less efficient point in the SR–$E[Y]$ plane.

A derivative is said to be socially efficient or cooperative if it permits to move from an interior and inefficient point to a superior aggregate risk allocation having a higher $E[Y]$ *with same or lower* SR *(i.e. moving in the second quadrant direction in the* SR–$E[Y]$ *plane).*

3. Case 1: Asset backed securities

An Asset Backed Security (ABS) is a security whose cash flows are derived from and colletaralized by a specified pool of receivables or other financial assets. Those underlying assets are typically represented by illiquid and risky assets which would individually have a very low rating score. The securitization process precisely consists in pooling various types of contractual debt (mortgages, loans or credit card debt) and selling said debt to carious investors. Pooling those assets together and slicing such a pool into different risk classes, or tranches, categorized into varying degrees of subordination, reduces the risk of the so called "senior" tranches, since these rely on the protection the junior tranches which would be the first to suffer the losses in the pool. Through this complex mechanism of pooling and splitting into di erent risk classes, the senior tranches were able to achieve AAA-ratings. Prior to the 2007-2008 nancial crisis, this extremely high rating induced many banks and other investors to hold large amount of AAA-tranches of a vast variety of ABS products. As it was apparent after the burst of the crisis, those risk evaluations of ABS were severely issuing a debt: in case of a default the protection buyer is compensated for the loss generated by the failure of the third party. The protection buyer pays, on a regular basis, a premium to the protection seller usually expressed in percentage points of the notional, the so called CDS spread. The CDS are then simply a form of insurance against default. However, unlike insurance contracts, CDS do not require an exposure to the underlying credit risk. If the protection buyer does not hold the underlying security the CDS is said to be *naked*. Naked CDS can then be used to build speculative bets on the default of the third party: the naked protection buyer is betting on default while the other is betting against. The large amount of volume of the CDS market (in principle even larger than the total debt of the underlying entity) indicates that a substantial portion of contracts are naked [24, 33].

CDS have come to play an important role in convey informations about the market consensus on the creditworthiness of the underlying, especially in cases when the underlying debt market is not particularly liquid. This price discovery properties of the CDS, if viewed in the light of our model, translate in a reduction of the variance (and possibly bias) of the estimation errors e.

Non-naked CDS simply imply transferring of the credit risk from the protection buyer to the protection seller leaving the total amount of credit risk in the economy unaltered. So the systemic risk implication of this relocation of risk depends on the relative risk capacity of the protection seller compared to the one of the protection buyer. If the protection seller has a greater risk capacity (in terms of larger capital, smaller leverage or better diversified portfolio which results in greater DD) than the protection buyer systemic risk is reduced, otherwise it will be increased.

However, in the presence of naked CDS the total amount of counterparty risk in the economy is increased by the two-sided bets on the default event. Although such contract are a zero sum game, they are certainly not "zero sum risk", in the sense that the risk over the two sides does not compensate. The risk produced by these naked bets does not contribute to $E[Y]$ but has either to absorb capital diverted from other investments projects which instead contribute to Y, or increase the position leverage of the agents. Naked CDS can also encourage investors to divert their capital away from financing real investment leading in some cases to the selection of riskier ventures with lower expected returns [11].

Moreover, being the market of CDS highly concentrated in few large protection sellers, the counterparty risk generated by the default of one of these dominant actors can generate default contagion and domino effects. In the presence of a large market of naked CDS, the risk is not only given by the loss generated by the default of the issuer of debt, but also by the counterparty risk of all the protection sellers who wrote CDS on that entity. In other words, if CDS protection sellers have insufficient capital to cover CDS losses, the default of the issuer of the debt also causes the default of protection sellers, hence widening the scope for contagion and systemic risk [12].

This risk was clearly illustrated by the AIG case during the 2008 crisis which exerted domino effects through enormous CDS contractual links. In fact, AIG's collapse was caused largely by its $526 billion portfolio of credit default swaps (CDSs): the Federal Reserve Chairman Ben Bernanke has characterized AIG operations in derivative markets as the

SR could be mitigated by moving the trading of CDS from the OTC market to a centralized clearinghouse which would greatly reduce the counterparty risk of CDS.

5. Conclusions

Nowdays, the first and most fundamental problem in risk allocation is to understand the complex effects induced by financial derivatives and how they could be so badly misused to ignite a global crisis. We argued that part of the answer lies in the relation among individual risk, systemic risk and the related notions of correctly assessing risk capacity and leverage. The importance of systemic risk has been recently recognized and acknowledged by many researchers and think-tanks: in order to be able to reliably assess the systemic risk caused by various institutions, more transparency is badly needed. The present state-of-the-art is quite far from optimal: it is obvious that governments and regulators do not have access to all necessary data to evaluate global and systemic financial risks.

Financial, insurance firms and regulatory and supervising authorities they should all cooperate to provide more direct and better quality information concerning the leverage and linkages among financial institutions, much of which is currently proprietary and not available to any single regulator. An integrated approach, which aims at the control of the buildup of systemic risk by using econometric and statistical relationships as well as financial statements and regulatory data and performance measures, is probably the correct way of addressing the complexity of the global financial system. Many definition of systemic risk still coexists and it is unrealistic to expect that a single measure of systemic risk is sufficient. A more plausible alternative is a collection of measures, each designed to capture certain aspects of systemic risk (liquidity, leverage, interconnection, fragility, losses, etc.). Hence, the goal of constructing a more robust framework for risk-sharing and financial innovation remains an enormous but vital challenge which requires an extraordinary coordination and cooperation effort [32] both from financial and insurance firms and supervisionary and regulatory entities.[7]

[7] The paper [1] provides a good example of the kind of action which is suggested: *The most important principle underlying the regulation of derivatives must encircle three primary issues: (i) uncertain counterparty credit risk exposure which can generate illiquidity and can cause markets to break down, (ii) capital*

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erosion which can cause the nancial system to break down if the erosion is large and concentrated in institutions that provide liquidity to the nancial system, and (iii) prices that are away from fundamentals due to illiquidity in the market, which can cause distortions in capital allocation. Since the most important component for understanding counterparty credit risk is the level of transparency, any regulatory action should explicitly be organized around increasing the level of transparency to, at the very least, the regulator. In fact, real-time availability of prices, volumes and positions at the trade level to regulators is unambiguously bene cial so long as the costs associated with gathering and processing the information are not prohibitive. This information will allow regulators to manage systemic risk in the nancial system. For example, AIG's $400 billion worth of exposure to credit defaults across markets presumably would have alerted regulators. There are, of course, also strong bene ts to providing transparency to the public as well. Regulators may not always be able to monitor or understand the exposures. The market may discipline the counterparties in question. For example, would Goldman Sachs, Merrill Lynch and others have entered into agreements with AIG knowing the degree to which AIG was exposed similarly to all its counterparties? Unlike with regulators, unfettered transparency of prices, volumes and positions to the public at large involve a tradeo . On the positive side, greater transparency will help limit the risk externality created by counterparty credit risk. On the negative side, transparency may be onerous for institutions since it may (i) reveal their trading strategies, and (ii) it may reduce their inclination to trade, and thereby also a ect liquidity in an adverse manner.

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