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L. Buzzacchi,G. Turati

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OPTIMAL RISK ALLOCATION IN THE PROVISION OF LOCAL PUBLIC SERVICES: CAN A PRIVATE INSURER BE BETTER THAN A FEDERAL RELIEF FUND?†

Luigi Buzzacchi
DIST, Polytechnic University of Torino
e-mail `luigi.buzzacchi@polito.it`

Gilberto Turati♣
Department of Economics and Statistics (ESOMAS), University of Torino
e-mail `gilberto.turati@unito.it`

Abstract

We study the institutional solutions needed in a decentralized framework to cope with the potential adverse welfare effects caused by localized negative shocks, that impact on the provision of public services and that can be limited by precautionary investments. We consider first a public relief fund to cover these "collective risks". We analyze the under-investment problem stemming from the moral hazard of Local administrations, when investments are defined at the local level and are not observable by the Central government that manages the relief fund. We then examine the potential role of private insurers in solving the under-investment problem. Our analysis shows that the public fund is almost always a better institutional arrangement with respect to the private insurance solution, but competitive private insurers can improve social welfare in the presence of Central government's soft budget constraints problems, especially when the number of Local administrations is large.

JEL Codes: H23, H77, G22

Keywords: collective risk, disaster insurance, public relief fund, private insurance

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♣ Corresponding author: Università di Torino, Dipartimento di Scienze Economico-Sociali e Matematico-Statistiche (ESOMAS), C.so Unione Sovietica 218 bis, I-10134 Torino, Italy, phone +39.011.6706046, fax +39.011.6706062.

1. Introduction

In many countries, most public services (e.g., schooling, health care, public safety) are provided and managed by local administrations, while they are financed – at least partly – with funds from the centre. The reason for Central government funding is usually recognized in the need of "equalizing" the provision of such services across the country, since most of these represent constitutional basic rights for citizens. However, despite these equalization efforts, the provision of local public services can be affected by a number of different risks, the realization of which can potentially imply an unequal level of provision. For instance, natural disasters or terrorist attacks can destroy public schools or hospitals; organizational inefficiencies or even human mistakes by public employees can generate adverse welfare shocks that heavily impact on both the level and the quality of services. Indeed, in all these examples – which we define as *collective risks borne by local communities* – two questions are put at the forefront of the public discussion whenever an unfortunate event occurs: what can public administrations do *ex-post* to alleviate the adverse welfare effects on communities hit by negative shocks? What should have been done *ex-ante* in order to avoid the occurrence of these negative shocks?

As for the first question, depending on the level of damage, a transfer policy aimed at providing initial help and at least a partial reimbursement by the Central government of the adverse effects of the shocks is usually called for[1]. This expresses *a common claim for solidarity* toward those communities who suffered welfare losses, which are coupled with losses also at the individual level[2]. As for the second question, it is recognized that much of the

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[1] For instance, considering post-loss arrangements aimed at sharing catastrophic risks among citizens belonging to different communities, Cole *et al.* (2011) illustrate public loss financing in the US with a particular focus on the Florida case. Raschky and Weck-Hannemann (2007) describe several relief programs in the EU.

[2] For instance, in the case of a natural disaster, the destruction of a school or a hospital will be almost always

damage (or some of its consequences at least) can be avoided by *investing in mitigation*[3]. In the case of floods, for instance, dams and barriers can be built to reduce the likelihood of losses occurring, or the severity of damage; in the case of terrorist threats, better organization of the counter-terrorist intelligence can prevent potential attacks.

Given the importance of these investments, it is crucial to understand how incentives to invest for local communities are affected by different institutional arrangements to cope with collective risks. But unless Local administrations are obliged to cope by themselves with the realization of losses[4], *any* 'risk-transfer' mechanisms which provide Local governments a coverage of these collective risks will actually *reduce* incentives to invest in mitigation. These *diluted incentives* are particularly problematic in multi-layered systems of government/federations, especially if – as it is the case - protection investments can be only partially observable by the Central government: this latter would share losses to guarantee equality, but this goes against efficiency, since it leaves room for opportunistic behaviors by Local governments.

The literature on inter-regional insurance in federations has only partially addressed this issue so far. For instance, Persson and Tabellini (1996) and Bucovetsky (1998) consider stochastic shocks affecting income disparities across individuals and Local administrations. Lockwood (1999) add to this framework also stochastic events impacting on the cost of producing a pure public good or the demand for the public good. All these contributions

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coupled with the destruction of private houses. Our analysis here will be limited to risks characterizing the management of the first type of assets.

[3] As reported by Linnerooth-Bayer and Mechler (2008, p. 5), "*in many contexts every Euro invested in risk prevention returns roughly 2 to 4 Euros in terms of avoided or reduced disaster impacts on life, property, economy and environment*".

[4] This can be obtained for instance by making compulsory for Local governments to save funds ex-ante. An example is given in the U.S. by the "rainy day funds" (or "budget stabilization funds"), i.e., States reserve funds used to partially offset revenue shortfalls and to maintain the level of public expenses (see, e.g., Maag and McCarthy, 2006). A similar arrangement is represented by the "mandatory disaster reserves" discussed in Wildasin (2007) in the context of flood risks in the U.S. There are two main problems with these mechanisms: first, losses – especially in the case of natural disasters – can be much higher than reserves; second, difficulties in public budgets make it difficult to save monies for the future.

highlight the potential problem of opportunistic behavior by lower levels of government that can emerge when Central government provide them "insurance". Looking specifically at insurance for collective risks (including natural disasters and terrorist attacks), the possibility that ex-post transfers can dilute the ex-ante incentives for Local governments has been investigated prominently by Wildasin (2002; 2007; 2008; 2012), and by recent contributions by Goodspeed and Haughwout (2012) and Lohse and Robledo (2013).

However, this literature on risk transfers mechanisms to deal with shocks in federations substantially focuses on *public* intra-national risk-sharing arrangements only, and does not consider alternative *private* financial schemes. But Local administrations do often buy coverage on private insurance markets, transferring risks to private companies. Examples include coverage for a variety of collective risks, from damage to public infrastructures to liability insurance for public administrations[5]. Moreover, the Central government frequently imposes *positive* (and sometimes even *negative*) mandatory limits to the use of the private insurance solution, thus emphasizing the need to discipline Local administrators. For instance, the insurance for malpractice liability of public hospitals is compulsory in different countries (OECD, 2006), but the insurance for public assets is illegal in Sweden (Linnerooth-Bayer and Mechler, 2008). What will be the impact on the incentives to invest in mitigation when risks are transferred to private insurers as an alternative to a public risk-sharing arrangement?

In this paper we provide a first answer to this question. We take a normative approach and - in a decentralized 'federal' framework – we compare the welfare properties of (a) a

[5] Private coverage for smaller collective risks is widely diffused: for instance, the "Supplement to the Official Journal of the European Union", dedicated to European public procurement, weekly reports hundreds of tender notices from public administrations in the European Economic Area. Private coverage for larger catastrophic events is common especially in small countries and/or in the form of public-private partnership (e.g., Hofman and Brukoff, 2006; CEA, 2007; Linnerooth-Bayer and Mechler, 2008).

"Federal Relief Fund" (FRF in the following; i.e., a system of *ex-ante* defined transfers to Local administrations) with those of (b) a private insurance for Local administrations, both in the case of a hard and a soft budget constraint for the Central government. These two institutional arrangements require local administrations to pay a contribution – implicit in the case of the FRF, explicit in the case of the premium to be paid to the private insurer – in order to obtain coverage for risks. Given the coverage, in both cases an under-investment problem in protection – stemming from the moral hazard of local administrations – will emerge. Our analysis shows that – under fairly general hypotheses – the public solution is almost always superior to the private one in the presence of hard budget constraints for Local administrations, but this advantage declines quickly as the number of local governments grows. Furthermore, when the Central government cannot credibly commit to an optimal transfer rule, competitive private insurers are *sometimes* able to improve on the FRF solution by inducing a higher level of precautionary investments, even when the number of Local administrations is relatively small. The main intuition for these results is that while the public solution operates with *ex-post* contributions defined on the *actual* realization of losses, private insurers need to define an *ex-ante* premium. This latter mechanism is less efficient because – given a target level of equality among Local administrations – an optimally designed FRF mechanism provides more incentives to invest in mitigation.

The remainder of the paper is structured as follows: Section 2 describes the working of a system of inter-governmental transfers, which defines the Federal Relief Fund, both under a hard and a soft budget constraint regime. The role of private insurers is studied in Section 3. Section 4 provides a discussion of the results. Section 5 briefly concludes the paper.

2. The Federal Relief Fund (FRF)

2.1. The baseline model

Our analysis is based on a very simple and stylized game, where a Federal ("Central") government interacts with N (identical) lower level ("Local") administrations. One can think of these actors as Regional (or State) governments, or even some other local autonomous public bodies such as schools, hospitals, or universities[6]. The main differences between the two layers of governments are related to the assignment of taxing power and to the management of public assets. Only the Central government retains the power to tax citizens, whereas this right is not awarded to Local administrations[7]. The latter are entitled to manage some public assets essential to produce local public services. The assets face specific risks: Local administrations can reduce potential losses by investing in protection, but these investments are assumed to be unobservable by the Central government[8]. A typical example would be a public hospital: risks range from medical errors (assuming that the hospital is liable for the economic losses caused by such errors, as it is in many countries) to natural disasters which can hit the infrastructure. Managers can reduce clinical risk by better organizing work shifts, and earthquake risk by adopting anti-seismic building

[6] Notice, however, that the number of Regions is very different from the number of Municipalities in almost all countries. Taking Italy as an example, the 20 Regions compare with about 8,000 Municipalities. We will loosely refer throughout the paper to small and large N to catch this variation, which can be basically referred to the layer of government in charge of investing in protection.

[7] In real world cases, local governments often have their own taxes. However, the Central government retains the possibility to "equalize" resources by smoothing differences in fiscal capacity among Local administrations.

[8] In reality, mitigation investments can be observable with different degrees, both by the Central government and by other third parties, like private insurers (or the courts in charge of verifying contingencies). However, even the more observable investment programs retain a significant component of non-observability. Think for instance to anti-seismic buildings. While their structural characteristics can be relatively easily observed, it is difficult – without assuming large control costs – to assess cement quality. Notice that this is exactly what happens in the real world whenever a disaster occurs. Examples include the recent earthquake in Italy: public buildings (like schools and hospitals) has been discovered to be built with poor cements. An interesting evidence on the imperfect observability of building risk is provided by Emons (2001).

techniques. There is only one period: precautionary investments exhaust their preventive impact during the period that also coincides with the electoral cycle, at both the local and the central level.

The Central government C defines ex-ante a global budget $N\Omega$ of total transfers to Local administrations to be used for three main purposes: (a) current expenditures (i.e., expenditures for providing the public service); (b) precautionary investments; (c) repayment of losses. We consider two different commitments by the Central government, which identify two different 'soft budget constraints' problems: a commitment on the global budget size $N\Omega$, and a commitment on a pre-determined transfer rule given a fixed global budget size $N\Omega$. In both cases, when the budget is soft, the distribution of funds to Local administrations will be *discretionally* determined by the Central government.

The timing of the game is defined as follows:

a) first, Central government announces a 'transfer rule' T, i.e., the amount of funds that will be transferred to each Local administration (T_1, T_2, …, T_N);

b) then, Local administrations (acting simultaneously) define the amount of resources to be invested in protection I_i. Investments are not observable by the Central government. As a consequence, transfer rules cannot be made contingent on investments;

c) Nature determines the realization of loss d_i in each single administration i; losses are assumed to be independent (i.e., $\mathrm{Cov}[d_i, d_j] = 0$) and observable by all players. To simplify the presentation of our argument, we also assume that d takes up only two possible outcomes D (> 0) and 0 with probability respectively $\delta(I)p$ and $(1 - \delta(I)p)$.[9] Investments I clearly influence the loss probabilities[10]; we assume that $\partial\delta/\partial I < 0$, $\partial^2\delta/\partial I^2 > 0$, and we normalize $\delta(0) = 1$;

d) finally, the Central government implements the transfers, according to the pre-determined transfer rule T and the budget constraint regime (hard or soft), and each Local administration i is able to define the (ex-post) budget for current expenditure $x_i = T_i - I_i - d_i$.

Central government's payoff is represented by an "abbreviated" social welfare function (SWF)[11], explicitly defined on a standard efficiency-equality trade-off, in order to account for both the total (expected) amount of current expenditures x_i and the (expected) inequality in expenditures among Local administrations:

$$\Pi_C = E\left[\sum_{i=1}^{N} x_i\right] - \alpha E\left[\sum_{i=1}^{N} (x_i - \bar{x})^2\right], \tag{1}$$

where $\bar{x}$ is the mean expenditure of Local administrations. Notice that α (≥ 0) accounts for the degree of inequality aversion of the Central government: the higher α, the higher the loss in utility stemming from inequality. Moreover, as the first term in Eq. (1) is the sum of current expenditures, Central government payoff shows a sort of "aversion" to

[9] Notice that the probability and the size of damage D can be thought to vary from small to large amounts, identifying very different classes of risk. For instance, 'catastrophic' risks can be identified when a very small p is associated to a very large damage D. Furthermore, notice that the independence assumption easily stems from the *localized* nature of these risks. Fires, floods, terrorist attacks, clinical mistakes are all investing in a *specific* local community (or a group of communities), not a whole country.

[10] The literature (see for example Jullien *et al.*, 1999) distinguishes between protection investments (when the investment is aimed at reducing the probability of the adverse event) and prevention investments (when the investment is aimed at reducing the severity of the damage). In our setup, I is consequently a 'protection' investment.

[11] An "abbreviated" SWF is an increasing function of efficiency and equality. This term has been introduced by Lambert (1993); Champernowne and Cowell (1997) use the alternative term "reduced" SWF.

losses, since these clearly reduce expected current expenditures[12].

Local administrations' payoffs are defined only on expected current expenditures:

$$\Pi_i = E[x_i]; \quad i = 1,...,N \tag{2}$$

The intuition behind this formulation is quite simple: local politicians are rewarded for local expenditures, but not for investments in protection, which are unobservable by assumption also by citizens. Hence, the higher x_i, the higher the probability they will be re-elected.

Notice that, while the Central government is modeled as a risk-averse player, Local administrators are modeled as risk-neutral players. Following Bucovetsky (1998), we associate citizens' risk-aversion to the layer of government that can raise taxes. Indeed, recall that the Central government – after each localized adverse event has occurred – needs to restore equality by generally imposing taxes on *all* taxpayers. Hence, the "risk" to raise additional taxes to cover damages is retained by the Central Government only.[13] This differential attitude toward risks seems also to be confirmed empirically when considering that – at least in many circumstances – Local governments are *obliged* to purchase coverage

[12] Notice that our payoff function can be derived as an utilitarian SWF that aggregates the utilities of risk-averse individuals, or as a non-utilitarian SWF in the presence of inequality aversion *per se* of the social planner (see, e.g., Carlsson et al., 2005). The inequality index we are using – the variance of the current expenditures – belongs to the set of "appropriate" indexes considered in this literature. It is important to notice that our results do not hinge on the specific index we use, and hold also considering alternative inequality indexes. Moreover, a sufficiently low α ensures monotonicity of the SWF. The use of a payoff function for the central planner allowing for the standard efficiency-equality trade-off is not new in the literature. See, e.g., Konrad and Seitz (2003), for the study of the optimal mutual insurance contract between States within a federation, and Picard (2008), for an analysis of the role of private insurance in the prevention of natural disasters.

[13] As it has been suggested by the literature on public bankruptcies (see, e.g., McConnell and Picker, 1993), the imposition of new taxes, at least in principle, is in fact a remedy for coping with welfare losses that no private insurer can duplicate, and thus makes private insurance a Pareto-inferior solution in a centralized framework. That private insurance are Pareto-dominated by a public relief fund is in line with the Arrow and Lind (1970) theorem, which shows that the expected utility losses are approximately zero as the number of taxpayers becomes larger and larger. Hence, in a centralized framework, the costs of risk-bearing can be optimally spread throughout the whole community by the Central government. What happens in a decentralized framework is, however, unclear.

on private markets.[14] As we will discuss below, this risk-neutrality assumption will have obvious consequences on the choice to buy private insurance by Local administrations, and the need to impose a minimal degree of coverage. We relax this assumption in Section 4, showing that this does not affect the generality of our results, since the attitudes towards risk impacts in the same way on both the FRF mechanism and the private insurance solution.

2.2. The transfer rule

The transfer rule T – defined ex-ante by the Central government – is a formula to distribute the global budget $N\Omega$ among Local governments. In the absence of a public relief fund to cover collective risks, the transfer rule will simply assign a flat transfer Ω to each Local government, and leave each community to cope with the realization of losses. On the contrary, in the presence of a relief fund, losses can be fully or partially shared. Consider first *full risk sharing*. If M is the number of Local administrations hit by losses D ($0 \leq M \leq N$), the transfer rule able to fully share losses is:

$$T_i(d_i) = \Omega + d_i - \bar{d}(M) \tag{3a}$$

where $\bar{d}(M) = \frac{1}{N}\sum_{j=1}^{N} d_j = D\frac{M}{N}$ represents the average actual loss. In other words, the transfer rule expressed by Eq. (3a) can be interpreted as the sum of three components: (a) a symmetric flat transfer Ω; (b) a transfer from a 'risk sharing fund' that repays each loss d_i

[14] Notice that in any case inequality aversion of the Central government and the Local administrations cannot be compared directly. The Central government is averse to the variance of welfare *between localities*, whereas the possible inequality aversion of a Local government could be related to welfare inequalities of citizens *within its own boundaries*. Notice that the larger is N, the lower is the variance of services provided at the local level, hence, the less important are the inequalities within boundaries. The limit situation is that of municipalities: within-boundaries inequality is unimportant in this case, especially for small cities.

($d_i = D$ or 0); (c) a contribution to the 'risk sharing fund', equal to the average realized loss $\bar{d}(M)$. As long as $\bar{d}(M)$ depends on every realized level of d_j, the budget of each Local administration is really contingent on the whole distribution of losses.

In the case of *partial* risk sharing, the general form of the transfer rule becomes:

$$T_i(d_i) = \Omega + \sigma\left[d_i - \bar{d}(M)\right] \tag{3b}$$

The second term, again, represents the working of the 'risk sharing fund', which includes the reimbursement of losses σd_i, and the risk sharing contribution $\sigma \bar{d}(M)$ needed to finance (partial) reimbursements of losses. Clearly, $\sigma \in [0,1]$ is the degree of coverage provided by the fund, and for every level of σ, T_i satisfies the budget balance constraint, since $\Sigma_I\, T_i = N\Omega$.

The expected payoff for the Central government can then be expressed as:

$$\begin{aligned} \Pi_C &= E\left[\sum_{i=1}^{N}(T_i - I_i - d_i)\right] - \alpha\, E\left[\sum_{i=1}^{N}(x_i - \bar{x})^2\right] = \\ &= N\Omega - \sum_{i=1}^{N}\left(I_i + \delta(I_i)\hat{d}_0\right) - \alpha(1-\sigma)^2 \Psi\left(N, \delta(I_1), \ldots, \delta(I_N)\right) \end{aligned} \tag{4}$$

where $\hat{d}_0 = D\, p$ is the *expected* loss in the absence of any investments, and:

$$\begin{aligned} \Psi(N, \delta(I)) &= \sum_{M=0}^{N} \pi(M) \frac{M(N-M)}{N} D^2 = \\ &= D \sum_{M=0}^{N} \frac{N!}{M!(N-M)!} [\delta(I)p]^M [1-\delta(I)p]^{(N-M)} (N-M)\bar{d}(M) \end{aligned} \tag{4a}$$

Each term of the sum represents the variance of current expenditures among local administrations in the specific state of nature when M shocks occurred, weighted for the probability of such state of nature $\pi(M)$. Notice that the first term in Eq. (4) (i.e., $E[\Sigma\, x_i]$)

does not directly depend on σ, since this only affects the level of compensating transfers (added to some Local administrations and subtracted from others)[15]. The term Ψ does not depend on σ either, and decreases as N increases[16]. Finally, the payoff of Local administration i (i.e., the expected expenditure) is the following[17]:

$$\begin{aligned} \Pi_i &= E\left[T_i - I_i - d_i\right] = \\ &= \Omega + \sigma\,\delta(I_i)\hat{d}_0 - \sigma E\left[\sum_{M=0}^{N} \pi(M)\bar{d}(M)\right] - I_i - \delta(I_i)\hat{d}_0 = \\ &= \Omega - I_i - (1-\sigma)\delta(I_i)\hat{d}_0 - \frac{\sigma}{N}\sum_{j=1}^{N}\delta(I_j)\hat{d}_0. \end{aligned} \tag{5}$$

2.3. The benchmark case: full centralization

We begin our analysis by defining the benchmark case, without any strategic interaction between different layers of government, and considering all decisions to be centralized. In this case, Central government defines both the transfer T and investments I in each Local administration. Remember that since Local administrations are identical, it follows that $I_i = I\ \forall i$. The Central government problem can then be simplified to:

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15 As will soon become clear, the transfer rule indeed affects the investment strategies of the Local administrations, thus defining the ultimate amount of the budget that is free for current expenditures.

16 As it is evident in Eq. [4a], given N, Ψ is increased in particular by the terms where $(N - M)$ and M assume similar values. When damage is uncommon, the probability of such states of nature decreases when the number of administrations (N) is greater. In the simplest case of only two Local administrations, the variance of current expenditures is equal to $2\delta(I_i)p(1-\delta(I_i)p)\frac{(1-\sigma)^2 D^2}{4}$, which is the probability of observing an unequal outcome (only one Local administration is hit by a shock) times the variance of expenditures.

17 Notice that the payoffs expressed in Eq. (4) and (5) are obtained assuming that losses can take only two possible outcomes, an hypothesis we maintain throughout the paper. Clearly enough, this assumption of a binomial distribution of losses is made only to simplify presentation. All of our results can be easily interpreted also in a more general framework, where losses are distributed according to a generic probability density function including those describing extreme events as discussed in Wildasin (2008). In this case, the average actual loss $\bar{d}(M)$ and the average expected loss in the absence of precautionary investments $\hat{d}_0$ are still defined accordingly. The definition of Ψ becomes more complex, but it retains the property of independence from σ, and of a negative correlation with N.

$$max_{I,\sigma}\, \Pi_C = max_{I,\sigma} \left\{ N\left[\Omega - I - \delta(I)\hat{d}_0\right] - \alpha(1-\sigma)^2 \Psi(N, \delta(I)) \right\} \tag{6}$$

Central government first determines σ (given I), then selects the amount of resources to be invested in protection I. The F.O.C. for the solution of the problem is:

$$\frac{\partial \Pi_C}{\partial \sigma} = 2\alpha(1-\sigma)\Psi(N, \delta(I)) = 0 \tag{7}$$

which brings us to the optimal degree of 'risk sharing' σ^{*c} = 1 (where superscript *c* is a mnemonic for 'centralized')[18]. Notice that σ^{*c} is determined by looking solely at the 'equality component' of the Central government's payoff function. Given the fixed budget $N\Omega$, the result is not surprising: Local administrations will be sharing losses, whenever they occur. σ^{*c} makes null the second term of Eq. (1) (the equality component): consequently, given σ^{*c}, the Central government defines the optimal investment in protection I to be implemented, by maximizing the 'efficiency component' of its payoff:

$$max_I \left\lfloor \Omega - I - \delta(I)\hat{d}_0 \right\rfloor \tag{8}$$

The F.O.C. implies:

$$1 = -\frac{\partial \delta(I)}{\partial I}\hat{d}_0 \tag{9}$$

which implicitly characterizes the optimal investment I^{*c} [19]. Interpretation of Eq. (9) is straightforward: marginal benefits of investing in protection (given by the marginal reduction in the value of expected losses) equals marginal costs.

[18] Identical results could be obtained in the case of *observable* investments, thanks to the opportunity for the Central government to design transfers which are contingent on the actual value of I.

[19] An interior equilibrium solution (i.e., $I > 0$) is obtained only if mitigation investments are sufficiently productive. More formally, in this case, only if $\delta'(0) < -1/\hat{d}_0$. We assume that $\delta'(0)$ is sufficiently negative in all the cases illustrated in the paper so that an optimal solution with positive investments always exists.

2.4. The decentralized case when the Central government can credibly commit **ex-ante**

In the benchmark case all decisions are centralized. However, in most real-world cases, precautionary investment are in the hands of Local administrations; and these can decide their amounts, which Central government cannot observe. We solve the game by backward induction, and look for sub-game perfect Nash equilibrium. We begin with the decision of Local administrations to invest, and then we analyze the choice of the transfer rule T (i.e., the level of σ) by the Central government.

When each Local administration decides the optimal investments to be implemented, given σ, it will maximize its own expected payoff, considering only total current expenditures x in its administration. The problem to be solved by Local administration i (see Eq. (5)) amounts to:

$$max_{I_i}\ \Pi_i = max_{I_i}\left[-I_i - (1-\sigma)\delta(I_i)\hat{d}_0 + \Omega - \frac{\sigma}{N}\sum_{j=1}^{N}\delta(I_j)\hat{d}_0\right] \tag{10}$$

The F.O.C. for the solution of the problem can then be written as:

$$1 = -\frac{\partial\delta(I_i)}{\partial I_i}\left(1-\sigma\frac{N-1}{N}\right)\hat{d}_0 \tag{11}$$

which implicitly defines the optimal investment I_i^*, which clearly depends on σ.

Given that the Local administrations are identical, we will of course have $I_i^* = I^{*d}\ \forall i$ (where now superscript d is mnemonic for 'decentralized'). Notice that – by simply comparing Eq. (9) with Eq. (11) – it is clear that protection investments are reduced with respect to the benchmark case, $\forall\sigma > 0$; moreover, I^{*d} decreases when N increases. This is a strategic effect stemming from σ itself, that relies on the unobservability of investments: each Local administration prefers to free-ride on investments and spend in *x*; the free-riding effect being clearly emphasized when the number of Local administrations is greater. Indeed, own investments increase the probability that Local administration will subsidize the other ones for (potential) losses, and this clearly reduces the incentive to invest. There is then a *vertical externality* quite common in the literature on fiscal federalism, which influences the optimal amount of σ that will be chosen by the Central government[20]. Notice also that I^{*d} will be strictly positive even when σ = 1[21]. As we will show in the next Section, the mechanism aimed at financing reimbursements marks a striking difference between public transfer rules and the private insurance mechanism: when insurers are involved, the premium paid by a specific Local administration is not affected by the realization of losses, while in the public case, each realized loss increases the risk sharing contribution, $\sigma \bar{d}$, of each single administration (see Eq.(3b)).

Given the choice of the investments to be implemented by the Local administrations, Central government will then define the optimal transfer rule *T*. Since the total budget $N\Omega$ is fixed, this amounts to defining the degree of risk sharing σ. The optimal transfer σ^{*d} stems from two countervailing effects: on the one hand, Central government has the incentive to fix σ^{*d} as close as possible to $\sigma^{*c} = 1$ in order to guarantee equality among local constituencies; on the other hand, by guaranteeing full sharing of losses, it reduces the incentive of a Local administration to invest in *I*, since $\partial I^{*d}/\partial\sigma < 0$. This trade-off is summarized in the following Proposition 1:

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[20] This effect could also be interpreted as a *common-pool problem*, since the mutual fund is a sort of public good whose financing is shared among Local administrations.

[21] The optimal investment I^{*} monotonically decreases when σ and N increase, until it becomes zero. If the absolute value of $\delta'(0)$ is sufficiently high, I^{*} is positive in the whole range [0,1] of σ. See again footnote 19.

Proposition 1: *The degree of risk sharing in the case of decentralization is lower than the one in the centralized case, i.e.* $\sigma^{*d} < \sigma^{*c} = 1$, *and* $\partial\sigma^{*d}/\partial N < 0$. *Protection investments* I^{*d} *will be reduced with respect to the centralized case* I^{*c}, *unless Central government cares only about efficiency.*

Proof: see Appendix.■

Proposition 1, in line with, e.g., Goodspeed and Haughwout (2012), suggests that decentralization almost always leads to an inefficient outcome: precautionary investments will be reduced with respect to the centralized case. By fixing σ, the Central government trades off equality and efficiency: on the one hand, a lower σ is used to induce more incentives to invest in protection; on the other hand, σ must be higher in order to guarantee a sufficient degree of loss sharing. Since we have ruled out commitment problems thus far, notice that the inefficiency stems *only* from the free-riding behavior of Local administrations[22]: risk is shared among all the Local administrations and the effort to lower the probability of adverse events decreases the risk sharing contribution $\sigma\bar{d}$ for all the participants. This inefficiency will be magnified when the Central government is not able to credibly commit to a pre-determined level of financing, a point that will be discussed next.

[22] Interestingly, this idea of free-riding behavior among local governments has received the attention of legislators. One example is the arrangement provided by Law 353/2000 in the case of forest fires in Italy. In the experimental period between 2000 and 2002, the Central government defined a budget of 10 million euro per year ($N\,\Omega$ in our notation) to be distributed to regional governments. In turn, regions redistribute financial resources to various municipalities according to the following rule: half proportional to the size of the local forestry area; half inversely related to the ratio between the size of forestry land destroyed by fire and the original size of forested land. As noted by Pazienza and Beraldo (2004), the law "has tried to introduce a management of the financial resources used in the fight of forest fires in such a way as to discourage any form of free-rider behavior that could be taken up by regional or other local authorities".

2.5. The decentralized case when the Central government cannot credibly commit ex-ante

We have assumed so far that Central government is able to commit both to a predetermined transfer rule and to a predetermined budget. While this may be true in some situations, especially when the Central government cares only about efficiency, it is definitely difficult to sustain when *large* welfare losses occur (i.e., when D is above a threshold 'subjectively' defined by the Central government each time an adverse event occurs). In the case of floods, earthquakes or other natural disasters, and more generally when there are 'catastrophic' losses, Central government might be unable not to renege on its ex-ante commitment. In other words, in all these cases, *after* the disaster occurred, Central government can step in and redefine the transfers ex-post[23]. Clearly enough, if Local administrations anticipate this move by the Central government, both the size of the global budget and the announcement of the transfer rule at the first stage of the game are just 'cheap talk'. Actual transfers will then be fixed *after* the level of damage in every Local administration has been observed, and they maximize ex-post the Central government's payoff.

Consider first the case in which the Central government is unable to commit to the transfer rule, but still keeps the budget fixed to $N\Omega$. The equilibrium strategies in this case are easily obtained from results in the previous section. Simply note that, since the initial definition of the transfer rule by the Central government is now 'cheap talk', the sequence of moves is reversed here: at the final stage of the game, given protection investments are sunk once losses are realized, the transfer rule has no incentive role, and Central government

[23] Notice that this is a simple application of the well-known Samaritan's dilemma, a typical situation of time inconsistency of public policies. See the seminal paper by Buchanan (1975), and the application to the context of disaster insurance by Lohse and Robledo (2013).

maximizes the equality component of its payoff by fixing $\sigma^{*dnc} = 1$ (where now superscript *dnc* is mnemonic for 'decentralized and no commitment'), regardless of what was announced before. Moving backwards, each Local administration decides the optimal investments to be implemented, anticipating the optimal response by the Central government. The problem to be solved amounts to:

$$max_{I_i} \Pi_i = max_{I_i} \left\{ -I_i + \Omega - \frac{\sum_{j=1}^{N} \delta(I_j)\hat{d}_0}{N} \right\} \tag{12}$$

The F.O.C. for the solution of the problem can then be written as:

$$1 = -\frac{\partial \delta(I_i)}{\partial I_i} \frac{\hat{d}_0}{N}, \tag{13}$$

which can also be obtained directly from Eq. (11) by setting $\sigma = 1$. Given our assumption of identical local administrations, the optimal investment implicit in Eq. (13) is symmetric, i.e., $I_i^* = I^{*dnc}$. Notice also that by simply comparing Eq. (13) with Eq. (11), protection investments are reduced by the inability of the Central government to commit to a predetermined transfer rule, since $\sigma^{*d} < 1$ (see Proposition 1)[24].

Consider now the case in which the Central government is unable to commit to the budget size $N\Omega$ ex-post. Taking into account, e.g., external constraints on public finances, the availability of some sort of 'rainy day' funds, the size of the damage, and the localities hit by the adverse event, the Central government can *discretionally* renege on the promised budget in many different ways. In general, however, considering previous Eq. (10), for a given

[24] This specific kind of dilution of incentives to invest in mitigation is also dubbed 'charity hazard'. Actually, when referring to this type of hazard, the literature usually focuses on the decreased demand of insurance (see, e.g., the review in Raschky and Weck-Hannemann, 2007).

level of risk sharing σ, the Local administration expects now to receive $(\Omega + \Delta\Omega)$ instead of simply Ω. As can be easily observed, if the size of the extra-budget $\Delta\Omega$ does not depend on the level of damage (hence, on I_i), the marginal incentives to invest in protection are unaffected. On the contrary, if we reasonably assume that the budget – given the inequality-aversion of the Central government – will be increased *considering the level of damage*, every Local administration expects to receive *more* only when the negative shock strikes its community, i.e., the expected extra-budget is $\delta(I_i)\, p\, \Delta\Omega$. Consequently, the marginal benefits of investing in mitigation - the RHS of previous Eq. (13) - is reduced by $\frac{\partial \delta(I_i)}{\partial I_i} p\Delta\Omega$, and the investment I^{*dnc} is further reduced with respect to the case in which the Central government is unable to commit to a pre-determined transfer rule. We are now able to show the following Corollary to Proposition 1:

Corollary to Proposition 1: *In the case of decentralization, when Central government is unable to commit either to a pre-determined transfer rule or to a fixed global budget, protection investments I^{*dnc} will be reduced with respect to the case of perfect commitment I^{*d}, unless Central government cares only about efficiency.*

Proof: Directly from discussion above.■

Notice however that, even if lower than I^{*d}, I^{*dnc} will be strictly positive[25], because a loss d in each Local administration increases, *ceteris paribus*, the risk sharing contribution $\sigma\, \bar{d}$ by the amount $\sigma\, d/N$. Still, for even a very small degree of inequality aversion by the Central

[25] See footnote 19 again.

government, the inability to commit to a pre-determined transfer rule will result in a lower level of investments in protection by Local administrations. Can the present situation be improved by allowing for a private insurance solution? This is the issue we address in the next Section of the paper.

3. The role of private insurers

3.1. The optimal private solution

In the previous Section of the paper we assume that Local administrations can recover from losses only by resorting to transfers from the Central government. As already discussed in the introduction, however, in many real world cases Local administrations do buy (sometimes are obliged to buy) insurance coverage from private providers to hedge against the risks they face in producing local services. An intriguing question is then to understand the role of private providers as *substitutes* for the FRF. Before moving on to a more formal analysis, we can list a number of advantages and disadvantages of private insurers. On the one hand, for instance, private insurers may be better suited than the Central government to observe a proxy for the realized investments in protection. On the other hand, in the case of imperfect competition in private insurance markets, private insurers will be able to extract rents from the public administrations. To avoid easy arguments in favor of institutional arrangements where private insurers can play a role, we rule out these possibilities here. We assume perfectly competitive insurance markets and we then normalize loadings to zero[26]. Moreover, we also assume that private insurers can only observe realization of losses, as the Central government is able to do[27].

If the private insurance solution is chosen, the Central government will transfer the amount Ω to each Local administration, leaving the private market the task of covering the risk of losses. The premium charged by the insurer needs to deal with the classic moral hazard problem due to the unobservability of investments (Shavell, 1979). Hence, the fair premium *P* charged by the insurer to the Local administration depends on the level of coverage λ, where λ is the share of total losses to be reimbursed. In particular, the premium is fixed equal to the expected loss, i.e., $P(\lambda) = \lambda\delta\left(I^{*Ins}(\lambda)\right)\hat{d}_0$ (where *Ins* is now a mnemonic for the 'private insurance' case) and, in return, the Local administration receives the amount λ *d* from the insurer.

Let us first assume that the Local administration can freely choose the coverage level together with the investment I^{*Ins}:

$$\begin{aligned} max_{I_i,\lambda_i}\, \Pi_i = max_{I_i,\lambda_i} \left\lfloor \Omega - P(\lambda_i) - I_i - (1-\lambda_i)\delta(I_i)\hat{d}_0 \right\rfloor \\ s.t. \quad P(\lambda_i) = \lambda_i\, \delta\left(I^{*Ins}(\lambda)\right)\hat{d}_0 \end{aligned} \tag{14}$$

We drop subscript *i,* since each identical Local administration deals individually with a number of competitive private insurers. Noting that investments are fixed after λ has been chosen and the insurance premium represents a sunk cost, the F.O.C. for the solution of the problem is:

26 It is worth noting that we have already assumed the cost of managing the mutual fund by the Central government to be zero as well.

27 In other words, insurance contracts cannot be contingent on mitigation investments. Notice also that we do not consider here 'experience rating' contracts, and limit the analysis to the most simple insurance contract, which mirrors the structure of the FRF. As the literature suggests (see, for instance, Rubinstein and Yaari, 1983), the disciplining effect from 'experience rating' is effective only when the frequency of adverse events is relatively high. This is not the case for the types of risks under scrutiny here.

$$
\begin{aligned}
&1 = -\frac{\partial \delta(I)}{\partial I}(1-\lambda)\hat{d}_0 \\
&\rightarrow I^{*Ins} = I^{*Ins}(\lambda)
\end{aligned}
\tag{15}
$$

and[28]:

$$
\begin{aligned}
&\left.\frac{\partial \Pi_i}{\partial \lambda}\right|_{I^{*Ins}=I^{*Ins}(\lambda)} = 0 \rightarrow \frac{\partial\left[\Omega - I^{*Ins}(\lambda) - \delta\left(I^{*Ins}(\lambda)\right)\hat{d}_0\right]}{\partial \lambda} = 0 \\
&\rightarrow -\frac{\partial \delta(I)}{\partial I}\frac{\partial I^{*Ins}}{\partial \lambda}\hat{d}_0 = \frac{\partial I^{*Ins}}{\partial \lambda} \rightarrow \frac{1}{1-\lambda} = 1 \rightarrow \lambda = 0
\end{aligned}
\tag{16}
$$

Summing up, as expected, none of the Local administrations purchases any coverage in the private insurance market[29], and the protection investments are fixed to the efficient level. This result can be easily understood since the private insurer simply dilutes the investment incentives, and the optimal coverage is then the one that guarantees optimal individual incentives (see Eq. (9)), given that the Local administrator is modeled as a risk neutral player (i.e., the solution illustrated by Eq. (16) maximizes E [Σx_i]). Recalling our previous discussion, when a Central government simply provides a flat transfer Ω (i.e., $\sigma = 0$), the outcome is suboptimal because – as we have already shown – *minimal equality is obtained*. Hence, also this private solution is suboptimal.

Given the inequality-aversion by the Central government, the optimal second-best solution in the private case can be obtained by requiring *a compulsory minimal coverage level*, λ^m. This is exactly what happens in many real world cases[30]. Given the mandatory insurance, the

[28] Remember that $P(\lambda) - (1-\lambda)\delta(I)\hat{d}_0 = \delta(I)\hat{d}_0$.

[29] Notice that $\partial \Pi_i / \partial \lambda < 0$ when $\lambda > 0$.

[30] Notice, however, that a minimal coverage level needs to be imposed also in case of an *inadequate* level of risk aversion by Local administrations. We will discuss the implications of incorporating this assumption in the payoff function of local governments in the next section. But note from now that risk-aversion by Local administrations would have affected also the mutual fund solution in the same fashion. In particular, marginal benefits of protection investments will increase both in the case of a FRF, and in the case of a private insurance.

maximization problem of the Central government is then the following[31]:

$$
\begin{aligned}
& max_{\lambda^m}\, \Pi_C = max_{\lambda^m} \left\{ N\left[\Omega - I \underbrace{- P\left(\lambda^m\right) - \left(1-\lambda^m\right)\delta(I)\hat{d}_0}_{-\delta(I)\hat{d}_0} \right] - \alpha\left(1-\lambda^m\right)^2 \Psi\left(N, \delta(I)\right) \right\} \\
& s.t.\quad I = I^{*Ins}\left(\lambda^m\right)
\end{aligned}
\tag{17}
$$

which implicitly defines the optimal compulsory coverage level λ^{*m}.

The issue is then whether it is possible to obtain a larger payoff for the Central government if this minimal mandatory coverage λ^{*m} on the private market substitutes the public mechanism of the FRF described in the previous sections. Before analyzing this question in the two credibility regimes, by simply comparing Eq. (9) with Eq. (15), it is clear that if $\lambda^m > 0$, precautionary investments are reduced with respect to the benchmark case[32]. This is a strategic effect which is *different* from the free-rider problem in the decentralized solution: in the present case, no positive externality is generated by precautionary investments in each single Local administration on the cost of coverage of the other ones. Here the level of investments is suboptimal because the unit price of coverage increases with λ^m in order to discipline the moral hazard. Each Local administration thus prefers to retain the risk and devote more resources to current expenditures x. By imposing a minimal coverage, the Central government trades off efficiency and equality.

[31] Again, the strategies of the Local administrations are symmetric, so that we can simplify notation to $I_i = I^{Ins}$ $\forall i$.

[32] Remember from footnote 29 that the Local administration will choose the minimal compulsory coverage. This is due to the risk-neutrality assumption of the players. When the risk aversion of Local administrations is sufficiently high, there is no need to impose coverage.

3.2. The comparison when the Central Government can credibly commit ex-ante

We first compare the private insurance solution to the FRF when the *ex-ante* commitment by the Central government to a pre-determined transfer rule or a pre-determined budget size is credible. The crucial point to be emphasized here is what distinguishes the private solution from the public one. The net transfer in the case of a private insurer is $T_i = \Omega + \lambda d_i - P$, while the net transfer in the presence of a FRF is $T_i = \Omega + \sigma\, d_i - \frac{\sigma}{N}\sum_{j=1}^{N} d_j$ or, equivalently, $T_i = \Omega + \sigma\left(\frac{N-1}{N} d_i - \frac{1}{N}\sum_{\substack{j=1 \\ j\neq i}}^{N} d_j\right)$. As for the private solution, the Local administration pays the insurer a fixed premium P which is defined *ex-ante* (i.e., *before* the realization of losses is known); obviously, the insurer commits to repay *ex-post* a share λ of the actual loss. As for the public solution, the net transfer rule is contingent on the distribution of *realized* losses. Note that the funding mechanism of the Central government to the Local administration looks very similar to the net flow of capital between the Local administration and the insurer: given the same level of ex-ante coverage $\sigma = \lambda$, the term σd corresponds to the amount paid out by the insurer $\lambda\, d$, while the *expected* value of the contribution $E\left(\frac{\sigma}{N}\sum_{j=1}^{N} d_j\right)$ corresponds to the premium paid to the insurer $\lambda\, \delta(I)\hat{d}_0$. However, by simply inspecting the definitions of transfers above, it is clear that the incentive effect of a mutual fund is *different* from the one provided by a private insurer. In fact, the marginal impact of d_i on the transfer T is $\sigma (N-1)/N$ in the former case, while simply λ in the latter. The (fair) premium P is a sunk cost for the Local administration, while the risk sharing contribution $\frac{\sigma}{N}\sum_{j=1}^{N} d_j$ is fixed *ex-post* to cover the *actual* average loss. Hence, it does not represent a sunk cost for the Local administration and, consequently, it generates different investment incentives. In other words, when the two mechanisms are based on the same degree of coverage *ex-ante*, they actually produce *ex-post* a different level of efficiency, with the FRF allowing to obtain a higher level of investments; hence, to provide equal incentives, the private insurer must apply *ex-ante* a lower degree of coverage, thus determining lower equality *ex-post.* The working of the mechanism becomes evident considering that complete private insurance (i.e., $\lambda = 1$) generates null protection investments, while in the decentralized solution protection investments are positive even when $\sigma = 1$. These observations bring us to the following Proposition 2:

Proposition 2: *The incentive schemes of the private insurer can always be perfectly replicated by the FRF with a higher degree of coverage. In particular,* $\forall\tilde{\lambda}$ *, the degree of risk sharing* $\tilde{\sigma} = \frac{N}{N-1}\tilde{\lambda}$ *generates equal incentive schemes. As a consequence, the FRF solution always dominates the private insurance solution when the Central Government can credibly commit ex-ante and the number of Local administrations N is relatively small. As* $N \rightarrow \infty$*, the advantage of the public solution disappears.*

Proof: See Appendix. ■

As Proposition 2 makes clear, the decentralized scenario with the relief fund strictly dominates the private insurer solution when the number of Local administrations is relatively small, which could be the case when the layer of government in charge of investing in protection is closer to the Central government (i.e., the Regions in regional countries, or the States in federal countries). Decentralizing the task of protection investments to the lowest possible level of government (i.e., Municipalities, or even hospitals or universities) will increase the number of local administrations N involved, reducing the advantages of covering collective risks with a FRF.

An example can be useful to understand this key point. Assume that there are only two localities ($N = 2$), the degree of coverage offered by the FRF is $\sigma = 50\%$ and with a certain probability only one locality will experience a loss $D = 100$. According to Eq. (3b), the administration hit by the damage will obtain a net transfer $T = \sigma D - \sigma D/N = 50 - 25 = 25$: the transfer from the FRF to the locality experiencing the loss would be 50, but the two localities will have to contribute $50/2 = 25$ to the FRF in order for it to remain solvent. In the case of private insurance, localities pay a fixed premium P irrespective of their losses, so that their net balance is $\sigma D - P$. While investing in mitigation can reduce the term $\sigma D/N$ of the net reimbursement in the FRF regime, it has no effect on P paid to the private insurer. This is why the incentives to invest in disaster avoidance differ in the two cases. In this example, the same incentive effect provided by $\sigma = 50\%$ in the FRF case would have been determined by a private insurance coverage $\lambda = 25\%$, that obviously offers much less equality. The crucial point is that each locality is assumed to recognize that any "gross" transfers that it receives in the event of a loss will be partially offset by the amount that it (and all other localities) have to pay to keep the FRF solvent, in the case of credible commitment. This differential impact vanishes rapidly when N becomes large. For instance, if $N = 20$, the number of Italian regions, a locality with a loss of 100 will obtain $47.5 = 50 - (1/20)\ 50$, and the higher incentive to invest in mitigation offered by the FRF solution lies in the possibility to reduce the contribution to the fund which is now 2.5 instead of 25. In this case the incentive effects of the FRF when $\sigma = 50\%$ is provided by a private insurance coverage $\lambda = 47.5\%$ which offers about the same degree of equality.

On the normative side, Proposition 2 provides then an interesting policy suggestion: an intergovernmental system of transfers to cope with collective risks is better than private insurance when the number of lower-level jurisdictions is small; if protection investments are decentralized to a large number of Local administrations, then also private insurers work well.[33]

3.3. The comparison when the Central government cannot credibly commit ex-ante

We now compare the private insurance solution to the public mutual fund when the Central government cannot make a credible commitment. Consider the inability to commit to an optimal pre-determined transfer rule first. In this case, Central government is expected to perfectly equalize ex-post current expenditures among Local administrations in every state of nature (i.e., to fix $\sigma^{*dnc} = 1$). The incentive constraint for Local administrations is then expressed by Eq. (13), leading to a payoff for Central government which is given by:

$$\Pi_C^{dnc} = N\left[\Omega - I^{*dnc} - \delta\left(I^{*dnc}\right)\hat{d}_0\right] \tag{18}$$

When the Local administrations are insured, the payoff for the Central government is given by:

[33] Notice that, throughout the paper, we maintain the assumption of symmetric Local governments but, in practice, in many countries there are "urban giants" and numerous small municipalities. This is the case of Brussels in Belgium, Paris in France, Bangkok in Thailand, and Mexico City in Mexico to name a few. In all these instances, our analysis suggests that the public relief fund is preferable to private insurance. We thank an anonymous referee for pointing out this issue.

$$\Pi_C^{Ins} = N\left[\Omega - I^{*Ins}(\lambda) - \delta\left(I^{*Ins}(\lambda)\right)\hat{d}_0\right] - \alpha\,\Psi\left(N, \delta\left(I^{*Ins}(\lambda)\right)\right)(1-\lambda)^2 \tag{19}$$

The question is again whether an optimal compulsory λ^m can be chosen such that $\Pi_C{}^{Ins} > \Pi_C{}^{dnc}$, or:

$$\left[\delta\left(I^{*dnc}\right)\hat{d}_0 + I^{*dnc}\right] - \left[\delta\left(I^{*Ins}(\lambda)\right)\hat{d}_0 + I^{*Ins}(\lambda)\right] > \frac{\alpha\,\Psi\left(N, \delta\left(I^{*Ins}(\lambda)\right)\right)(1-\lambda)^2}{N} \tag{20}$$

According to Eq. (20), private insurance markets can generate higher payoffs for the Central government when, *ceteris paribus*: (i) the degree of inequality-aversion α is sufficiently low; (ii) the adverse events are very infrequent; (iii) the productivity of protection investment is high; and (iv) the number of local governments N is high (i.e., when the task of investing in protection is assigned to, e.g., municipalities). Remarks (i) to (iii) define a framework where Central government favors efficiency over equality because of its own preferences, or because adverse events are quite rare, or because incentives to invest in mitigation are highly valuable. In this case, the risk of diluting incentives to invest because of the limited credibility of the Central government makes the private solution more appreciated. Remark (iv), as already discussed, indicates that when the number of local governments N becomes large, the advantage for the public mechanism is reduced, so that the negative effects of the inability to commit prevail in favor of the private solution. This discussion is summarized in the following:

Proposition 3: *When the Central government cannot commit to a pre-determined optimal transfer rule, the FRF solution always dominates the private insurance solution for* $\lambda^{*m} \geq (N-1)/N$. *When* $0 \leq \lambda^{*m} < (N-1)/N$ *the private insurance solution can be preferred to the decentralized public fund solution under specific combinations of parameters* α, p, δ, N.

Proof: See Appendix. ■

Proposition 3 suggests that a welfare-enhancing role of the private insurer is possible when the Central government is unable to commit to a predetermined level of risk sharing. In this framework, private insurers are expected to improve welfare with respect to the FRF solution when they cover risks associated to infrequent events in small localized areas, like for instance in the case of a terrorist attack or an earthquake hitting a city. In the presence of recurring events hitting larger areas (for example, seasonal hurricanes or floods), the increase in p should make the public fund solution preferable with respect to the private insurance even in the presence of soft budget constraint. However, this preference should be considered in the light of the number of local communities hit by the recurring event which are called to invest separately in protection: for given p, as N increases, the public fund solution loses its dominance in favour of the private insurer.

While fully characterizing the conditions which make the FRF preferred over the private insurance solution would require a number of assumptions on the specific functional forms for all the components of Eq. (20), we can get some insights on the magnitudes involved assuming: (i) an exponential specification for the productivity of mitigation investments $\delta(I) = e^{-\gamma I}$; and (ii) a zero probability of experiencing two or more catastrophes in a single period (e.g., the probability of observing more than one earthquake in a country is zero), which greatly simplifies expression Ψ. With these assumptions, further normalizing D to 1, Eq. (20) simplifies to:

$$\frac{N}{\gamma}-\frac{\ln N-\ln p\gamma}{\gamma}-\frac{1}{\gamma(1-\lambda^{*m})}-\frac{\ln p\gamma(1-\lambda^{*m})}{\gamma}>\alpha(1-\lambda^{*m})^{2}p\frac{N-1}{N^{2}}$$

where:

$$\lambda^{*m} = \arg\max_{\lambda}\left[-\frac{1}{\gamma(1-\lambda)} - \frac{\ln p\gamma(1-\lambda)}{\gamma} - \alpha(1-\lambda)^2 p\frac{N-1}{N}\right]$$

Fixing p, γ and α, from the expression above we can easily compute the minimum number of local administrations *N^* which makes the private insurance solution socially more efficient than the FRF solution in the soft budget regime. For instance, when p = 5% and γ = 140 (i.e., investing in mitigation $I = D/100$ obtains to reduce p to a quarter of the original probability), *N^* increases from 4 (when α = 2.5) up to 9 (when α = 10). Holding p constant over the same range of α, *N^* increases from 4 to 8 if γ reduces to 70, and from 5 to 10 if γ doubles. When p reduces to 1%, for the same values of γ and α, the corresponding *N^* shift downwards, ranging from 3 to 7. On the contrary, when p augments to 10%, *N^* vary from 5 to 11. Overall, these examples suggest that – if we assume Central government to be unable to commit to a predetermined transfer rule – the private solution would be preferable even taking into account the 20 Italian regions, the layer of government closest to the central government.

Consider now the case of Central Government being unable to commit to a pre-determined budget size. While for the public mutual fund solution this means that funds are augmented *ex-post*, for the private insurance solution this means that Central Government can step in *ex-post* to integrate private (partial) repayments. This behavior reflects the assumption of a different degree of enforceability between the two "contracts". In fact, while we consider the possibility that the Central government is unable to commit to a pre-determined transfer rule or budget, we ruled out this problem in the case of a private insurer. In this case, the Local administration is assumed to pay an ex-ante premium *P*, and the insurer to reimburse a share λ of losses in case a damage occurs. Whenever one of the parties does not accomplish its contractual obligation, the other can recur to a Civil Court and ask for the enforcement of the contract. This enforcement is assumed to be more credible than the one provided by an Administrative or a Constitutional Court, because the Central government can always renege on the commitment and – through a special law – pump more money into specific communities hit hard by a disaster. But the partial coverage of private insurance contracts can induce the Central government to increase *ex-post* equality by increasing funds to constituencies hit by losses beyond $N\Omega$. As a consequence, however, the disciplining role of partial coverage used by the private insurer disappears: the Local administration keeps mitigation investments low, relying on the *ex post* intervention by the Central government. Hence, the private insurer definitely loses its welfare-enhancing role if the Central government is unable to credibly promise that he will not pay for damage that is not completely reimbursed by a private insurer:

Corollary to Proposition 3: *When the Central government cannot commit to a predetermined budget size and step-in to integrate partial reimbursement by private insurers, the FRF solution always dominates the private insurance solution.*

Proof: Directly from discussion above. ■

4. Discussion

The intuition for the results presented in the previous Section is grounded in the institutional differences between the FRF and the private insurance solution[34]. In both institutional arrangements, Local administrations receive a transfer, which is contingent on realized losses *in all administrations* in the case of a public relief fund, whilst it is contingent only on the actual loss of *the specific administration* in the case of a private insurer. As discussed above, the second mechanism is less efficient in terms of providing the right incentives to invest in protection. In this Section we discuss the robustness of these findings to some of our assumptions. Let us consider first the issue of the risk-neutrality of Local governments. The question is whether the incentives of a risk averse Local administration – given a certain level of inequality aversion of the Central government – still determine the preference for the public fund solution with respect to the private insurance solution. Clearly enough, when a Local administration is risk averse, the marginal benefits of protection investments will increase, and – consequently – also the incentives to invest in protection. However, this is true *both* in the case of a FRF and in the case of a private insurance. As we show more formally below, under very general circumstances, the incentive to invest remains stronger in the former than in the latter case, since in the FRF regime the variance in the payoffs across different states of nature is larger. Hence, even when we model Local administrations as risk-averse players, the FRF continues to guarantee more efficiency for the same level of equality. More precisely, this is strictly true

[34] Notice that even a private insurer could, at least in principle, adopt a mutual mechanism similar to the one characterizing our public fund. The mutual insurance firms indeed adjust ex-post the ex-ante defined premium. The literature acknowledges the efficiency of this organizational structure in managing moral hazard problems (Smith and Stutzer, 1995). However, mutual insurances are not immune by inefficiencies that are driving this type of organizations out of the market (e.g., Viswanathan and Cummins, 2003).

when the probability *p* of the adverse event is sufficiently low for a given degree of risk aversion by Local administrations[35]. Intuitively, when adverse events are quite common, the states of nature in which the Local administration suffers no losses, but several other administrations do, are relatively more likely. In the FRF regime, these states of nature are associated with a lower payoff as compared with the payoff in the private insurance regime where the other administrations' losses are irrelevant; and this makes mitigation investments more costly. This result could – at least in principle - offset the incentive effects of the FRF solution discussed so far. The intuition is summarized in the following Proposition 4:

Proposition 4. *Consider the case of a credible commitment to a predetermined transfer rule. When Local administrations are risk averse, optimal mitigation investments are greater in the case of a* FRF *than with a private insurer when the adverse event probability p and/or the degree of risk aversion are sufficiently small.*

Proof: See Appendix. ■

A second issue that should be discussed is the assumption of zero marginal costs for the additional funds that needs to be raised by the Central government, in case of being unable to commit. On the one hand, the costs to raise additional taxes to cope with ('catastrophic') adverse events are in favor of the private solution: the higher these costs, the higher the likelihood that private insurers can improve social welfare with respect to the FRF solution.

[35] Notice that catastrophic events are often characterized by low values for *p*. Hence, our results suggests that – at least for this class of risks – the FRF solution is always better than the private insurance solution in the hard budget constraint case, independently of the risk preferences of Local administrations. This conclusion can be reversed when the Central government cannot commit to a pre-determined transfer rule and the type of catastrophic event is such that its underlying losses affect a *relatively small area* of the country.

On the other hand, the need to raise capital also for insurers and the likelihood of a default in the presence of very large losses are in favor of the public solution. As for the first argument, capital is costly also for insurers, and can be more costly than the (shadow) cost of public funds. As for the second argument, the larger the damage, the higher the probability that the insurer will not be able to repay all claims. Indeed, throughout the paper we implicitly maintained the assumption that the private insurer *will never default*. In general, this 'no-default hypothesis' can be realistic considering that the insurance industry is strongly regulated, and companies are forced to maintain adequate loss reserves in order to guarantee default risk sufficiently low. Moreover, the underwriting capacity of the insurance industry is enlarged by reinsurers, who assume parts of these risks (in particular catastrophic risks, more difficult to be diversified on a non-global scale), thus providing part of the necessary reserves. However, there could be some instances for which losses exceed the capacity of the worldwide insurance/reinsurance industry, and in such cases, the advantage of the public solution will further increase.[36] Intuitively, the mechanisms used by the Central government and by the private insurer in order to financially support the risks' coverage are actually associated with different risk profiles of these parties. The ex-ante definition of the private insurer's premium implies that it is the one who bears the risk that the collected premiums (based on the *expected* losses) are insufficient to cover the ex-post *realised* losses. On the contrary, the ex-post ability by the Central government to collect taxes makes it somewhat indifferent to this type of risks. Hence, it is better for the Central

[36] In 2012, for example, rating agencies report of moderate excess of reserves in the reinsurance industry for the catastrophe segment, despite the confirmation of the negative trend of catastrophe losses. However, Swiss Re (2012) observes that this capital is unevenly distributed across a few players and the underwriting capacity will be reduced (on average) by raising capital requirements. On the superiority of a public program to cover catastrophic risks when private insurers are insolvent see also Charpentier and Le Maux (2014). These authors, however, do not consider a number of issues discussed here, including the notable moral hazard problem which is key for understanding the inefficiency of the Federal Relief Fund.

government to directly intervene with a FRF, than having to step in to rescue private insurers hit by large losses in order to guarantee equalization.

A final question is clearly related to the private nature of the insurer, which maximizes its profits. This is unlike the Central government, which aims at maximizing welfare. Our results are based on the assumption of perfectly competitive insurance markets. However, if insurance markets are not perfectly competitive, there is an additional disadvantage of the private insurer solution which further reinforces our main conclusions.

5. Concluding remarks

In this paper, we consider the institutional arrangements needed in a decentralized framework to cope with the potential adverse welfare effects caused by negative shocks which impact directly on the provision of public services and can be 'limited' by precautionary investments. We analyze the functioning of a Federal Relief Fund aimed at covering losses from collective risks investing Local administrations. We then study the potential role of private insurers in solving the under-investment problem in protection that stems from the free riding of Local administrations facing a transfer rule by the Central government, which takes into account the equalization of resources across Regions. Taking a normative approach, our analysis shows that a public fund is almost always superior to the private insurance solution in the presence of hard budget constraints for Local administrations, but this advantage quickly declines as the number of administrations increases. Furthermore, when the Central government cannot credibly commit to an optimal transfer rule or to a fixed budget size, competitive private insurers are *sometimes* able to improve on the FRF solution by inducing a higher level of investments even when the number of Local administrations is relatively small. In other words, our results suggest that an answer to the question of why a public administration should insure itself is because private insurers act as strategic substitutes of redistributive policies for the allocation of collective risks. Central governments do then actually impose Local governments to buy insurances sometimes, because they believe to be intrinsically unable to commit not to intervene in the case of an adverse welfare shock. In the light of our analysis, this solution is probably unwarranted for small risks, for which central government can commit to a hard budget constraint regime. It is probably not enough for large catastrophic risks, for which also private insurers become rapidly unfit. But real world examples include *mixed solutions* (a sort of 'public-private partnerships'), where a public solution is combined with compulsory private insurances for Local administrations. In the case of natural disaster insurance, Jametti and von Ungern-Sternberg (2010) suggest for instance that 'risk-selection' (i.e., the fact that private companies 'skim-off' low risk from the market, leaving high risk to the public insurer) is a notable issue, and provide policy suggestions to mitigate the problem. However, an interesting question that remains to be analyzed is the superiority of the mixed institutional arrangement with respect to the 'pure-public' (or 'pure-private') solution. This is left for future research.

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Appendix

A.1. Proof of Proposition 1

The problem to be solved can be written as:

$$max_{\sigma}\,\Pi_C = max_{\sigma}\left\{ N\left[\Omega - I - \delta(I)\hat{d}_0\right] - \underbrace{\alpha E\left[\sum_{i=1}^{N}\left(x_i - \bar{x}\right)^2\right]}_{\alpha(1-\sigma)^2\Psi(N,\delta(I))} \right\} \tag{a.1}$$

$$s.t. \quad I = I^{*d}(\sigma)$$

F.O.C. for the solution of the problem is:

$$-N\frac{\partial I^{*d}}{\partial \sigma}\left(1+\hat{d}_0\frac{\partial \delta(I)}{\partial I}\right)=\alpha\frac{\partial E\left[\sum_{i=1}^{N}(x_i-\bar{x})^2\right]}{\partial \sigma} \tag{a.2}$$

Eq. (a.2) shows the efficiency-equality trade-off implicit in the payoff function of the Central government. First, one can notice that the LHS of Eq. (a.2) – which corresponds to $\partial E\left[\sum_{i=1}^{N}x_i\right]\Big/\partial\sigma$ – is always negative $\forall\sigma>0$. Intuitively, the lower the additional transfer, the closer the investment will be to its efficient level, which in turn implies a better trade-off between investments and expected loss, hence higher current expenditures x. More formally, considering the F.O.C. in Eq. (11) and $\partial I^{*d}/\partial\sigma < 0$, one can show that:

$$-N\frac{\partial I^{*d}}{\partial \sigma}\left(1+\hat{d}_0\frac{\partial \delta(I)}{\partial I}\right)=-\frac{\partial I^{*d}}{\partial \sigma}\left(\hat{d}_0\frac{\partial \delta(I)}{\partial I}\sigma\frac{N-1}{N}\right)<0 \tag{a.3}$$

given $\sigma > 0$.

Second, the function $E\left[\sum_{i=1}^{N}(x_i-\bar{x})^2\right]$ is always non-negative, and reaches a minimum at σ=1, when all losses are fully shared and expenditures equalised in every Local administrations. In particular, when $\sigma < 1$, $E\left[\sum_{i=1}^{N}(x_i-\bar{x})^2\right]$ strictly decreases with σ, while for $\sigma > 1$ the inequality component of the payoff of the Central government increases. As a consequence, the RHS of Eq. (11) assumes negative values in the $0 \leq \sigma < 1$ range.

Moreover, note that if $\alpha = 0$ (i.e., the Central government cares only about efficiency), the F.O.C. reduces to Eq. (9) and investment will consequently be fixed like in the benchmark case. The higher α, the closer the additional transfer σ^{*d} will be to 1, hence $\frac{\partial \sigma^{*d}(\alpha)}{\partial \alpha} > 0$.

Since LHS of Eq. (a.2) is always negative and RHS of Eq. (a.2) is negative only for $\sigma^{*d} < 1$, it must be that the optimal degree of risk sharing σ^{*d} is lower than the one in the centralised case $\sigma^{*c} = 1$. As far as $\partial I^{*d}/\partial N < 0$, the optimal trade-off between efficiency and equality asks for stronger investment incentives, i.e., a lower σ, when the number of Local administrations increases. ■

A.2. Proof of Proposition 2

For every pair ($\tilde{\lambda}, \tilde{\sigma} \mid \tilde{\lambda} = \frac{N-1}{N}\tilde{\sigma}$; $\tilde{\lambda} \in [0,1]$) it is possible to compare $\Pi_C{}^d(\tilde{\sigma})$ with $\Pi_C{}^{Ins}(\tilde{\lambda})$. Since $I^{*d}(\tilde{\sigma}) = I^{*Ins}(\tilde{\lambda})$, the efficiency component of the payoff is the same; consequently, $\Pi_C{}^d(\tilde{\sigma})$ > $\Pi_C{}^{Ins}(\tilde{\lambda})$ if and only if $(1-\tilde{\lambda})^2 > (1-\tilde{\sigma})^2$, which is always verified. When the number of Local administrations $N \to \propto$, the cost of risk sharing for each single Local administration cannot be significantly reduced by its own protection investments. Hence, decentralized risk sharing and private insurance tend to be isomorphic, i.e., every strategy in both regimes can be perfectly replicated in the other so that $\Pi_C^{*d}(\sigma^{*d})$ = $\Pi_C^{*Ins}(\lambda^{*Ins})$.

Since $N/(N-1) > 1$, the incentive mechanism provided by the FRF is more powerful than the insurer's, namely, equal investments can be induced by the decentralized solution by means of higher coverage. The reason is that – given the coverage level – a higher investment I does not reduce the premium P, while it reduces the term $\sigma\, \bar{d}(M)$ in T_i. ■

A.3. Proof of Proposition 3

Recalling that $\delta(I)\hat{d}_0 + I$ monotonically decreases with I, reaching its minimum when $I = I^{*c}$ (see Eq.(9)), one can notice that the LHS of Eq. (20) is positive if and only if $I^{*dnc} < I^{*Ins}$, since both $I^{*Ins} < I^{*c}$ and $I^{*dnc} < I^{*c}$. We need to distinguish between two cases based on the value of the compulsory λ^{*m}. (A) If $\lambda^{*m} \geq (N-1)/N$, then - by comparing Eq. (11) with Eq. (15), and recalling that $\sigma^{*dnc} = 1$ – we obtain $I^{*Ins}(\lambda^{*m}) < I^{*dnc}$: LHS of Eq. (20) is negative and the condition is never verified (remember that RHS is always positive). The public solution gives better incentives to the Local administrations and perfect equality: the private market solution is then dominated by the decentralized public solution even when the Central government cannot credibly commit to an ex-ante defined transfer rule. (B) If $0 \leq \lambda^{*m} \leq (N-1)/N$, then $I^{*Ins} \geq I^{*dnc}$ and $\delta(I^{*Ins}) < \delta(I^{*dnc})$. Consequently, LHS of Eq. (20) proves to be positive and the condition in Eq. (20) is verified for some combinations of the model's parameters. ■

A.4. Proof of Proposition 4

In order to prove our result, we show that a FRF provide better incentives for mitigation investments than a private insurer, *ceteris paribus*. The *ceteris paribus* condition applies in particular to the level of coverage, so that we fix $\lambda = \sigma$. Remember that the payoff of the i–th Local administration in a (credible) FRF scenario and under a private insurer are respectively:

$$\Pi_i^F = p\delta\left(I_i^F\right)\sum_{M=0}^{N-1}\pi(M)u\left(\Omega - I_i^F - (1-\sigma)D - \frac{M+1}{N}\sigma D\right)$$
$$+\left[1 - p\delta\left(I_i^F\right)\right]\sum_{M=0}^{N-1}\pi(M)u\left(\Omega - I_i^F - \frac{M}{N}\sigma D\right) \tag{a.4}$$

and

$$\Pi_i^I = p\delta\left(I_i^I\right)u\left(\Omega - I_i^I - (1-\sigma)D - P\right) + \left[1 - p\delta\left(I_i^I\right)\right]u\left(\Omega - I_i^I - P\right) \tag{a.5}$$

where superscript F refers to the FRF solution, while I refers to the private insurer solution. M is the number of adverse events occurring outside Local administration i. $\pi(M)$ is defined accordingly to Eq. (4a). FOCs are the following:

(a.6)

$$I_i^{F*} \rightarrow \underbrace{p\delta'\left[\sum_{M=0}^{N-1}\pi(M)u\left(\Omega - I_i^F - (1-\sigma)D - \frac{M+1}{N}\sigma D\right) - \sum_{M=0}^{N-1}\pi(M)u\left(\Omega - I_i^F - \frac{M}{N}\sigma D\right)\right]}_{MB^F} =$$
$$= \underbrace{p\delta\left(I_i^F\right)\sum_{M=0}^{N-1}\pi(M)u'\left(\Omega - I_i^F - (1-\sigma)D - \frac{M+1}{N}\sigma D\right) + \left[1 - \delta\left(I_i^F\right)p\right]\sum_{M=0}^{N-1}\pi(M)u'\left(\Omega - I_i^F - \frac{M}{N}\sigma D\right)}_{MC^F}$$

and

$$I_i^{I*} \rightarrow \underbrace{p\delta'\left[u\left(\Omega - I_i^I - (1-\sigma)D - P\right) - u\left(\Omega - I_i^I - P\right)\right]}_{MB^I} =$$
$$= \underbrace{p\delta\left(I_i^I\right)u'\left(\Omega - I_i^I - (1-\sigma)D - P\right) + \left[1 - \delta\left(I_i^I\right)p\right]u'\left(\Omega - I_i^I - P\right)}_{MC^I} \tag{a.7}$$

Notice that the LHS of both equations (a.6) and (a.7) represents the marginal benefits (MB) of the investment, while the RHS represents the marginal costs (MC). Let us assume that I is fixed to the same level in both cases, so that we can use the notation $I_i^F = I_i^I = I_i$. Notice that:

$$\sum_{M=0}^{N-1}\pi(M)\left(\Omega - I_i - (1-\sigma)D - \frac{M+1}{N}\sigma D\right) < \Omega - I_i - (1-\sigma)D - P$$

since $P = \frac{\sigma D}{N} \sum_{M=0}^{N} \pi(M) M = \frac{\sigma D}{N} p \, \delta(I_i)$. Thanks to the concavity of the utility function given the risk-aversion assumption, in the case of an adverse event in the Local administration *i* the expected utility in the presence of the mutual fund is lower than the one associated to the private insurer solution.

For the same reason, $\sum_{M=0}^{N-1} \pi(M) \left(\Omega - I_i - \frac{M}{N} \sigma D \right) > \Omega - I_i - P$ and the difference between $\sum_{M=0}^{N-1} \pi(M) \left(\Omega - I_i - \frac{M}{N} \sigma D \right)$ and $\Omega - I_i - P$ increases as *p* decreases. Consequently, the expected utility of the FRF solution when no adverse events hit the administration *i* is higher than the one of the private insurer if *p* is small enough. Summing up, in the case of risk-averse Local administrations, when *p* is relatively small, marginal benefits of investments are larger in the FRF regime for every level of *I*.

As for the marginal costs of the investment, for the same reasons recalled above – i.e., $\sum_{M=0}^{N-1} \pi(M) \left(\Omega - I_i - \frac{M}{N} \sigma D \right) > \Omega - I_i - P$ and the concavity of the utility function of Local administrations - we can conclude again that for every level of *I* the marginal costs of the investments are larger in the private insurer regime when *p* is relatively small.

Hence, for *p* small enough and every level of coverage, the incentive to invest in mitigation is higher both on the cost side and on the benefit side. This situation determines that:

$$\sigma^{*d} < \lambda^{*m}$$

$$\Pi_C{}^{*Ins} < \Pi_C{}^{*d} \,. \blacksquare$$