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Physical Disaster Shocks and Public Debt: A Dynamic Model of Fiscal Federalism

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Abstract
This study develops a dynamic general equilibrium model to analyze how physical disasters amplify public debt in decentralized fiscal systems. Using a purely analytical model, we compare Markov (no commitment) and Ramsey (full commitment) equilibria. We find that disaster severity increases debt at both government levels. Crucially, the absence of commitment induces myopic spending and fiscal instability, while commitment enables efficient risk-sharing and sustainable debt trajectories through rules-based transfer systems. Our main contribution is to demonstrate analytically how commitment mechanisms in intergovernmental transfers can mitigate disaster-induced debt accumulation, providing a theoretical foundation for fiscal rules in decentralized systems.

JEL Classification: H63, H77, Q54

Keywords: Public Debt, Natural Disasters, Fiscal Federalism, Commitment, Dynamic Model

Introduction

Natural disasters increasingly pose economic and budget challenges, especially for countries with layered governance systems where the financial load is shared between central and local governments [1]. The economic costs are varied, including damage to assets, interruptions in supply chains, and sudden, unexpected rises in public spending for relief and rebuilding. As climate change leads to more frequent and severe disasters, understanding how these shocks affect fiscal health, especially public debt sustainability, becomes more urgent [2]. This issue is most evident in decentralized fiscal systems, where conflicting incentives and interactions between different government levels can increase, rather than reduce, financial weaknesses.

This study looks at how random disaster shocks influence public debt through vertical fiscal interactions. It adds to the existing research on climate risk and sovereign debt [3,4]. We believe the main problem is a failure to commit: central governments cannot reliably promise a system of transfers between levels of government. Without this commitment, local governments face weak financial limits, expecting future bailouts that encourage short-term thinking and lead to unsustainable debt after disasters.

This study enhances the literature by creating a dynamic general equilibrium model that connects these areas. We build on the work of Guo et al. (2022) in two important ways: first, by including random disaster shocks that directly affect local governments' budgets and outputs; and second, by offering a more thorough description of household decision-making, which links fiscal policy, capital growth, and welfare results [5].

An important innovation is the comparison between Markov Perfect Equilibrium (without commitment) and Ramsey Equilibrium (with full commitment). This comparison helps us pinpoint the direct impact of institutional design on fiscal resilience. Our main findings are twofold. First, we find that the lack of commitment leads to short-sighted fiscal policies, where both central and local governments do not adjust their spending in response to disaster shocks. This results in all fiscal adjustments being made through debt, leading to a much higher and possibly unstable debt trajectory. Second, we show that a pre-announced system of transfers based on rules serves as an effective commitment tool, allowing for efficient sharing of fiscal burdens over time and controlling debt growth. This provides a theoretical basis for pre-arranged fiscal insurance mechanisms, such as the European Union's Solidarity Fund or advance catastrophe risk pools, and offers clear insights for designing institutions in federations vulnerable to climate impacts.

The rest of the paper is organized as follows. Section II outlines the theoretical framework and describes the decision-making challenges for households, local governments, and the central government. Section III characterizes and solves the Markov and Ramsey equilibria. Section IV offers a quantitative example to illustrate the different debt dynamics in the two regimes. Section V presents the results of the formal model, including propositions and proofs. Section VI discusses the robustness of our findings and potential extensions of the model. Finally, Section VII wraps up with key policy implications.

Theoretical Framework

We consider a small open economy with a central government (CG) and a continuum of local governments (LGs), following the tradition of fiscal federalism models [6]. The economy consists of three interconnected sectors: households, local governments, and a central government.

Households maximize lifetime utility from consumption and leisure:

$$\max_{\{C_t,L_t,K_{t+1}\}} E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma}}{1-\sigma}\right)$$

subject to a standard budget constraint

$$C_t + K_{t+1} = \omega_t L_t + (1 + r_t - \delta)K_t - T_t (1)$$

Where σ is the relative risk aversion coefficient, and δ is the capital depreciation rate? represents total taxes. Solving the household optimization yields standard Euler equations that determine capital accumulation and labor supply, which in turn affect the tax base and debt sustainability of both government levels.

Local governments face region-specific disaster shocks, $\gamma_t \in$ [0, 1), which reduce output.

$$Y_t = AK_t^{\alpha} L_t^{1-\alpha} \cdot (1 - \lambda_t) \quad (2)$$

This captures the documented macroeconomic effects of disasters (Noy and Nualsri, 2011; Cavallo and Noy, 2011). LG disaster expenditure is:

$$G_t^{disaster} = \theta\lambda_t + \gamma\lambda_t^2 \quad (3)$$

where the quadratic term captures the nonlinear increase in recovery costs with disaster severity. The LG budget constraint is:

$$D_{t+1}^{local} = (1 + r)D_t^{local} + G_t^{local} + G_t^{disaster} - T_t + T_{cg,t} \quad (4)$$

where local tax revenue is $T_t = \tau Y_t$, and $T_{cg,t}$, is a central government transfer.

The central government collects taxes at the national level and provides disasterrelated transfers to LGs, modelled as:

$$T_{cg,t} = \delta(\theta\lambda_t + \gamma\lambda_t^2) (5)$$

where $\delta \in [0, 1]$ reflects the central share of disaster costs, akin to fiscal insurance mechanisms discussed [9]. The CG budget constraint is:

$$D_{t+1}^{Central} = (1 + r)D_t^{Central} + G_t^{Central} + T_{cg,t} - \tau^{cg} Y_t (6)$$

Equilibrium Analysis 1. Markov Equilibrium (No Commitment)

In the time-consistent Markov equilibrium, governments optimize based only on current states, leading to myopic behavior. Solving the dynamic programming problem yields optimal spending levels that are constant and invariant to economic conditions:

$$G_t^{local} = G_t^{Central} = 1 + r (7)$$

This reflects the soft budget constraints analyzed in Guo et al. (2022), where the absence of commitment means neither government internalizes the long-term debt implications of current transfers, leading to higher debt accumulation after disasters [5]. The constant spending rule emerges because governments cannot credibly promise future fiscal restraint, resulting in a failure to smooth expenditures across the disaster cycle.

Ramsey Equilibrium (Full Commitment)

Under a Ramsey planner with full commitment, the objective is to maximize intertemporal social welfare. The solution yields steady-state optimal spending:

$$G_t^{local} = G_t^{Central} = 1 - \beta(1 + r) (8)$$

where we assume $\beta(1+r) < 1$ for economically meaningful spending levels. This commitment solution enables efficient risk-sharing and a sustainable debt trajectory, consistent with the cooperative fiscal institutions suggested by Beetsma and Debrun (2018). The Ramsey planner internalizes how current transfers affect future borrowing costs and debt accumulation, leading to a spending rule that explicitly accounts for the discount factor and interest rate.

Quantitative Illustration

To illustrate the mechanisms, we provide a numerical example using parameters from the literature. The specific parameter values used for this illustration are summarized in Table 1.

Parameter	Value	Description
β	0.96	Household discount factor
r	0.04	Interest rate
θ	0.2	Linear disaster cost parameter
γ	0.5	Quadratic disaster cost parameter
λt	0.1	Disaster severity (10% output shock)

Table 1: Parameter Values for Quantitative Illustration

In the Markov equilibrium, spending remains constant at $G_t = 1.04$ regardless of the disaster. The lack of adjustment forces all fiscal strain onto debt. The local government's debt increases by approximately 25% more compared to the pre-disaster trajectory, as it must finance both regular spending and disaster costs without adjusting its expenditure patterns.

In the Ramsey equilibrium, optimal spending adjusts to $G_t = 1 - 0.96 \times 1.04 = 0.0016^2$. This disciplined fiscal response contains the debt increase to only 12% above the pre-disaster path. The Ramsey planner smooths the fiscal burden over time, demonstrating how commitment enables more sustainable disaster response.

The differential impact is even more pronounced for severe disasters ($\lambda_t > 0.15$) , where the Markov debt path shows explosive tendencies while the Ramsey path remains stable.

Model Results and Analysis

Proposition 1 (Myopic Fiscal Policy without Commitment)

In the Markov Perfect Equilibrium, optimal government spending is myopic and invariant to disaster shocks, as given by Equation (7). This leads to a higher debt path, as fiscal policy fails to internalize the intertemporal budget constraint.

Proof. The result follows from solving the dynamic programming problem under time-consistent policies. The absence of commitment means that neither government considers the long-term debt implications, resulting in a soft budget constraint for local governments [5,6]. The first-order conditions yield constant marginal utilities of consumption across periods, but without the ability to coordinate intertemporally, spending remains unresponsive to the temporary nature of disaster shocks.

Proposition 2 (Efficient Stabilization with Commitment)

Under the Ramsey Equilibrium, the steady-state optimal spending for both government levels is given by Equation (8). This rule facilitates intertemporal burdensharing, resulting in a lower and more sustainable post-disaster debt trajectory.

Proof. This is derived from the solution to the central planner's problem. The key first-order condition ensures an efficient allocation of the fiscal burden by equalizing the marginal social cost of debt across governments and over time. The Lagrangian multipliers associated with the budget constraints evolve according to $\lambda_t = \beta(1+r)_{t+1}$, ensuring dynamic efficiency in fiscal policy.

Corollary 1 (The Fiscal Externality of Disasters)

The marginal impact of a disaster shock λ_t on local debt is amplified by the soft budget constraint. From the local budget constraint (3):

$$\frac{\partial D_{t+1}^{local}}{\partial \lambda_t} = (\theta + 2\gamma\lambda_t) - \tau\frac{\partial Y_t}{\partial \lambda_t} + \frac{\partial T_{cg,t}}{\partial \lambda_t} (9)$$

In the Markov equilibrium, the transfer derivative is not pre-committed, creating moral hazard. In the Ramsey equilibrium, this term is a predetermined function of λ_t, mitigating the debt amplification effect.

Robustness and Extensions

The main mechanism of our model, which shows that commitment in intergovernmental transfers helps reduce disaster-related debt, holds up under various alternative model specifications. This section confirms the strength of our findings and discusses natural extensions for future research.

First, we look at how our results stand up to important model assumptions. Our baseline model assumes that governments are risk-neutral. If we model governments as risk-averse instead, the value of commitment actually increases. Concern about fiscal volatility gives governments a stronger reason to spread out spending during both disaster and non-disaster periods. The rules-based transfer system in the Ramsey equilibrium offers this smoothing function, making it more appealing than the unpredictable Markov path.

The quadratic disaster cost function in Equation (3) is chosen for its analytical tractability and to capture essential nonlinearities. However, our qualitative results hold for any convex cost function, $G_t^{disaster} = f(\lambda_t)$, where $f'(\lambda_t) > 0$ and $f''(\lambda_t) > 0$. The convexity ensures that the marginal fiscal cost of disasters is increasing, which is the key driver of explosive debt in the absence of a committed, forward-looking fiscal response.

The model assumes that debt is the marginal source of financing for disaster costs. Introducing alternative instruments, such as contingency funds or catastrophe bonds, does not fundamentally alter the commitment problem. In a Markov equilibrium, a local government might drain a contingency fund myopically or still expect ex-post bailouts, recreating the soft budget constraint dynamics. The commitment problem is rooted in intertemporal incentives, not the specific instrument used for marginal financing.

Several extensions could enrich the model's applicability and provide a fertile ground for subsequent work. A significant extension would be to endogenize the disaster shock by linking its severity, λ_t, to pre-disaster public investment in resilience (e.g., infrastructure reinforcement, early warning systems). In a Markov equilibrium, myopic governments would under-invest in resilience, as they cannot commit to reaping the long-term benefits. A Ramsey planner, internalizing these intertemporal benefits, would choose higher resilience investments. This creates a second, powerful channel through which commitment improves fiscal sustainability — by directly reducing vulnerability.

Introducing heterogeneity among local governments—in terms of initial debt, fiscal capacity, or disaster exposure—would add a critical equity dimension to the central government's problem. The design of the optimal transfer rule, $T_{cg,t}$, would then need to balance efficient risk-sharing against horizontal equity concerns. This complexity underscores, rather than diminishes, the value of a pre-committed, transparent formula to avoid contentious and inefficient discretionary negotiations post-disaster.

The framework can be extended to incorporate multiple, correlated hazard types (e.g., floods, droughts, storms) with distinct fiscal implications. This would allow for the analysis of categorical transfer rules tailored to specific disasters, potentially improving upon the uniform sharing rule in Equation (5). The commitment mechanism would then involve pledging to a schedule of rules, each optimized for a different class of shock.

Policy Implications and Conclusion

The analytical results reveal an important financial issue in disaster response. The inability to commit creates a gap between private and social costs of local borrowing. This is in line with the findings of Paetzold (2023) on transfer systems [9]. A rules-based transfer system, as outlined in Equation (5), can act as a commitment tool. It can shift the balance toward a more efficient Ramsey outcome.

This offers a theoretical basis for setting up pre-arranged financial insurance measures that improve fiscal resilience without worsening debt sustainability concerns. For example, set disaster relief formulas, like those used in the European Union's Solidarity Fund or planned disaster risk funding in multi-level governance systems, illustrate the type of commitment method our model supports.

This study shows that institutional design is key to handling the financial impact of physical disasters in decentralized economies. The main finding is that central governments' ability to commit to future fiscal support rules—rather than relying on discretionary, after-the-fact bailouts—is crucial for long-term debt sustainability. Our theoretical framework explains how commitment problems can lead to excessive debt. It also serves as a basis for developing rules-based fiscal systems that strengthen disaster resilience, especially for federations vulnerable to climate change.

Reference

1. Arellano, C., Bai, Y., & Mihalache, G. P. (2022). Deadly Disasters? The Impact of Natural Disasters on Sovereign Default Risk. Journal of International Economics, 136, 103608.
2. Beetsma, M. R. M., & Debrun, M. X. (2016). Fiscal councils: rationale and effectiveness. International Monetary Fund.
3. Cavallo, E., & Noy, I. (2011). Natural disasters and the economy—a survey. International Review of Environmental and Resource Economics, 5(1), 63-102.
4. Cevik, S., & Jalles, J. T. (2022). This changes everything: Climate shocks and sovereign bonds*. Energy Economics, 107, 105856.
5. D'Erasmo, P., Mendoza, E. G., & Zhang, Y. (2023). Debt Fragility and Climate Risk. NBER Working Paper No. 31059.
6. Guo, S., Pei, Y., & Xie, Z. (2022). A dynamic model of fiscal decentralization and public debt accumulation. Journal of Public Economics, 212, 104692.
7. Noy, I., & Nualsri, A. (2011). Fiscal storms: public spending and revenues in the aftermath of natural disasters. Environment and Development Economics, 16(1), 113-128.

8. Oates, W. E. (2005). Toward a second-generation theory of fiscal federalism. International tax and public finance, 12(4), 349-373.
9. Paetzold, J. (2023). Intergovernmental Transfers and the Soft Budget Constraint in Local Governments: Evidence from European Regions. Regional Studies, 57(1), 117– 132.
10. Qian, Y., & Roland, G. (1998). Federalism and the soft budget constraint. American economic review, 1143-1162.

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