WORKING paper

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Committed to Flexible Fiscal Rules[*]

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Abstract

We study the impact of fiscal rules on macroeconomic performance. To address the endogeneity of rule adoption, we use data on large, random natural disasters. We document empirically that countries with rules perform significantly better following such exogenous shocks than countries without rules. GDP and private consumption are persistently higher. This is associated with more expansionary fiscal policy and hinges on the existence of fiscal space and escape clauses. We rationalize the findings in a model of sovereign default, which replicates the empirical dynamics and shows that tight rules create fiscal space in good times for deficit-spending in bad times.

Keywords: Fiscal Policy, Fiscal Regimes, Natural Disasters, Sovereign Default Model, Panel Data.

JEL classifications: E62, C32, E32, H50

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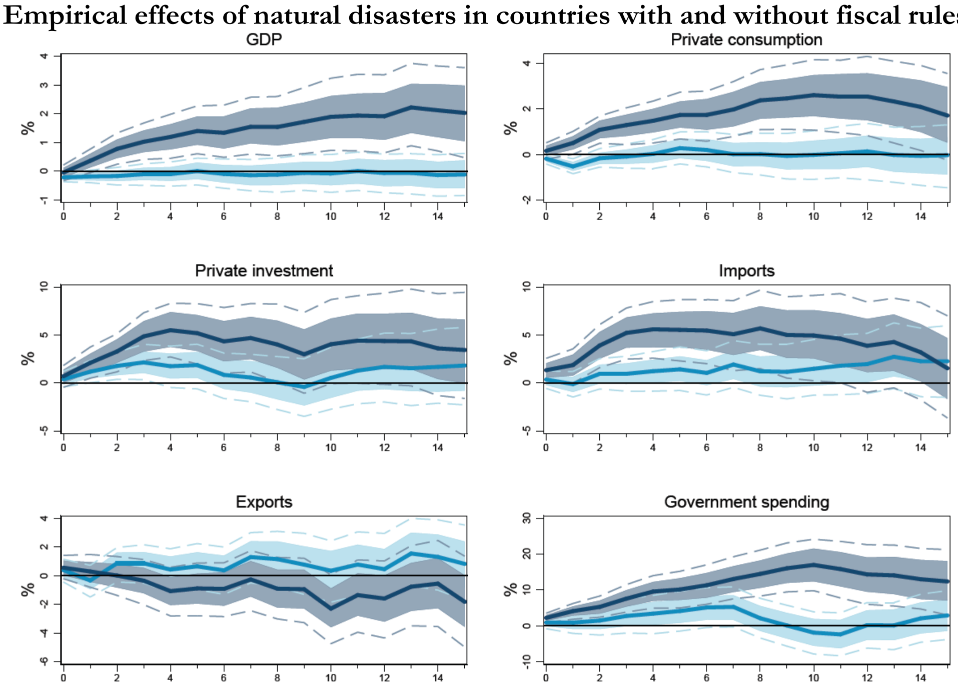
NON-TECHNICAL SUMMARY

In response to the Covid-10 pandemic, many governments have suspended fiscal rules and implemented deficit spending at an unprecedented amount. This has revived a classical discussion about the benefits and costs of fiscal rules. Such rules are defined as persistent constraints on fiscal policy in the form of numerical targets for budgetary aggregates, such as debt or deficits.

The main goal of fiscal rules is to restrict the secular increase in government debt, which is viewed as reflecting political economy factors, but not optimal macroeconomic policy. There is a growing consensus in the empirical literature that fiscal rules are successful at achieving this objective. At the same time, a main contention is that the benefit of stabilizing debt involves a fundamental tradeoff with the flexibility to respond to economic shocks.

In this paper, we evaluate the tradeoff argument and provide a new stylized fact using natural disasters. We show empirically and theoretically that countries with fiscal rules buffer such adverse economic shocks better (not worse) than countries without fiscal rules. First, we document empirically that output and private consumption are significantly higher and fiscal policy significantly more expansionary, in the aftermath of disasters in fiscal rule countries (see Figure). Furthermore, we show that the superior performance depends on the existence of fiscal space before entering the crisis and on the presence of escape clauses. Then, we rationalize the findings through a model of sovereign default with endogenous fiscal space and tax plans, in which a numeric fiscal rule prevents a myopic government from accumulating excessive debt. The model predicts that, relative to a situation without a rule, sovereign spreads spike less and fiscal policy is more expansionary, with higher output and private consumption, when disasters strike.

Empirical effects of natural disasters in countries with and without fiscal rules



Notes: The figure shows the cumulative response of growth in output and its components in countries with fiscal rules (dark shaded area) and in countries without fiscal rules (light shaded area) to large natural disasters, based on model (1) over the 1970Q1-2018Q4 period. The frequency is quarterly. Confidence bands refer to the 68% and 90% level and are based on 500 Monte-Carlo draws.

Engagé dans des règles budgétaires flexibles

Résumé

Nous étudions l'impact des règles budgétaires sur les performances macroéconomiques. Pour aborder l'endogénéité de l'adoption des règles, nous utilisons des données sur les grandes catastrophes naturelles aléatoires. Nous démontrons empiriquement que les pays dotés de règles ont une performance significativement meilleure après de tels chocs exogènes que les pays sans règles. Le PIB et la consommation privée sont durablement plus élevés. Ce résultat est associé à une politique budgétaire plus expansionniste et dépend de l'existence d'un espace budgétaire et de clauses de sauvegarde. Nous rationalisons les résultats dans un modèle de défaillance souveraine, qui reproduit la dynamique empirique et montre que des règles strictes créent une marge de manœuvre budgétaire en période de prospérité pour des dépenses déficitaires en période de crise.

Mots-clés : politique budgétaire, régimes fiscaux, catastrophes naturelles, modèle de défaut souverain, données du panel

1 Introduction

Facing one of the largest shocks in modern peacetime history and with monetary policy constrained by the zero lower bound, many countries responded to the adverse economic consequences of the Covid-19 pandemic with large-scale fiscal stimulus packages. Beyond an unprecedented amount of deficit spending, many governments have also suspended fiscal rules. This has revived a classical discussion about the benefits and costs of fiscal rules (Eichengreen and Wyplosz, 1998; Bouton et al., 2020; Blanchard et al., 2020; Piguillem and Riboni, 2021). Such rules are defined as persistent constraints on fiscal policy in the form of numerical targets for budgetary aggregates, such as debt or deficits. They are an increasingly important framework for macroeconomic policy around the globe. As of 2021, they are in place in around 90 countries.

The main goal of fiscal rules is to restrict the secular increase in government debt, which is viewed as reflecting political economy factors—rising electoral uncertainty, political polarization, or an aging population—but not optimal macroeconomic policy. There is a growing consensus in the empirical literature that fiscal rules are successful at achieving this objective (Alesina and Passalacqua, 2016; Asatryan et al., 2018; Heinemann et al., 2018). At the same time, a main contention in the theoretical literature, and among policy makers, is that the benefit of stabilizing debt involves a fundamental tradeoff with the flexibility to respond to economic shocks.[1] These potential costs of fiscal rules receive less attention in the literature but are arguably at least as important as determining the benefits.

In this paper, we evaluate the tradeoff argument and provide a new stylized fact using natural disasters. We show empirically and theoretically that countries with fiscal rules buffer such adverse economic shocks better (not worse) than countries without fiscal rules. First, we document empirically that output and private consumption are significantly higher, and fiscal policy significantly more expansionary, in the aftermath of disasters in fiscal rule countries. Furthermore, we show that the superior performance depends on the existence of fiscal space before entering the crisis and on the presence of escape clauses. Then, we rationalize the findings through a model of sovereign default with endogenous fiscal space, in which a numeric fiscal rule prevents a myopic government from accumulating excessive debt. The model predicts that, relative to a situation without a rule, sovereign spreads spike less and fiscal policy is more expansionary, with higher output and private consumption, when disasters strike.

We use natural disasters as a measure of adverse economic shocks for several reasons. Floods, earthquakes, and windstorms have economy-wide effects. They destroy

[1] See, among others, Amador et al. (2006); Battaglini and Coate (2008); Halac and Yared (2014).

physical capital and durable consumption goods (Noy, 2009; Kousky, 2014). Moreover, windstorms and floods are increasingly important for macroeconomic fluctuations as the global climate changes. At the same time, catastrophes are arguably exogenous to the decision to adopt a fiscal rule. This allows us to address an endogeneity problem: countries may introduce a rule because of their macroeconomic conditions or social preferences. Natural disasters, however, are unpredictable and not caused by economic conditions or preferences. These properties imply that we can identify the conditional effects of fiscal rules using relatively weak and verifiable assumptions about the distribution of the unobserved factors determining economic outcomes and the systematic relation between catastrophes and fiscal rules.

To measure the economic impact of natural disasters, we use the estimated damage to property, crops, and livestock reported in the Emergency Events Database (EM-DAT). Further, we collect quarterly data for 89 countries over the 1970Q1-2018Q4 period, dedicating considerable work to the collection of fiscal data. We estimate a set of dynamic panel models to trace out the macroeconomic effects of disasters in countries with and without fiscal rules. We find that in the former group, GDP, private consumption, and private investment are significantly higher than in the latter group, while the trade balance is more negative. Furthermore, we show that countries with fiscal rules also have significantly higher fiscal deficits following the shocks. Specifically, public transfers, government consumption and investment as well as other expenditures are significantly higher in the aftermath of disasters. Finally, we document that the differential response to the shocks depends critically on two factors: the existence of fiscal space before the shock and the presence of an escape clause that allows a fiscal authority to temporarily deviate from the numerical constraint.

To rationalize our empirical findings, we build a structural model with sovereign default, fiscal rules, and natural disasters that highlights the role of fiscal space for countercyclical fiscal policy. Endogenous fiscal space arises from a commitment problem of the government, which might default on its outstanding debt (Eaton and Gersovitz, 1981). We assume that the government is myopic. This leads to higher than optimal borrowing (Laibson, 1997) and motivates the introduction of a fiscal rule. We consider a correction of the deficit bias through a rule that constricts either public debt or the deficit. We model disasters as a temporary exogenous reduction in the physical capital stock. This lowers output obtained from a neoclassical production function with labor and capital inputs. The government decides optimally about spending, taxes, and foreign borrowing in response to natural disasters. If the rule is sufficiently tight and features an escape clause, sovereign spreads rise less following disaster shocks. The associated more countercyclical fiscal response leads to higher output and private consumption vis-à-vis a situation without fiscal rule.

The paper relates to the empirical literature on fiscal rules. The main challenge in this literature is the identification of the impact of fiscal institutions on fiscal policy. The majority of studies investigates the benefits of fiscal rules, that is, whether they are effectively constraining public deficits and debt (Wyplosz, 2012; Yared, 2019). In general, the evidence is supportive of this idea. However, Alesina and Passalacqua (2016) and Heinemann, Moessinger, and Yeter (2018) show that earlier studies are plagued by endogeneity. Fiscal institutions and fiscal outcomes are determined by similar factors, for example, by voter preferences for fiscal prudence, giving rise to omitted variable problems. Moreover, economic conditions might affect the decision whether to introduce a fiscal rule, generating reverse causality. Therefore, recent approaches are based on instrumental variables or difference-in-difference strategies. These articles also largely document positive effects of fiscal rules on fiscal discipline (Grembi et al., 2016; Asatryan et al., 2018; Combes et al., 2018).

Another set of empirical articles estimates the potential costs of fiscal rules, that is, whether they are associated with more procyclical fiscal policy. Here, the standard approach is to estimate fiscal reaction functions and to test whether these change with fiscal rules. While some papers find that rules-based restrictions induce more procyclicality (Lane, 2003; Fatás and Mihov, 2006), others document more countercyclicality (Galí and Perotti, 2003; Debrun, Moulin, Turrini, Ayuso-i Casals, and Kumar, 2008). However, the relation between fiscal rules and fiscal cyclicality is also subject to both omitted variables and reverse causality. Societies' preferences may determine rule adoption and fiscal reaction functions simultaneously. Moreover, the initial fiscal cyclicality can affect self-selection into rules. These identification challenges may also explain the mixed evidence in the literature.

This paper is more closely linked to the second set of empirical papers. Our contribution is to address the endogeneity problem by conditioning the estimation of fiscal reaction functions on an exogenous event, a natural disaster, and to show that the macroeconomic and fiscal responses change with the introduction of a fiscal rule. The benefit of this identification approach is that it allows for causal inference. It deals with the endogeneity problem by netting out the linear (and potentially endogenous) relation between fiscal rules and macroeconomic performance. In the terminology of the treatment literature, it assumes that the treatment, in the form of a catastrophe, is random, conditional on country characteristics. However, the interest does not lie in the treatment effect itself, but in whether fiscal rules change the response to the treatment. Thereby, our identification strategy is in the spirit of Poterba (1994) and Clemens and Miran (2012), who use annual data for a sample of U.S. states and estimate fiscal reactions to unexpected fiscal deficits. A drawback of the identification strategy is less generality as it conditions on a specific type of shock. However, Romer and Romer (2018) show that more fiscal space also helps recover from financial crises, suggesting that our results might apply to other shocks than natural disasters as well.

Finally, our paper relates to a theoretical literature on fiscal rules in models of sovereign default. Dovis and Kirpalani (2020) show, in a game-theoretic approach between a central government and local governments, under which conditions fiscal rules prevent overborrowing. Hatchondo, Martinez, and Roch (2015) study alternative anchors for fiscal rules. They find that a target for the sovereign spread leads to robust welfare gains across heterogeneous countries. Alfaro and Kanczuk (2017) focus on the implications of alternative fiscal rules in an endowment economy, finding sizable welfare gains in the presence of government myopia. We contribute to this strand of papers by introducing natural disasters into the analysis of sovereign debt sustainability. We focus on the economic responses to such shocks and how the dynamics are affected by alternative fiscal rules. Moreover, we model escape clauses, which are an important feature of existing fiscal rules and at the center of current reform proposals. We show that such contingencies are crucial for shaping the responses to large adverse shocks.

The remainder of the paper is organized as follows. Section 2 presents the data. The empirical analysis and results are discussed in Section 3, followed by the sovereign default model in Section 4. Section 5 concludes.

2 Data and empirical strategy

2.1 Data on natural disasters and fiscal rules

We use a large number of data sources to create a comprehensive dataset that allows us to investigate the role of fiscal rules in macroeconomic stabilization. Tab. A.2 in the Appendix provides a detailed list of all variables, definitions, and sources.

2.1.1 Natural disasters

We use the EM-DAT database from the Centre for Research on the Epidemiology of Disasters (CRED) as the basis for our shock variable. Collecting data from a variety of sources (UN agencies, governments, insurance companies, and press agencies), the database contains information on meteorological, geophysical, and climatological disasters that occurred worldwide since 1900. For an event to be reported, one of the following criteria must be met: 10 or more people were killed; 100 or more people were affected, injured or made homeless; the country declared a state of emergency; or the country appealed for international assistance.

The database provides information on each disaster's start date, its duration, as well as the human and economic impact. Following the literature on the macroeconomic effects of disasters (Noy, 2009), we use the estimated direct damage to property, crops, and livestock (in thousands of US dollars), valued at the event's occurrence. To focus on unexpected and exogenous shocks, we limit the selection to those types of disasters that have a sudden and immediate impact: earthquakes, landslides, floods, and storms. We exclude catastrophes that unfold slowly and subtly (such as droughts). To generate a quarterly shock variable, we take into account that events taking place earlier in the quarter have a larger impact on that quarter's output than shocks occurring toward the end of the quarter. We weight the estimated damage (DAM) by the onset month (OM), that is, the month of the reported starting date of the disaster, such that DAMw = DAM(3-OM)/3. Then, we sum the impact of all disasters per country and quarter. We standardize the disaster size by quarterly nominal GDP in US dollars one year prior to the event to make them comparable across countries.

Given the availability of quarterly macroeconomic data for our country sample, we use data from 1970Q1 to 2018Q4, which results in a total of 2,051 disaster shocks. To investigate the effects of large, nationally relevant disasters, we further limit the analysis to events above the median of the weighted and standardized shock measure. We winsorize the shocks at the 99th percentile to remove outliers. This gives a total of 1,026 shocks with an estimated damage between 0.03% and 4.55% of GDP. Of these, 320 shocks occur under a fiscal rule. In the sensitivity analysis, we show that the results are robust to alternative weighting schemes and different levels of winsorization.

2.1.2 Fiscal rules dataset

The International Monetary Fund (IMF) defines fiscal rules as "long-lasting constraint[s] on fiscal policy through numerical limits on budgetary aggregates" (Schaechter et al., 2012, p.5). It provides a Fiscal Rules Database, which documents the 95 countries that have introduced a fiscal rule at the national or supranational level between 1985 and 2015. The database also provides information on the legal basis and monitoring of the rules as well as on escape clauses. The latter define situations in which a deviation from the rule is admissible, such as natural disasters and other events outside the government's control.

The IMF distinguishes four types of fiscal rules based on the budgetary aggregate they refer to. First, debt rules limit public debt in percent of GDP, providing a direct link to debt sustainability. However, they lack short-term policy guidance and may lead to procyclical fiscal policy when an economy is hit by a shock and the debt rule is binding. Second, budget balance rules constrain the overall, structural, cyclically adjusted, or "over the cycle" balance. Although these rules entail more precise operational guidance, cyclical adjustment applied to prevent procyclicality is not straightforward and makes them more complex and difficult to communicate and monitor. Finally, expenditure rules limit total primary or current spending and revenue rules set floors or ceilings on revenues. While not controlling debt directly, they can prevent procyclicality and target the size of the government. Given the various advantages and disadvantages of the rules, two or more of them are often combined. Furthermore, the rules may be instituted and enforced on both the national and supranational level. For example, the European Union imposes the Stability and Growth Pact, which constrains the debt and budget balance of its members. Additionally, several European countries have national rules, for example, the German "debt brake".

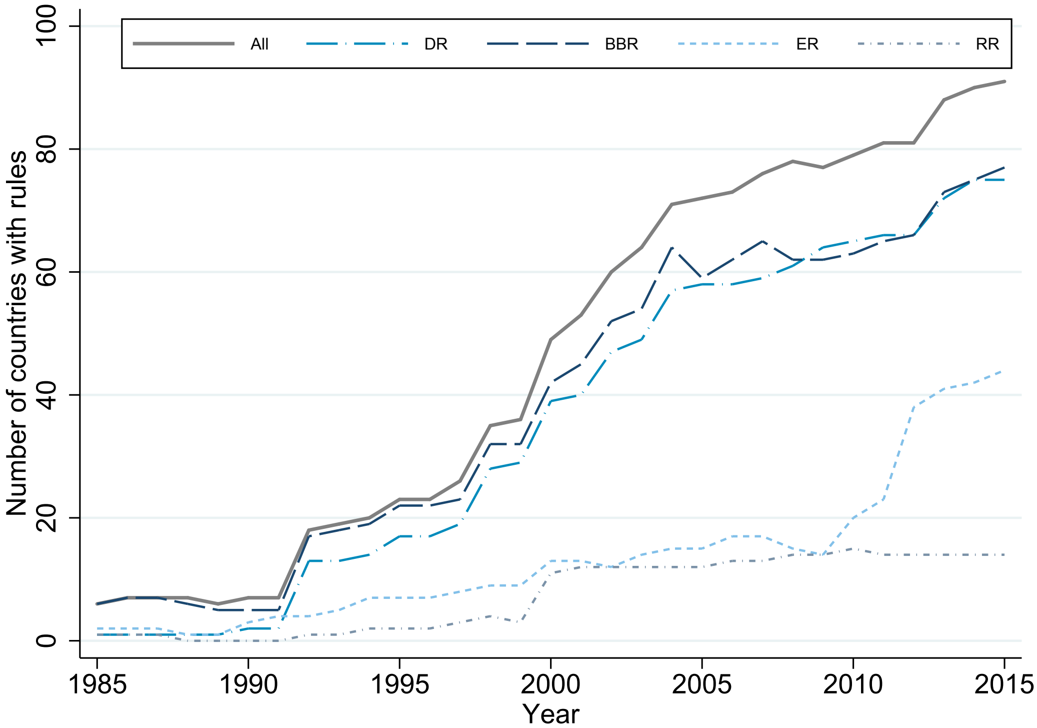
Fig. 1 displays the number of countries with fiscal rules over time. It shows that they have become increasingly popular over the past 30 years. In 1990, 7 countries had some sort of fiscal rule in place; in 2015, that number had risen to 91. Four countries in the database had retracted all rules by 2015: Argentina, Canada, Iceland, and India. We extend the sample by 24 countries that had no fiscal rule at any point in time to increase estimation efficiency for the control group. We also expand the data backward to 1970 using the information given in Lledó et al. (2017) and forward to 2018, assuming that no rules have been abolished or introduced between 2016 and 2018.[2] Fig. 1 also displays the number of countries that have a certain type of rule. It shows that debt and budget balance rules are most popular, while fewer countries have introduced expenditure rules. Revenue rules are rare.

From the yearly data provided by the IMF, we generate a dummy that equals one whenever a country has any fiscal rule in place. This comprises all types (debt, budget balance, expenditure, and revenue rules) as well as both national and supranational rules. The dummy does not differentiate between the number or type of fiscal rule, nor does it account for the stringency of enforcement. Thus, we aim to investigate whether the mere existence of any rule makes a country less or more resilient to shocks. We interpolate the data to obtain a quarterly dataset. To analyze the mechanisms in more detail, we also generate dummy variables for the types of rules. These dummies equal one when a particular rule is in place on the national or supranational level and zero when the country has no fiscal rule. Countries that do not have the rule in question are excluded in this case.

Fig. 2 brings together the data on disasters and fiscal rules. It shows the mean

[2] Given the evident dynamics of fiscal rules, this is a strong assumption. However, excluding the last three years from our dataset does not change the results.

Figure 1: Number of countries with fiscal rule



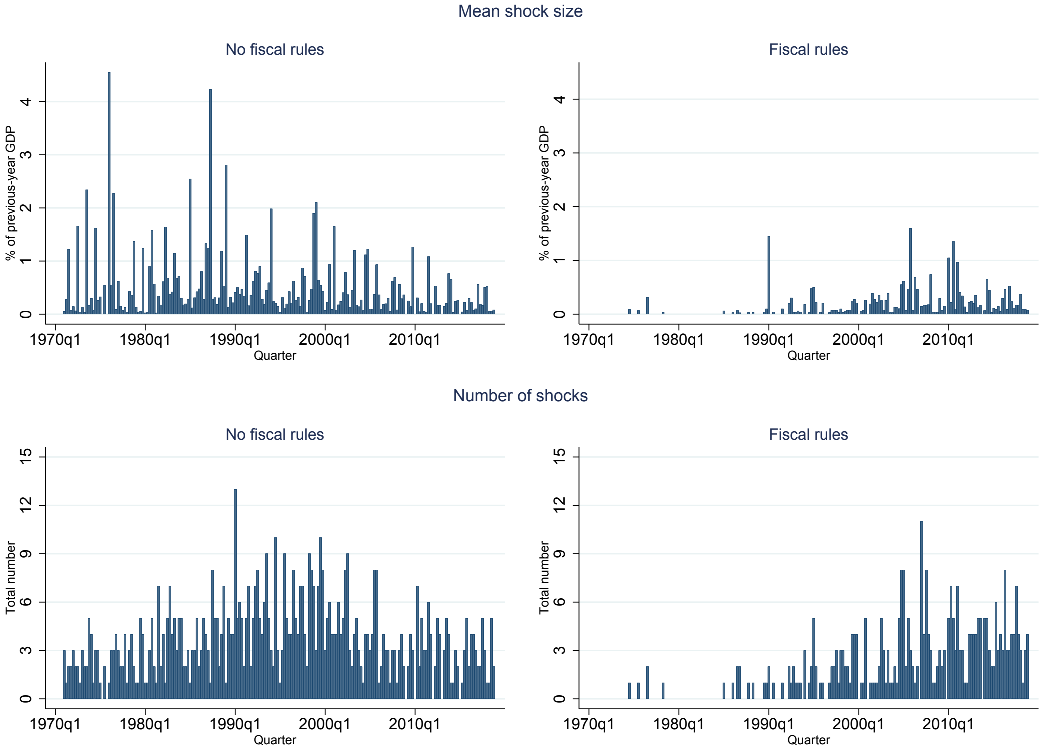
Notes: The figure shows the total number of countries that have any sort of fiscal rule as well as the number of countries with different types of fiscal rules in place each year. DR = Debt rule, BBR = Budget balance rule, ER = Expenditure rule, RR = Revenue rule.

shock size (upper panels) and the number of shocks (lower panels) for countries without (left panels) and with fiscal rules (right panels) over time. The figure indicates that both country groups are significantly affected by natural disasters. The large number and size of shocks in each group suggests that we can reliably estimate the impact of the shocks depending on the fiscal regime. The smaller number and later onset of disasters for fiscal rule countries reflects that most countries adopted fiscal rules after 1990. In addition, more severe and more prevalent shocks in countries without fiscal rules suggest a possible link between the susceptibility to disasters and the choice of rule adoption. We control for this possibility through both country fixed effects and institutional quality indicators.

2.1.3 Macroeconomic and fiscal data

We collect macroeconomic data at a quarterly frequency between 1970Q1 and 2018Q4. We obtain real and seasonally adjusted data on output, private consumption, private investment, exports, and imports from the OECD national accounts as well as from national sources. If real or seasonally adjusted data are not available, we do these

Figure 2: Distribution of large disaster shocks



Notes: The figure shows the average shock size in % of GDP (upper panels) and the frequency of shocks (lower panels) for countries without fiscal rules (left panels) and with fiscal rules (right panels) per quarter. The mean shock and the total number of shocks are computed from shock observations greater than zero.

transformations ourselves. Data on government bond yields and credit default swap rates are obtained from Datastream. To approximate institutional quality, we use government effectiveness from the Worldwide Governance Indicators of the World Bank. We also collect a number of control variables from a variety of sources, including a democracy index, population density, the level of urbanization, and an exchange rate index, see Tab. A.2. Tab. A.1 in the Appendix lists all countries in the sample, mostly advanced and emerging market economies. The dimensions of the dataset and of each regression are dictated by the joint availability of the variables included.

We invest considerable effort in the collection of quarterly government variables to analyze the behavior of fiscal policy following the shocks. The data include the broader aggregates of total spending and revenue as well as subcategories of expenditure, such as social benefits, subsidies, and employee compensation. The variables are obtained from Datastream, DBnomics, and the IMF International Financial Statistics. As fiscal data are provided only in nominal terms, we use the Consumer Price Index (CPI) to deflate them, seasonally adjust the data, and compute quarterly real growth rates.[3] In the same way, we compute a structural government surplus variable as the difference between revenue and spending, then dividing it by GDP to generate a ratio. Following Romer and Romer (2018), we net this ratio of automatic stabilizers by subtracting the product of the sensitivity of the fiscal balance to the output gap (estimated at 0.4 by these authors) and the change in the logarithm of GDP over the same quarter. Finally, we add government investment data from Ilzetzki et al. (2013).

2.2 Empirical model and identification

We estimate the dynamic effects of natural disasters using the following model:

$$\begin{aligned}\Delta y_{i,t} = \alpha + \sum_{j=0}^{J} [&\beta_j S_{i,t-j} + \gamma_j FR_{i,t-j} + \delta_j FR_{i,t-j} S_{i,t-j} \\ &+ \eta_j \text{GDPpc}_i^{1990q1} S_{i,t-j} + \theta_j \text{Goveff}_{i,t-j} + \lambda_j \text{Goveff}_{i,t-j} S_{i,t-j}] \\ &+ \Phi X_{i,t-4} + \nu_i + \nu_Y + \sum_{l=1}^{L} \mu_l \Delta y_{i,t-l} + \epsilon_{i,t},\end{aligned} \tag{1}$$

where $\Delta y_{i,t}$ denotes the quarterly rate of change in a generic dependent variable for country i in quarter t. We use alternative endogenous variables, including GDP, private consumption, government spending, and interest rates. The disaster shock is captured by $S_{i,t-j}$. $FR_{i,t-j}$ is the dummy variable that indicates the presence of a fiscal rule. We set the lag length to $J = 15$ to compute impulse responses over four years.

The key variables in (1) are the interactions between the shock and the rule dummy. The corresponding coefficients δ_j capture the difference in the dynamic effects of the shocks between countries with and without fiscal rules. Such rules may have an important impact on how quickly an economy recovers from the shocks. On the one hand, limits on debt and/or spending could prevent the government from rapidly and flexibly reacting to natural disasters, thereby inhibiting necessary measures for recovery and slowing down economic growth. On the other hand, if fiscal rules achieve debt sustainability in good times while allowing for flexibility in case of crises through escape clauses or cyclical adjustments, they may enhance governments' range of action to respond to shocks. For example, Romer and Romer (2018) interpret the inverse debt-to-GDP ratio as fiscal space and find that countries suffer less from financial crises the more fiscal space they have. Furthermore, fiscal rules may enhance market access through debt sustainability and improve credibility and decision making of policy makers (Romer and Romer, 2019). Thus, in the empirical part of this paper, we

[3] The choice of CPI over any other deflator is exclusively due to data availability.

test the following:

Hypothesis: *Fiscal rules affect the macroeconomic response to natural disasters.*

The vector $X_{i,t-4}$ in (1) contains the following control variables: the degree of urbanization, population density, a measure for the level of democracy, and the US-Dollar exchange rate. These enter with a lag of four quarters to prevent a feedback with the disaster shocks. We also include country fixed effects, ν_i, to account for time-invariant country characteristics (such as the exposure to disasters and the initial level of development) and year fixed effects, ν_Y, to correct for common unobservable time-varying factors, for example, global economic conditions or climate change.

To remove possible autocorrelation in the error term $\epsilon_{i,t}$, we include four lags of the dependent variable, $L = 4$. To account for the heteroskedasticity in the large cross-section, we estimate (1) using feasible generalized least squares with heteroskedastic panels. Modified Wald tests for groupwise heteroskedasticity reject the null hypothesis of homoskedastic panels at $p < 0.00$. Throughout, we base statistical inference on 500 Monte Carlo draws.[4]

To illustrate our identification strategy, which follows Ramcharan (2007), consider the case of $J = L = \eta_0 = \theta_0 = 0$ and all controls in (1) compiled in the vector $C_{i,t}$. Define the expected value of $\Delta y_{i,t}$ conditioned on $C_{i,t}$ and given that a shock occurs as $\mathbb{E}(\Delta y_{i,t}|S_{i,t} > 0, C_{i,t})$. The average effect of the shock is then

$$\begin{aligned}\mathbb{E}(\Delta y_{i,t}|S_{i,t} > 0, C_{i,t}) - \mathbb{E}(\Delta y_{i,t}|S_{i,t} = 0, C_{i,t}) &= \beta_0 S_{i,t} + \delta_0 \mathbb{E}(FR_{i,t}|S_{i,t} > 0, C_{i,t})S_{i,t} \\ &+ \gamma_0[\mathbb{E}(FR_{i,t}|S_{i,t} > 0, C_{i,t}) - \mathbb{E}(FR_{i,t}|S_{i,t} = 0, C_{i,t})] \\ &+ \mathbb{E}(\epsilon_{i,t}|S_{i,t} > 0, C_{i,t}) - \mathbb{E}(\epsilon_{i,t}|S_{i,t} = 0, C_{i,t}).\end{aligned} \tag{2}$$

To simplify (2), we make two assumptions. First, we postulate that the presence of a fiscal rule is not affected by a natural disaster, $\mathbb{E}(FR_{i,t}|S_{i,t} > 0, C_{i,t}) = \mathbb{E}(FR_{i,t}|S_{i,t} = 0, C_{i,t}) = FR_{i,t}$. This assumption is motivated by the considerable stability of fiscal rules. Only seven countries in the sample have abolished a fiscal rule at some point. Furthermore, just three countries have introduced a national fiscal rule in the four years following a large disaster (defined as an estimated economic damage of more than 0.5% of GDP). Excluding both types of countries does not change the results.[5]

[4] We use a parametric bootstrap, applying the estimated covariance matrix of the coefficients to draw new coefficients from a multivariate normal distribution, to compute a distribution of impulse responses (Romer and Romer, 2004).

[5] We focus on national fiscal rules when checking this, assuming that rules on the supranational level are not driven by natural disasters in single member countries. The results are also robust to

Second, we assume that the unobserved drivers of the dependent variable, captured by the residual $\epsilon_{i,t}$, are unrelated to $S_{i,t}$. We justify this assumption by the random nature of the shocks and the fact that we control for the general exposure to the shocks through country fixed effects. Thus, $\mathbb{E}(\epsilon_{i,t}|S_{i,t} > 0, C_{i,t}) = \mathbb{E}(\epsilon_{i,t}|S_{i,t} = 0, C_{i,t}) = 0$. These two assumptions simplify (2) to:

$$\mathbb{E}(\Delta y_{i,t}|S_{i,t} > 0, C_{i,t}) - \mathbb{E}(\Delta y_{i,t}|S_{i,t} = 0, C_{i,t}) = \beta_0 S_{i,t} + \delta_0 FR_{i,t} S_{i,t}, \tag{3}$$

such that δ_0 measures the causal effect of fiscal rules on the recovery from natural disasters, provided that we control for other shock absorbers.

To account for such potential further nonlinearities, we control for the level of development (proxied by the level of GDP per capita in 1990Q1, $GDPpc_i^{1990q1}$) and for institutional quality (measured by government effectiveness, $\text{Goveff}_{i,t-j}$). The interaction terms relax the standard assumption in panel models of common slopes across all panels. We investigate a variety of further shock absorbing mechanisms in the sensitivity analysis.

3 Empirical analysis of fiscal rules and disasters

This section contains the core results. Before we analyze whether fiscal rules change the response to natural disasters, we briefly develop a notion about these shocks. We defer a formal theoretical analysis of disaster shocks to Section 4. Natural disasters typically destroy the capital stock. They cause direct damage to houses and contents, machinery, and infrastructure as well as indirect damage due to business interruption. The replacement of destroyed capital through more productive investment and new technologies, spending of insurance payouts, and possible multiplier effects of increased household and business outlays usually imply higher private investment, generate catch-up consumption demand, and increase GDP (Noy, 2009; Kousky, 2014). However, we hypothesize that the precise form of the recovery depends on the presence of fiscal rules, which may also shape the public response to the shocks.

3.1 The estimated impact of fiscal rules on dynamics

Tab. 1 shows the regression results based on (1). The dependent variable in models 1-4 is the log change in GDP, private consumption, government spending, and the budget balance, respectively, in percent. The upper part contains the estimated δ_js that measure the direct differential effect of fiscal rules following a shock, with the

excluding 13 countries that introduced a national rule after any size of shock in the sample.

associated standard errors in parentheses. The middle part focuses on the coefficients of the lagged dependent variables, μ_l. The bottom part contains summary statistics. The large χ^2s of the regressions suggest that the models generally describe the data well. This is also reflected in the low p-values of tests for joint significance of the country and year fixed effects, which support the specification.

Table 1: Regression results for differential impact of fiscal rules

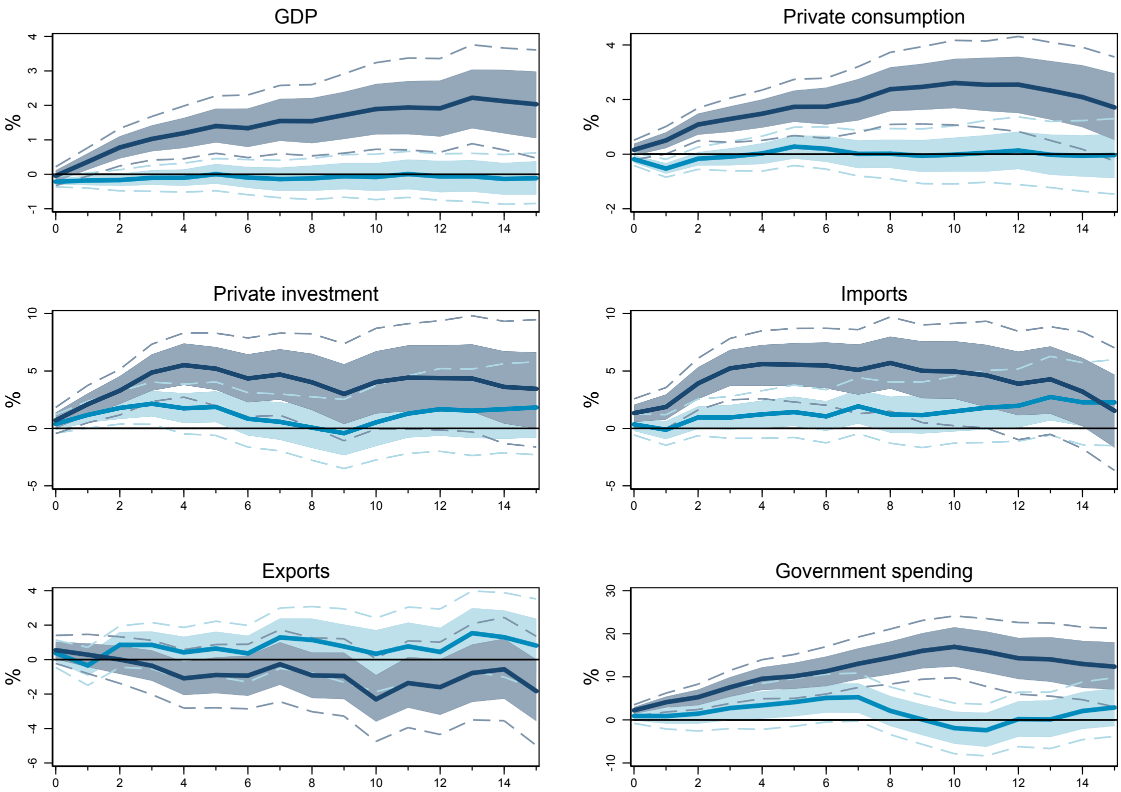
Dependent variable (Δ)	(1) GDP		(2) Priv. consumption		(3) Gov. spending		(4) Budget balance	
FR*shock in t-0	0.17	(0.18)	0.37**	(0.18)	1.27	(1.22)	-0.38	(0.38)
FR*shock in t-1	0.38**	(0.18)	0.71***	(0.18)	1.71	(1.22)	-0.25	(0.38)
FR*shock in t-2	0.36**	(0.18)	0.17	(0.18)	0.11	(0.97)	-0.23	(0.32)
FR*shock in t-3	0.10	(0.18)	0.00	(0.18)	0.56	(1.01)	-0.82**	(0.37)
FR*shock in t-4	0.09	(0.18)	-0.06	(0.19)	1.34	(1.06)	-0.46	(0.42)
FR*shock in t-5	0.02	(0.18)	-0.06	(0.18)	0.12	(1.05)	-0.65	(0.42)
FR*shock in t-6	-0.02	(0.18)	0.05	(0.19)	0.24	(1.07)	-0.25	(0.42)
FR*shock in t-7	0.22	(0.18)	0.40**	(0.19)	1.88*	(1.07)	-1.62***	(0.42)
FR*shock in t-8	-0.06	(0.19)	0.38**	(0.19)	4.71***	(1.06)	-0.62	(0.41)
FR*shock in t-9	0.08	(0.19)	0.09	(0.19)	2.52**	(1.06)	-0.29	(0.34)
FR*shock in t-10	0.19	(0.19)	-0.01	(0.19)	1.57	(1.07)	-0.37	(0.34)
FR*shock in t-11	-0.08	(0.19)	-0.23	(0.19)	-1.38	(1.07)	-0.21	(0.29)
FR*shock in t-12	0.02	(0.18)	-0.12	(0.19)	-2.96***	(1.04)	0.26	(0.29)
FR*shock in t-13	0.29	(0.18)	-0.06	(0.19)	1.68	(1.04)	-0.78***	(0.29)
FR*shock in t-14	-0.06	(0.18)	-0.18	(0.19)	-1.44	(1.00)	0.79***	(0.29)
FR*shock in t-15	-0.14	(0.18)	-0.39**	(0.19)	-0.91	(1.00)	0.29	(0.29)
Dependent in t-1	0.05***	(0.01)	0.01	(0.01)	0.24***	(0.02)	-0.53***	(0.02)
Dependent in t-2	0.10***	(0.01)	0.11***	(0.01)	0.12***	(0.02)	-0.33***	(0.03)
Dependent in t-3	0.03**	(0.01)	0.15***	(0.01)	0.08***	(0.02)	-0.23***	(0.03)
Dependent in t-4	0.05***	(0.01)	0.01	(0.01)	-0.35***	(0.02)	0.17***	(0.02)
Further controls	yes		yes		yes		yes	
Number observations	7,854		7,437		2,024		1,803	
Number countries	68		61		39		32	
χ^2 regression	2072.70		1408.70		997.22		1081.32	
Joint p-value country FE	0.000		0.000		0.012		0.002	
Joint p-value year FE	0.000		0.000		0.000		0.000	
Joint p-value interactions	0.473		0.004		0.000		0.000	
1st year	0.048		0.001		0.553		0.188	
2nd year	0.782		0.289		0.352		0.002	
3rd year	0.832		0.217		0.000		0.402	
4th year	0.510		0.271		0.008		0.188	

Note: The table shows the effect of natural disaster shocks on the quarterly percentage change in GDP, private consumption, government spending, and the surplus-to-GDP ratio, respectively, in countries with fiscal rules vis-à-vis those without fiscal rules; and further coefficient estimates. The estimates are based on (1). The bottom of the table contains p-values of F-tests for the joint significance of the interaction terms of the shocks with the fiscal rules dummy, both for the entire period and selected years, as well as of the country and time fixed effects. Coefficients marked with ***,**,* represent statistical significance at the 1%, 5%, 10% levels, respectively.

Model 1 shows that the estimated impact of fiscal rules on output growth is mostly positive. Only 5 parameters are negative, with all of these insignificant. The coefficients for the first and second lag are individually significant at the 5% level and the null hypothesis that the impact of the interaction terms on output growth in the first year after the shock is zero is rejected at the 5% level (see bottom of the table). Similarly, the distributed impacts of the interaction terms on private consumption and government spending growth are predominantly positive when they are individually significant (models 2 and 3), while they are mostly negative for the cyclically adjusted budget balance (model 4). Moreover, the 16 lag coefficients are typically highly significant jointly, as the p-values of the corresponding F-tests in the bottom of the table show. All in all, the results suggest that fiscal rules lead to greater output, private consumption, and government spending growth in the aftermath of the shocks as well as to wider public deficits.

The middle part of the table conveys a high persistence in the dependent variables. All but two of the lagged endogenous variables are statistically significant. This implies that the autoregressive part of the model is an important determinant of the dynamic effects of fiscal rules. The tabular presentation of the individual coefficients neglects these effects. Therefore, Fig. 3 shows the dynamic adjustment to the shocks graphically. They are based on the estimated coefficients β_j, γ_j, δ_j, and μ_l of (1), and take into account the lagged impact of the shocks through the dynamic part of the model. We show cumulative effects.

Figure 3: Effects of natural disasters in countries with and without fiscal rules



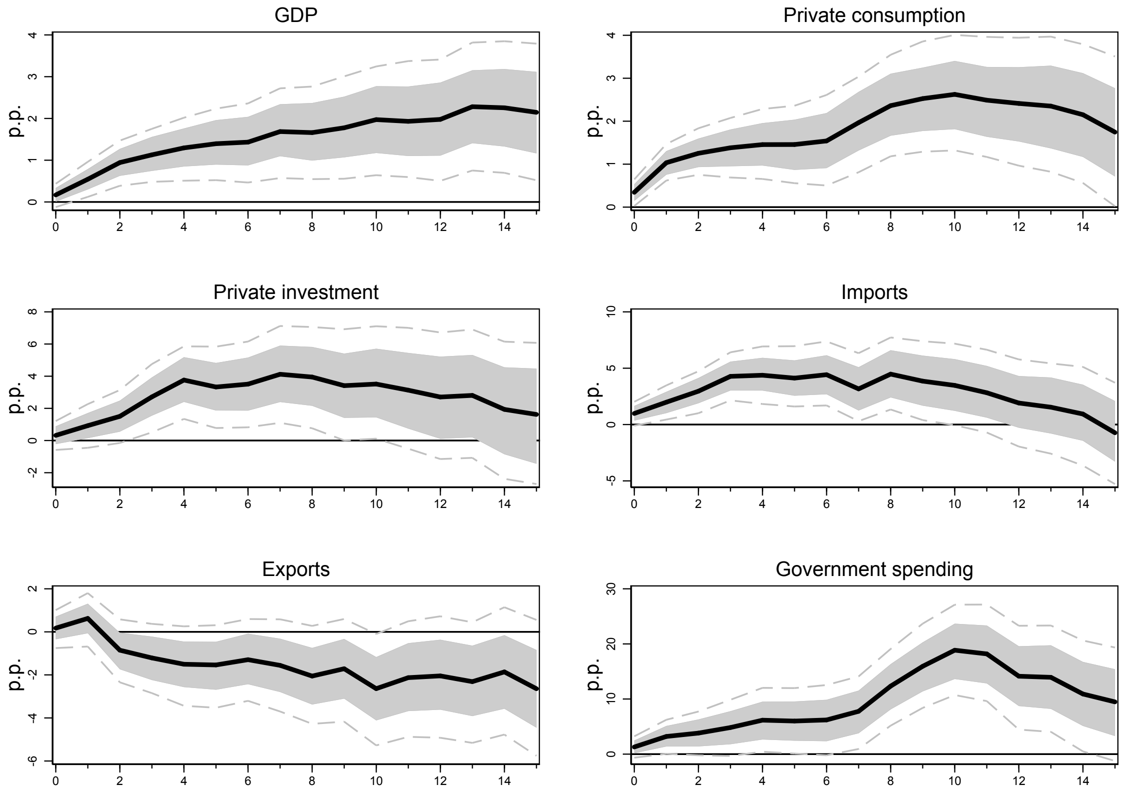
Notes: The figure shows the cumulative response of growth in output and its components in countries with fiscal rules (dark shaded area) and in countries without fiscal rules (light shaded area) to large natural disasters, based on model (1) over the 1970Q1-2018Q4 period. The frequency is quarterly. Confidence bands refer to the 68% and 90% level and are based on 500 Monte-Carlo draws.

There are important differences between the groups. First and foremost, output is higher under fiscal rules. The initial drop is insignificant and the subsequent recovery is strong. Output persistently and significantly rises above the level prevailing in the absence of the shock. In contrast, GDP drops in countries without fiscal rules and only returns to its pre-shock level; there is no overshooting. Similarly, private consumption increases significantly upon impact and subsequently under fiscal rules, while it drops without rules and recovers only gradually. Private investment rises in both groups, but the increase is stronger and longer-lasting with rules than without rules. A similar picture emerges for imports, whereas exports are marginally lower under fiscal rules. Taking the responses of imports and exports together suggests that rule countries have larger trade deficits. Finally, public spending increases in both groups for about a year and a half. Thereafter, it returns to trend without rules, whereas it keeps on rising with rules. In sum, the findings provide further support for the hypothesis that fiscal rules affect the absorption of disaster shocks.

To test this impression formally, we compute the differences between the responses of both groups and test whether they are statistically significant. Fig. 4 shows the results. They add to the initial impression. GDP and all components of domestic absorption are significantly higher under fiscal rules. Exports are marginally lower. The implicit trade deficit is wider. In general, the differences are large and persistent. Bar the initial quarter, output is significantly higher when fiscal rules are in place. The effect is roughly 2 percentage points (pp) after three years. In particular, private consumption contributes from the first quarter onward to the superior output performance. The difference in private investment is initially smaller, but adds increasingly to the widening GDP difference a year or so after the shock. Another key driver of the positive impact of fiscal rules on output and private demand seems to be the response of fiscal policy. Total spending is also significantly higher under fiscal rules. The maximum difference is close to 20pp. All in all, the formal evidence is consistent with the hypothesis that fiscal rules support a recovery from the shocks significantly.

In the Appendix, we present an extensive sensitivity analysis for the main findings that output and government spending growth are higher after a disaster shock in countries with fiscal rules. First, following the notion that those countries may systematically exhibit other characteristics that support the recovery after a shock, we control for the exchange rate and monetary regime as well as the general susceptibility to natural disasters as alternative shock absorbing features (Fig. A.1). Second, we show that the effects are qualitatively and quantitatively similar to the baseline when we split the sample into OECD and non-OECD countries (Fig. A.2). Third, we conduct a number of technical robustness tests, including alternative specifications and

Figure 4: Dynamic impact of fiscal rules on the recovery from natural disasters



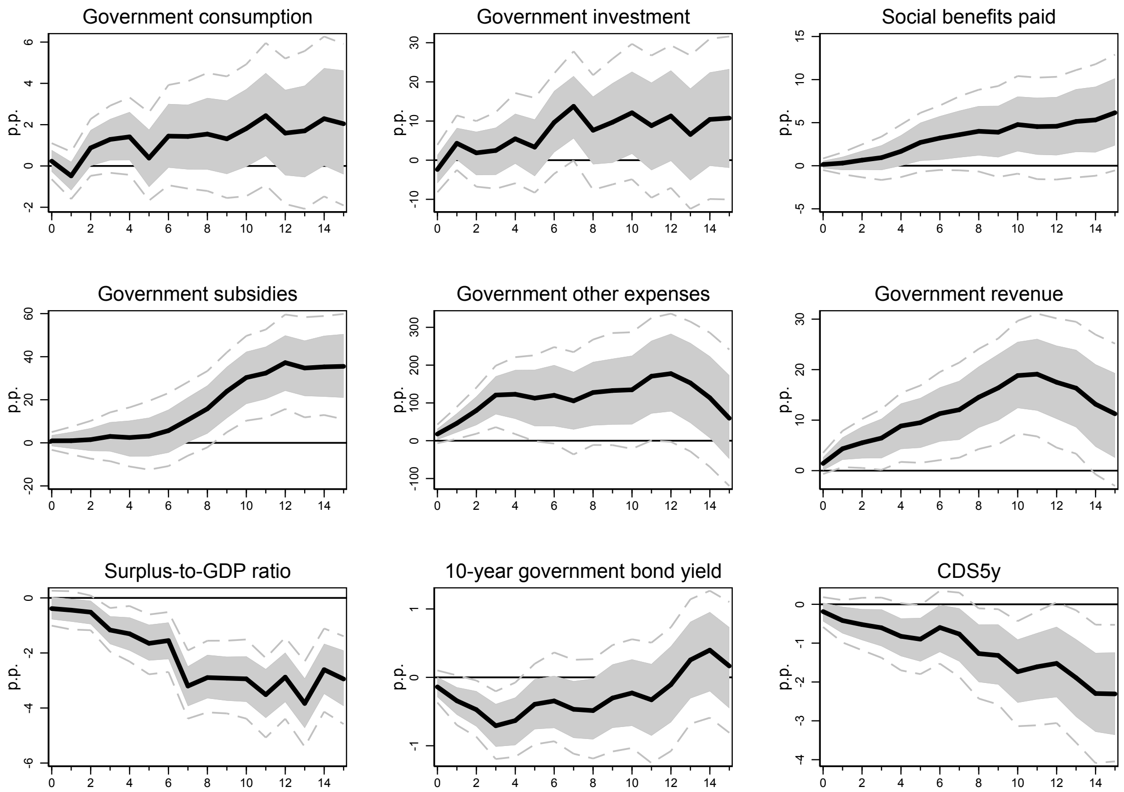
Notes: The figure shows the cumulative differential responses of output and its components between countries with and without fiscal rules to large natural disaster, based on model (1) over the 1970Q1-2018Q4 period. The frequency is quarterly. Confidence bands refer to the 68% and 90% levels and are based on 500 Monte-Carlo draws.

estimation methods and find that the impact of fiscal rules on the response of GDP is robust to all modifications (Fig. A.3).

3.2 Detailed empirical analysis of fiscal policy

To understand the mechanisms underlying the superior output performance of fiscal rule countries, we now take a closer look at the fiscal response to the shocks. Fig. 5 shows the differential evolution of selected government spending items, and revenues, following the shock. The figure focuses on the components that are significantly different at least at the 68% level. The drivers of the stronger fiscal spending expansion in rule countries are government consumption (compensation of employees and the use of goods and services), investment, social benefits, subsidies, and other expenses. Subsidies are transfers of government units to public and private firms and to other sectors, such as states or regions, for goods and services. Although this category only accounts for 3% of total public expenses, on average, in the sample, it appears to contribute to the stronger increase in total government spending under rules toward the end of the response horizon. The difference between the two groups reaches 40pp. Governmental transfers to households are usually not included in subsidies unless households are producers. Instead, these are contained in social benefits and other expenses.

Figure 5: Responses of government expenditure categories, revenues and interest rates.



Notes: The figure shows the cumulative differential responses of fiscal variables between countries with and without fiscal rules following large natural disasters, based on model (1) over the period 1970Q1-2018Q4. Confidence bands refer to the 68% and 90% levels and are based on 500 draws.

Other expenses are especially higher in fiscal rule countries. This category also includes payments and gifts by the government to individuals, private nonprofit institutions, nongovernmental foundations, corporations, or government units for damages to, or loss of, capital goods due to natural disasters. Moreover, it comprises purchased goods and services from market producers that are distributed directly to households for final consumption (other than social benefits) and exceptional capital transfers for extensive damages or serious injuries arising from the catastrophes, which are not covered by insurance policies. Indeed, other expenditures increase strongly in both groups (by about 100% and 200%, respectively) but much more strongly in countries with rules. The difference is 100pp and it is mostly significant. The share of these items within total expenses varies between 5% and 25% in the sample.

Government consumption, investment, and social benefits are also important categories. Together, they account for about two-thirds of total spending. The differences in the group-specific responses are quantitatively important, but imprecisely estimated. In contrast, total revenues increase significantly more in countries with fiscal rules. We view this as reflecting automatic stabilizers since the tax base also is much higher in these countries following the shock and tax revenues increase with output. Finally, the surplus ratio is four percentage points lower, showing that fiscal policy is generally more expansionary. This fiscal reaction along with the output response is consistent with the literature documenting positive fiscal multipliers (Caldara and Kamps, 2017).

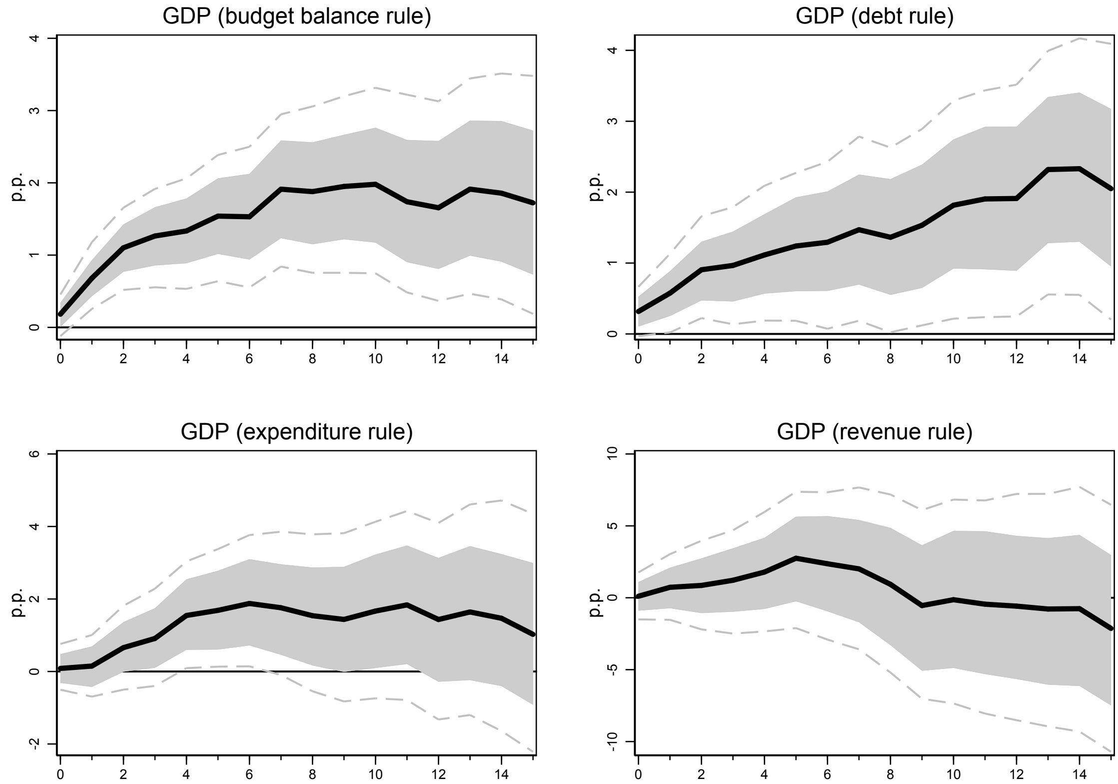
The last two panels in the figure provide an indication of the reasons for the more expansionary policy in countries with fiscal rules. The ten-year rate, a useful approximation of countries' financing conditions, is significantly lower under rules. This rate reflects several components. Next to credit risk, it comprises inflation and real growth expectations. To strip off the latter two components, the last panel shows the dynamic difference in the five-year credit default swap spread, which measures sovereign credit risk. The difference is also significantly negative. Both panels point to higher public solvency and better market access of rule countries as potential explanations for their more expansionary policy response.

3.3 Empirical mechanisms

We further investigate why governments under fiscal rules are able to increase their deficits more while also enjoying better market access in crisis times. Fig. 6 plots the differential GDP response between countries with and without fiscal rules, distinguishing between different types of rules. The fiscal rule dummy is now defined as equal to one whenever a country has, respectively, a balanced budget rule, a debt rule, an expenditure rule, or a revenue rule; and zero if the country has no rule at all.[6] The main result of a superior output performance under fiscal rules seems to be primarily driven by balanced budget rules and debt rules. For those two, the point estimates are similar to those based on the baseline definition of the rule dummy. The output difference between countries with and without rules is significant essentially for the full horizon. For expenditure rules, the effect is comparable in size but less statistically significant. The impact of revenue rules is indistinguishable from zero, but this finding must be treated with caution as the number of observations for revenue rules is small.

[6] As fiscal rules are often combined, this dummy definition does not discriminate sharply between different types of rules. Nevertheless, the results provide a clear picture, whereas a narrower definition of rule groups yields too few observations per group and imprecise estimates.

Figure 6: The differential GDP response under alternative fiscal rules

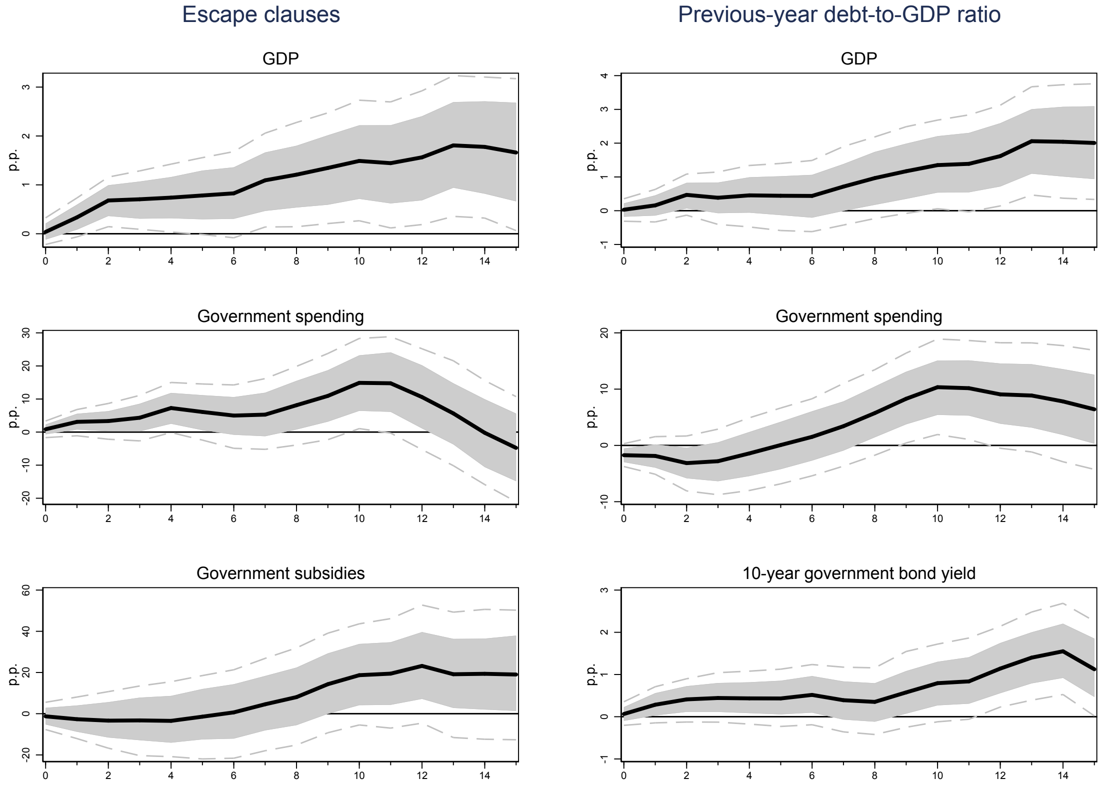


Notes: The figure shows the differential response of quarterly GDP between countries with a certain type of rule (budget balance, debt, expenditure or revenue rule) compared to countries without fiscal rules following large natural disasters. Countries with the respective rule may still have other rules. Confidence bands refer to the 68% and 90% levels and are based on 500 Monte-Carlo draws.

The rule-specific results are consistent with the institutional arrangements of these rules. Balanced budget requirements often contain escape clauses and/or are defined in cyclically adjusted terms. Both features aim at increasing the flexibility to accommodate economic shocks. Formal escape clauses explicitly allow for temporary deviations from the rule in the event of a disaster or other shocks outside of the control of the government. An example is the Covid-19 pandemic, which triggered the activation of the general escape clause in the Stability and Growth Pact (SGP). Countries can temporarily exceed the deficit ceiling without entering an excessive deficit procedure.

To study the role of such contingencies formally, the left column of Fig. 7 shows the differential response of GDP, government spending, and subsidies when controlling for escape clauses. We replace government effectiveness in (1) with a dummy variable equal to one whenever a fiscal rule contains an escape clause; and zero otherwise. Thus, we measure the impact of fiscal rules without escape clauses on the recovery relative to no rules. The differences partly vanish for both government spending variables and the impact of rules on the dynamics of output decreases. This indicates that escape clauses are important for the fiscal response to shocks because they increase flexibility. The finding supports the theoretical results of Halac and Yared (2020) who show that such clauses are optimal if shocks are sufficiently volatile and the costs of triggering the clause are low.

Figure 7: The role of escape clauses and fiscal space



Notes: The figure shows the differential response of selected variables between countries with and without fiscal rules to large natural disasters. The left column is based on a model where government effectiveness is replaced with a dummy variable for escape clauses to control for their impact. The right column is based on a model where government effectiveness is replaced with the previous year's debt-to-GDP ratio to control for fiscal space. The estimation is based on a quarterly sample over the 1970Q1-2018Q4 period. Confidence bands refer to the 68% and 90% levels and are based on 500 Monte-Carlo draws.

At the same time, the estimated dynamics suggest that escape clauses are not a necessary condition for flexibility as all three responses remain (partially or fully) significant. One potential reason is that balanced budget rules may exclude public investment. Furthermore, debt rules often define medium to long term limits or targets. Thus, they are compatible with deficits and fluctuations in debt. Debt limits may also not bind because debt is sufficiently far below the threshold such that these rules impose no short-run constraints on fiscal policy. Similarly, expenditure rules set limits on expenditures but are usually defined over horizons of several years. Moreover, they often allow for economic stabilization by excluding cyclically sensitive items.

While this institutional flexibility facilitates stabilization policy, it needs to be coupled with market access. Indeed, there is mounting evidence that, in the long-run, fiscal rules reduce sovereign deficits and debt (Debrun et al., 2008; Grembi et al., 2016; Heinemann et al., 2018). Sustainable public finances may allow governments to tap financial markets more easily in situations of stress. Romer and Romer (2018) show that governments with more fiscal space, measured by the inverse debt/GDP ratio, respond with more expansionary fiscal policy to financial crises.

To assess this idea formally, we conduct a similar regression to the one for escape clauses but controlling for fiscal space. The right column of Fig. 7 shows the impact of fiscal rules on the reaction of output, government spending, and the ten-year rate when replacing government effectiveness in (1) with the previous year's debt/GDP ratio. The picture is similar to the left column. The effect of fiscal rules on the difference in GDP and government spending decreases, although the differences remain positive and partially significant. The difference in the ten-year rates tends to even reverse sign. These findings suggest that fiscal space is a second channel through which fiscal rules affect the dynamics following natural disasters. In the next section, we build a theoretical model with both fiscal space and escape clauses to see whether these mechanisms can explain our empirical results.

4 Theoretical mechanisms

In this section, we present a theoretical model of sovereign default, fiscal rules, and natural disasters. The latter are modeled as a temporary exogenous reduction in the physical capital stock. This lowers output from a neoclassical production function with labor and capital inputs. Endogenous fiscal space arises from a commitment problem of the government, which might default on its debt (Eaton and Gersovitz, 1981). As a result, the government decides optimally about spending, taxes, and foreign borrowing in response to disasters. To motivate the presence of a fiscal rule, we assume that the government is myopic (Laibson, 1997). This leads to higher than optimal public borrowing and provides a rationale for constraining debt.

4.1 Natural disasters, fiscal rules and sovereign risk

Firms produce output y using a standard production function $y = zF(k, l)$ with capital k and labor l subject to aggregate productivity risk z. The latter follows a mean-zero AR(1) process $ln(z_t) = \rho ln(z_{t-1}) + \varepsilon_t$ to capture regular business cycle dynamics. We model a natural disaster as a temporary exogenous reduction in the physical capital stock. Disaster risk evolves exogenously according to a Markov process with two states for the capital stock $k_t \in (\bar{k}, k^\ell)$, where $\bar{k}$ and k^ℓ are the level of the capital stock without and with disaster, respectively. The transition matrix is

$$P = \begin{bmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{bmatrix} \equiv \begin{bmatrix} (1-\eta) & \eta \\ \varphi & (1-\varphi) \end{bmatrix},$$

where the disaster probability and the probability to exit from the disaster are η and φ, respectively. $\zeta = 1$ denotes an economy in a disaster state, then capital evolves as

$$k_t = \begin{cases} \bar{k} & \text{if } \zeta = 0 \\ k^\ell & \text{if } \zeta = 1 \end{cases} .$$

There is a continuum of infinitely lived households who own the firms. The households derive utility $u(.)$ from private consumption c_t, government spending g_t, and leisure $1 - l_t$. The representative household maximizes lifetime utility discounted with the factor $\delta < 1$ subject to a sequence of flow budget constraints

$$\begin{aligned} & E_0 \sum_{t=0}^{\infty} \delta^t u(c_t, g_t, 1 - l_t) \\ \text{s.t.} \quad & (1 + \tau_t)c_t = z_t F(k_t, l_t), \end{aligned} \tag{4}$$

where the household takes the tax rate on consumption τ_t, public expenditures, and the capital stock as given. The first order conditions can be combined to

$$\frac{u_l(c_t, g_t, 1 - l_t)}{u_c(c_t, g_t, 1 - l_t)} = \frac{z F_l(k_t, l_t)}{(1 + \tau_t)}. \tag{5}$$

(5) gives implicit labor supply as a function of the two exogenous states (z, ζ) and the tax rate τ.

The government maximizes expected lifetime utility of the representative household

$$U_t = u(c_t, g_t, 1 - l_t) + \beta E_t \sum_{j=0}^{\infty} \delta^j u(c_{t+j}, g_{t+j}, 1 - l_{t+j}), \tag{6}$$

where double discounting represents a present bias due to political distortions, leading to higher than optimal borrowing (Laibson, 1997). While the private sector discounts with $\delta < 1$, the government uses the additional factor $\beta < 1$ for the continuation value.

The markets for government securities b are incomplete and the government can only issue one-period discount bonds. Moreover, it cannot commit to repay the debt and may eventually default (Eaton and Gersovitz, 1981). We express the default decision in terms of a value function $\mathcal{W}_0$, where the government defaults when the value under default is strictly higher than under repayment

$$\mathcal{W}_0(b, z, \zeta) = \max \left\{ \mathcal{W}^p(b, z, \zeta), \mathcal{W}^d(z, \zeta) \right\}, \tag{7}$$

where superscript p denotes repayment and d default. The conditions for default imply a default set across exogenous productivity and disaster states

$$\mathcal{D}(b, z, \zeta) = \left\{ (z, \zeta) : \mathcal{W}^p(b, z, \zeta) < \mathcal{W}^d(z, \zeta) \right\}.$$

Taking the expected value across all possible states where the government defaults on its outstanding debt conditional on new debt issuance b' defines the probability to default in the consecutive period as

$$\lambda(b', z, \zeta) = \int_{\mathcal{D}(b,z,\zeta)} h(\zeta', \zeta) d\zeta' \int_{\mathcal{D}(b,z,\zeta)} f(z', z) dz',$$

which uses the conventional notation that period t variables have no time subscript, while variables at $t+1$ are denoted by a prime.

The government uses tax revenues and international borrowing to finance public expenditures g. It can issue new debt b' at a price $q(b', z, \zeta)$ in case of capital market access, while repaying debt from the previous period b:

$$g = \tau c + b - q(b', z, \zeta) b'. \tag{8}$$

The country is a net debtor if $b < 0$, such that the fiscal surplus is given by $\Gamma = q(b', z, \zeta)b' - b$. International borrowing allows the government to smooth its own spending and, via tax adjustments, household consumption.

Its problem in case of access to capital markets is

$$\mathcal{W}^p(b, z, \zeta) = \max_{\{\tau, b'\}} \left\{ u(c^*, g, 1 - l^*) + \beta\delta \int_\zeta \int_z V^p(b', z', \zeta') d\zeta dz \right\} \tag{9}$$

subject to the household and government budget constraint as well as the optimal labor supply:

$$
\begin{aligned}
g &= \tau c^* + b - q(b', z, \zeta) b' \\
zF(k, l^*) &= (1+\tau) c^* \\
\frac{zF_l(k, l^*)}{(1+\tau)} &= \frac{u_l(c^*, g, 1-l^*)}{u_c(c^*, g, 1-l^*)}.
\end{aligned}
$$

The asterisk denotes the optimal consumption and labor decision conditional on the policy (τ, b') given repayment.

In the default state, there is an asymmetric exogenous output cost that enters through lower aggregate productivity (Arellano, 2008). Aggregate productivity is given by the function $h(z)$

$$
h(z) = \begin{cases} \phi E(z) & \text{if } z > \phi E(z) \\ z & \text{if } z \leq \phi E(z) \end{cases},
$$

with $\phi \in (0, 1)$. The government value function under default is given by

$$
\mathcal{W}^d(z, \zeta) = \max_{\{\tau_d\}} \left\{ u(c_d^*, g_d, 1 - l_d^*) + \beta\delta \int_\zeta \int_z [\nu V_p(0, z', \zeta') + (1-\nu) V_d(z', \zeta')] \, d\zeta dz \right\}, \tag{10}
$$

where ν is the probability to re-access the capital market, subject to the optimal responses of the domestic private sector

$$
\begin{aligned}
g_d &= \tau_d c_d^* \\
h(z)F(k, l_d^*) &= (1+\tau_d) c_d^* \\
\frac{h(z)F_l(k, l_d^*)}{(1+\tau_d)} &= \frac{u_l(c_d^*, g_d, 1-l_d^*)}{u_c(c_d^*, g_d, 1-l_d^*)}
\end{aligned}
$$

Risk neutral investors price defaultable debt from a no-arbitrage condition reflecting the actual default risk and discounted at the risk free rate r^f

$$
q(b', z, \zeta) = \frac{1 - \lambda(b', z, \zeta)}{1 + r^f}. \tag{11}
$$

For the quantitative analysis, we focus on the two fiscal rules that drive our empirical results (Fig. 6). First, we model a debt rule as a floor on foreign assets $\bar{B}$

$$
b' \geq \bar{B}, \quad \text{with } \bar{B} < 0. \tag{12}
$$

Second, we model a deficit rule as a floor on the fiscal surplus $\bar{\Delta}$,

$$\Gamma \geq \bar{\Delta}, \quad \text{with } \bar{\Delta} < 0. \tag{13}$$

Given the importance of escape clauses (Fig. 7), we allow for deviations from the fiscal rule in the event of a natural disaster. Technically, if the economy is in the disaster state, $\zeta = 1$, the constraint (12) or (13) does not apply, while it is enforced immediately afterwards.[7]

Now, we have the following definition:

Definition *The recursive equilibrium for this economy is defined as*[8]

1. a set of policy functions for household's consumption $c(b, z, \zeta)$ and labor $l(b, z, \zeta)$,
2. a set of policy functions for government borrowing $b'(b, z, \zeta)$, taxes $\tau(b, z, \zeta)$ and spending $g(b, z, \zeta)$,
3. the default set $\mathcal{D}(b, z, \zeta)$, and
4. a set of value functions $\mathcal{W}_0(b, z, \zeta)$, $\mathcal{W}^p(b, z, \zeta)$ and $\mathcal{W}^d(b, z, \zeta)$

such that

1. taking as given the government policies, household's consumption $c(b, z, \zeta)$ and labor $l(b, z, \zeta)$ satisfy the optimality condition (5) and the budget constraint (4),
2. taking as given the bond price function $q(b', z, \zeta)$, the optimal policies of the household, the government policy functions $b'(b, z, \zeta)$, $\tau(b, z, \zeta)$ and $g(b, z, \zeta)$, and the default set $\mathcal{D}(b, z, \zeta)$ solve equations (7), (9) and (10), and
3. bond prices $q(b', z, \zeta)$ fulfill (11) with risk-neutral international investors earning zero expected profits.

4.2 Parameterization

The production function is Cobb-Douglas, $F(k, l) = k^\alpha l^{1-\alpha}$. The utility function is separable in consumption and labor

$$u(c, g, 1 - l) = \omega \left(\frac{g^{1-\gamma} - 1}{1 - \gamma} \right) + (1 - \omega) \left(\frac{\left(c - \frac{l^{1+\psi}}{1+\psi} \right)^{1-\gamma} - 1}{1 - \gamma} \right).$$

[7] We abstract from a number of interesting questions. First, we assume that the shock contains no private information, is perfectly contractable and does not require costly state verification. These assumptions are justifiable given the specific nature of natural disasters. Second, the fiscal rule is credible and enforceable, thus it does not suffer from the same commitment problem as the sovereign debt contract, for example, because it is in the constitution or imposed by a supranational institution. Halac and Yared (2014, 2019, 2020) study settings where these assumptions are relaxed.

[8] The Appendix provides more details on the implementation of the value functions taking into account the disaster state variable ζ.

Table 2: Calibration

Parameter		Value	Source/Target
Natural disaster risk	η	0.012	1.2% probability in data
Probability to exit from disaster	φ	0.1667	estimated investment response
Capital steady state	$\bar{k}$	1	standardization
Capital disaster state	k^ℓ	0.962	99th percentile shock in data
Risk aversion	γ	2	Aguiar and Gopinath (2006)
Discount factor	δ	0.97	Cuadra et al. (2010)
Present bias	β	0.90	Angeletos et al. (2001)
Labor elasticity	ψ	0.455	Mendoza (1991)
Capital share of output	α	0.3	Mendoza and Yue (2012)
Re-entry probability	ν	0.10	Gelos et al. (2011)
Default penalty	ϕ	0.99	Cuadra et al. (2010)
Weight government consumption	ω	0.30	Cuadra et al. (2010)
Risk-free interest rate	r^f	0.01	Arellano (2008)
Technology persistence	ρ	0.85	Cuadra et al. (2010)
Technology standard error	σ_z	0.006	Cuadra et al. (2010)

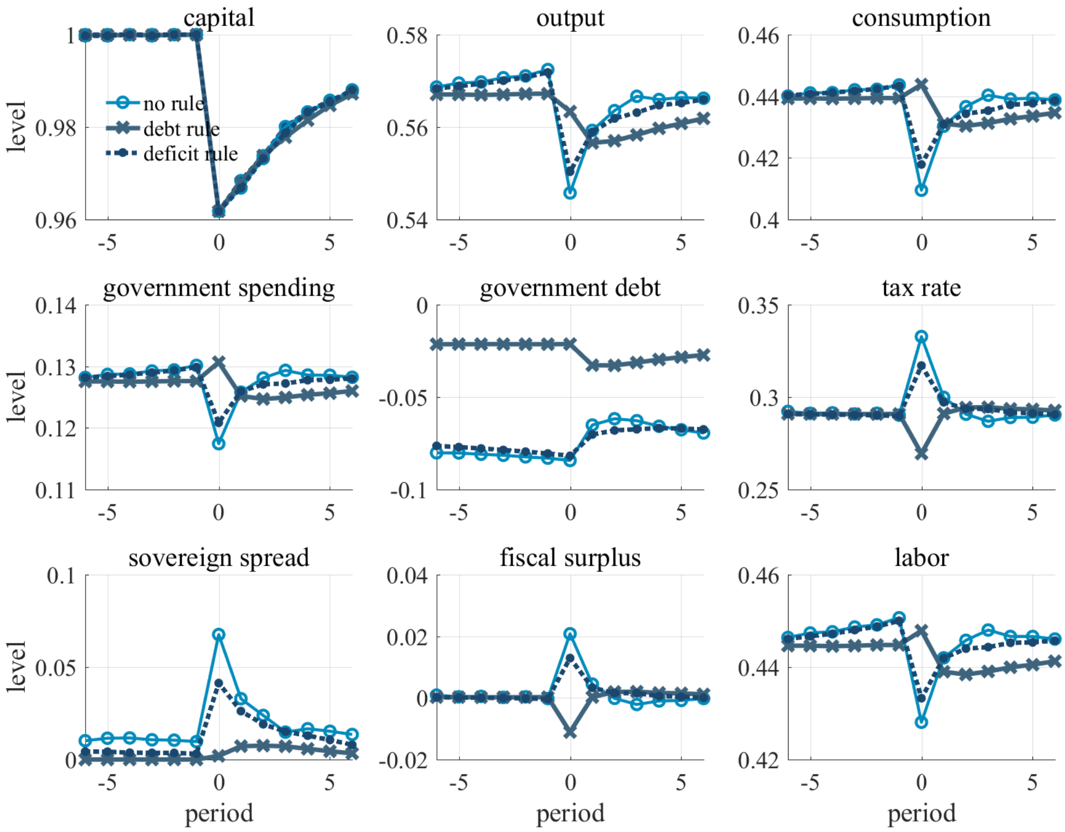
This specification of preferences leads to labor supply that is independent of current consumption (Greenwood et al., 1988). Table 4.2 contains the parameter values. Physical capital is 1 in the normal state and 0.962 in the disaster state. The disaster shock is calibrated to match the 99th percentile of the empirical disaster distribution, which is 7.6% of nominal GDP. We assume a capital-output ratio of 2 in the data, following Backus et al. (2008), which implies a reduction of capital by 3.8%. The exit probability $\varphi = 1/6$ replicates the response of investment in Fig. 3, which is statistically significant for roughly 6 quarters.

We set the risk aversion parameter γ equal to 2 (Aguiar and Gopinath, 2006). The capital share α is set to 0.3 to target a standard labor share in GDP of 0.7 (Mendoza and Yue, 2012). The probability to re-access capital markets ν is calibrated to 10% at a quarterly frequency (Gelos et al., 2011). The risk free interest rate r^f is 1% per quarter, in line with a 4% annual real interest rate. The parameter ψ governing the Frisch labor elasticity is set to 0.455, following Mendoza (1991). To induce a non-trivial amount of foreign borrowing in equilibrium, the literature uses fairly low discount factors. We set the household discount factor δ to 0.97 as in Cuadra et al. (2010), while the degree of present bias of the government is set to $\beta = 0.9$ (Angeletos et al., 2001). For the remaining parameters, we follow Cuadra et al. (2010) who calibrate a similar model as ours to Mexican data. The weight of government consumption in the utility function ω is 0.3, the persistence of technology is $\rho = 0.85$, the standard deviation of technology is $\sigma_z = 0.006$, and the exogenous output penalty is $\phi = 0.99$.

4.3 The theoretical impact of fiscal rules on dynamics

Fig. 8 summarizes the average responses of selected variables around disaster shocks.[9] We show output, private consumption, public consumption, the fiscal surplus, and sovereign spreads to see whether the model can replicate the estimated dynamics presented in Fig. 3 and Fig. 5. In the theoretical model, the fiscal surplus equals the negative trade balance. In the data, the trade balance is implicitly given by the estimated responses of exports and imports. We add several additional variables to Fig. 8 to understand the propagation of the shock and the policy response theoretically.

Figure 8: Theoretical responses to natural disasters



Note: Event windows from simulations of the benchmark model without fiscal rule (lines with circles), a model with a debt rule (lines with x), and a model with a deficit rule (dashed lines with dots). The responses of the variables in levels are computed as averages across simulation paths centered at the occurrence of a natural disaster.

The solid lines with circles refer to a model without fiscal rule as a benchmark.

[9]We use 3000 simulations with 200 periods each and discarding the first 50 periods as burn-in. Default events and periods of financial autarky are excluded. This leads to different average trajectories of technology across models. Thus, output and consumption are shown in productivity-adjusted terms, $\tilde{y}_t = y_t/z_t$, and $\tilde{c}_t = (y_t/z_t)/(1 + \tau_t)$.

There is an exogenous drop in the capital stock, which depresses output on impact. Given the persistence of the disaster state, a default in the consecutive periods becomes more likely, inducing a jump in the sovereign spread $s = 1/q(b', z, \zeta) - 1 - r^f$. The deterioration of external financing conditions reflects an endogenous tightening of fiscal space and government debt drops. In other words, fiscal space is procyclical and so is international borrowing. Hence, the spike in the sovereign spread does not reflect increased borrowing but higher default risk due to lower output.[10] To service outstanding debt in face of the contraction, the government hikes taxes, which lowers labor input further (see (5)). The increase in the fiscal surplus suggests that initially high government debt compromise international risk sharing in case of disasters.

Next, we consider the effects of fiscal rules. First, the dashed lines with dots in Fig. 8 show the average responses under a deficit rule with an escape clause. The rule (13) is parameterized to $\bar{\Delta} = -0.0015$. This value implies that the government runs the smallest possible non-zero deficit under the discretized state-space. The responses under a deficit rule are more muted. As the deficit rule constrains borrowing, government debt is lower on average before the shock.[11] Accordingly, the sovereign spread is lower and, when the shock hits, spikes less. This implies less procyclical tightening: the tax rate increases less, the drop in government consumption is attenuated, and government debt falls less, such that the increase in the fiscal surplus is smaller. Consequently, output and consumption are higher as in the no-rule case.

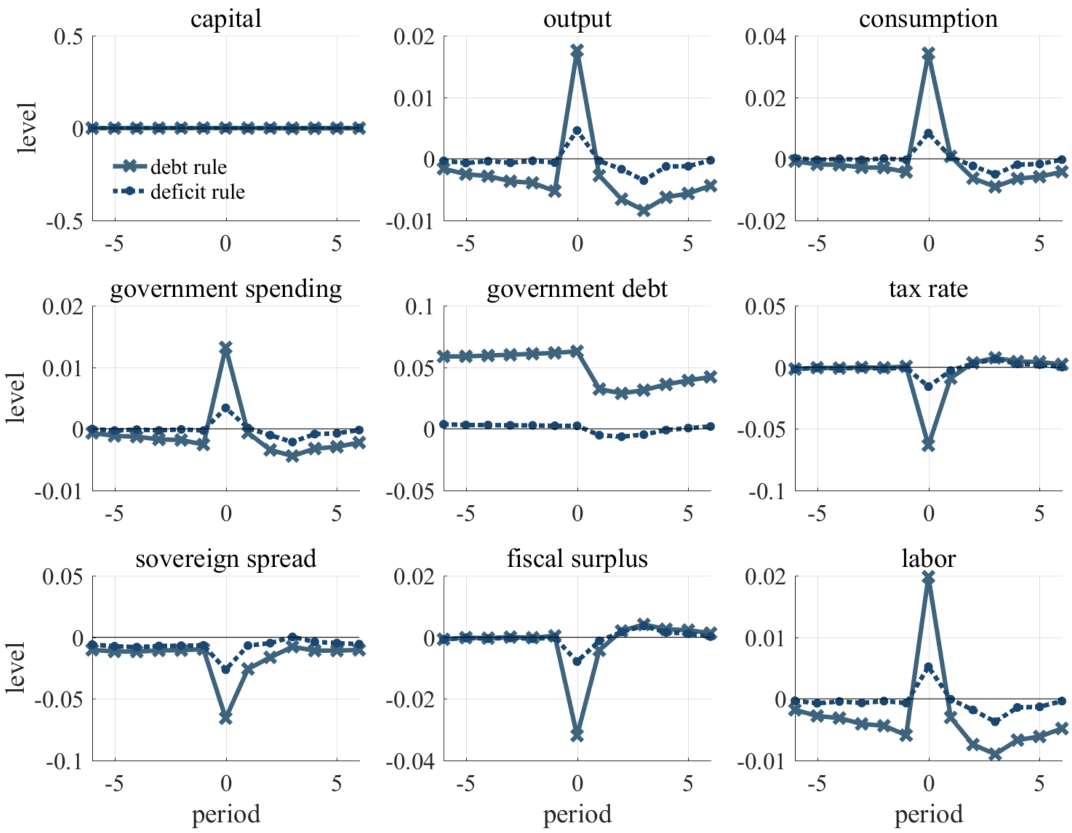
Second, the lines with x's show the dynamics under a debt rule with an escape clause. The debt limit is calibrated to $\bar{B} = -0.022$ (see 12). Since the debt rule is binding most of the time, the average level of debt and the sovereign spread are substantially lower before the shock. When the disaster strikes, the spread increases, as before, but much less. Now, fiscal policy is countercyclical. Government debt actually rises, whereas it falls in the benchmark model. The international funds are used to increase government spending and lower taxes. Hence, labor, output, and private consumption are all higher than in the no-rule case when the shock hits. In Fig. B.6 of the Appendix, we show that the countercyclicality of the fiscal surplus depends critically on the existence of the escape clause. Without such an exemption, government debt and spending cannot be increased to buffer the shock.

Fig. 9 shows the differences between the responses under a deficit rule, or a debt rule, and no rule to see whether the model matches the estimated differential dynamics documented in Fig. 4 and Fig. 5. The model predicts that output, private consumption, and public expenditures are all higher under a fiscal rule when the shock hits, thereby

[10]This is further illustrated by the bond price functions and borrowing decisions in the disaster state in the Appendix, Fig. B.4.

[11]Fig. B.5 in the Appendix shows the ergodic distributions of the models.

Figure 9: Differential simulated responses to natural disasters



Note: The figure shows the differential average responses of selected variables between the benchmark model without fiscal rule and either a model with a deficit rule (dashed lines) or a debt rule (solid lines). The responses of the variables in levels are computed as averages across simulation paths centered at the occurrence of a natural disaster.

replicating the evolution of these variables in the data. The model also matches the negative difference in the fiscal surplus and the sovereign spread. Moreover, it suggests that government debt is higher and the tax rate lower following the shock. After one or two quarters, these differences are typically reversed in sign as there are no endogenous persistence mechanisms, while such features are probably generating the persistence of the empirical responses. All in all, we conclude that fiscal space and escape clauses are mechanisms that can rationalize our empirical results.

5 Conclusions

We provide a novel stylized fact. Fiscal rules improve macroeconomic performance following large adverse economic shocks. We use natural disasters to measure such shocks and to overcome the endogeneity between rule adoption and economic conditions. Catastrophes are exogenous with respect to fiscal rules and the state of the macroeconomy. Estimating a set of dynamic panel models, we document that output, private consumption, and private investment are significantly higher under fiscal rules in the four years following the shocks than without rules. The results are robust to a large number of sensitivity tests.

We highlight potential mechanisms underlying the stylized fact. First, we document that in the aftermath of the shocks fiscal policy is more expansionary with than without rules. Then, we show that this depends on the presence of fiscal space and escape clauses. Finally, we build a model of sovereign default, fiscal rules with escape clauses, and natural disasters that replicates the empirical patterns and rationalizes them. The model implies that long-run government debt is lower under a fiscal rule. Accordingly, when hit by a disaster, market access is better such that fiscal policy is more countercyclical and output as well as private consumption are higher.

All in all, the results suggest that well-designed fiscal rules alleviate the fundamental tradeoff between constraining fiscal policy to rein in public debt and deficits and the need for countercyclical fiscal policy. They also bear some implications for the future of fiscal rules after the Covid-19 pandemic. Although the considerable increase in public debt issued to mitigate the consequences of this crisis is in line with an optimal fiscal response under a flexible fiscal rule, as long as there is fiscal space, our analysis suggests that re-enforcing the rule as the economies recover may be equally important to buffer future shocks.

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Online Appendix

Committed to Flexible Fiscal Rules

by C. Grosse-Steffen[1], L. Pagenhardt[2] and M. Rieth[3]

This online appendix is organized in two parts. Appendix A provides additional sensitivity analysis and tables that describe the data used in the empirical part. Appendix B complements Section 4 on the quantitative-theoretic model with notes regarding the solution algorithm and additional output.

A Appendix. Sensitivity analysis and data

A.1 Sensitivity analysis

In this section, we summarize the results of an extensive sensitivity analysis. We focus on the main finding that fiscal rules lead to higher output and government spending when countries are hit by disaster shocks. First, we carefully control for other shock absorbers. As outlined in Section 2.2, a crucial ingredient for attaching a causal interpretation to the impact of fiscal rules is the correction for alternative country characteristics, such as the level of development and the quality of institutions, that potentially affect the responses. But if countries with fiscal rules systematically adopt other policy frameworks, the previous results could still be affected by omitted nonlinearities.

To see whether this is the case, we first control for the monetary regime. Combes et al. (2018) show that fiscal rules are often combined with inflation targeting frameworks and that there are synergies between the two regimes. An inflation targeting central bank that credibly stabilizes inflation could prevent fiscal profligacy, similar to the impact of fiscal rules. We construct a dummy variable following the IMF classification in Roger (2009) for the quarter-country pairs with an effectively implemented inflation targeting regime. Second, we control for the excahnge rate regime. Ramcharan (2007) shows that flexible exchange rates are conducive to weathering natural disasters. We use a dummy variable which is equal to one in case of a flexible exchange rate, and zero otherwise. Third, we control for the total

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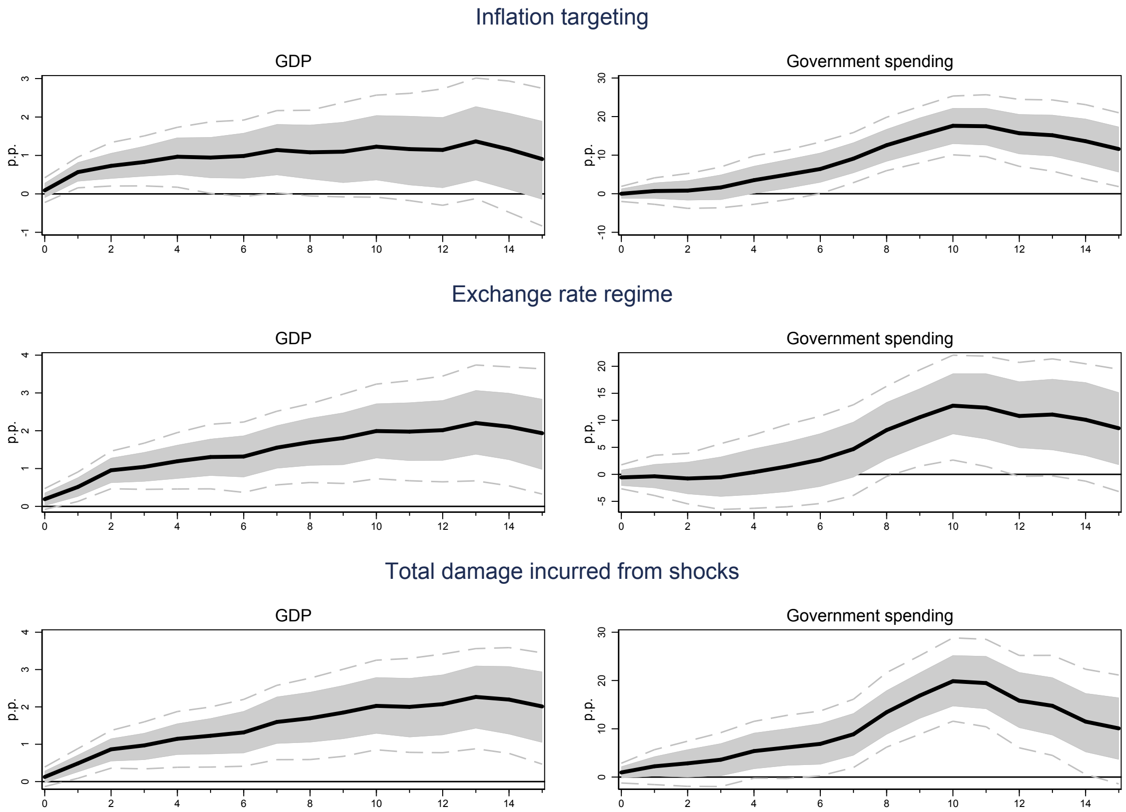
damage caused by natural disasters within sample to capture countries' susceptibility to the shocks, which potentially affects both the choice of the fiscal regime and the adjustment to the shock. Each control variable, one at a time, replaces government effectiveness in (1). Fig. A.1 shows that the main result holds. In all cases, output and government spending is significantly higher with than without fiscal rules following the shock.

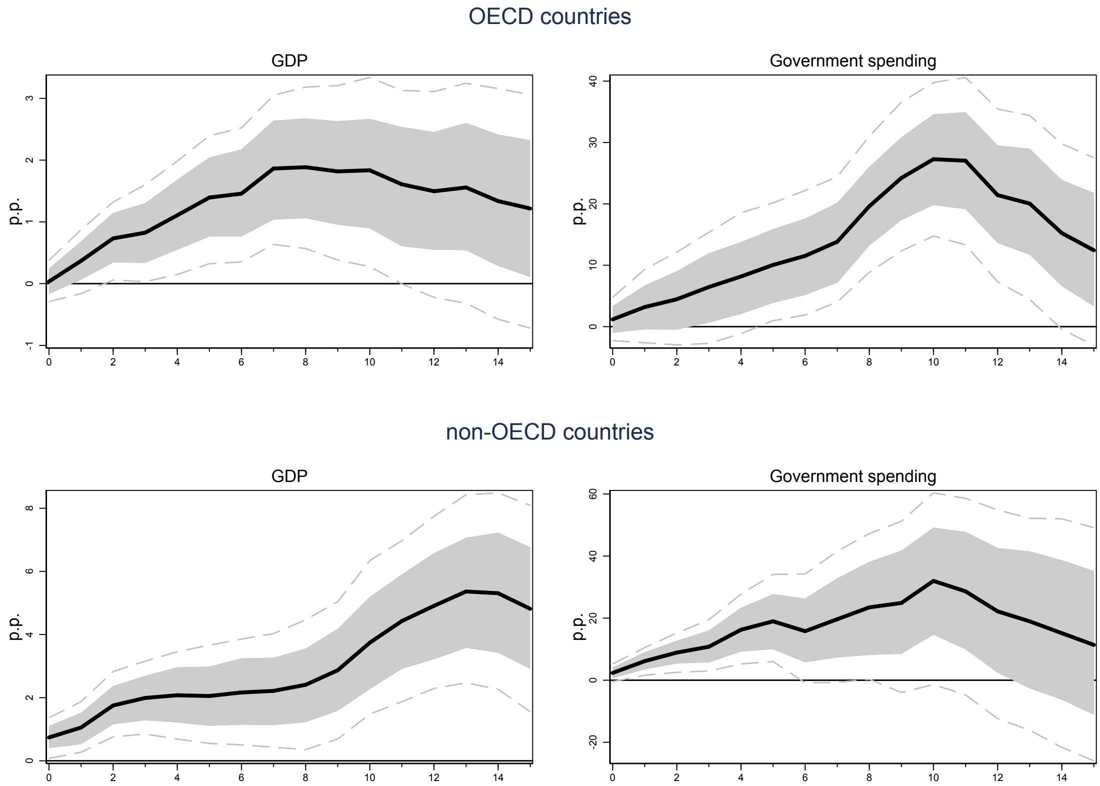
Figure A.1: Controlling for alternative shock absorbers.



Notes: The figure shows the differential response of output and government spending between countries with and without fiscal rules to large natural disasters. In each specification, the respective control variable replaces government effectiveness as the alternative shock absorber. The estimation is based on a quarterly sample over the period 1970Q1-2018Q4. Confidence bands refer to the 68% and 90% level and are based on 500 Monte-Carlo draws.

Next, we return to the baseline model but split the sample into OECD and non-OECD countries to find out whether one of the groups is driving the results. The motivation for the sample split is that, on the one hand, richer economies might be more likely to adopt fiscal rules, given their more developed democratic and financial institutions, and at the same time are better prepared to weather large disasters. On the other hand, it is conceivable that fiscal rules have a weaker impact on economic performance in developed economies as these have more efficient political and fiscal institutions and better debt market access in the first place, so that the the introduction of fiscal rules might yield smaller gains. Fig. A.2 contains the differential responses of GDP and government spending under fiscal rules for OECD (upper panel) and non-OECD members (lower panel). In both samples, the impact of fiscal rules is qualitatively and quantitatively similar to the baseline results. The effects tend to be larger in the non-OECD group, consistent with the notion that the marginal gains of fiscal rules are larger in developing countries. All in all, we conclude that fiscal rules enhance macroeconomic performance following disaster shocks in both developed and developing economies.

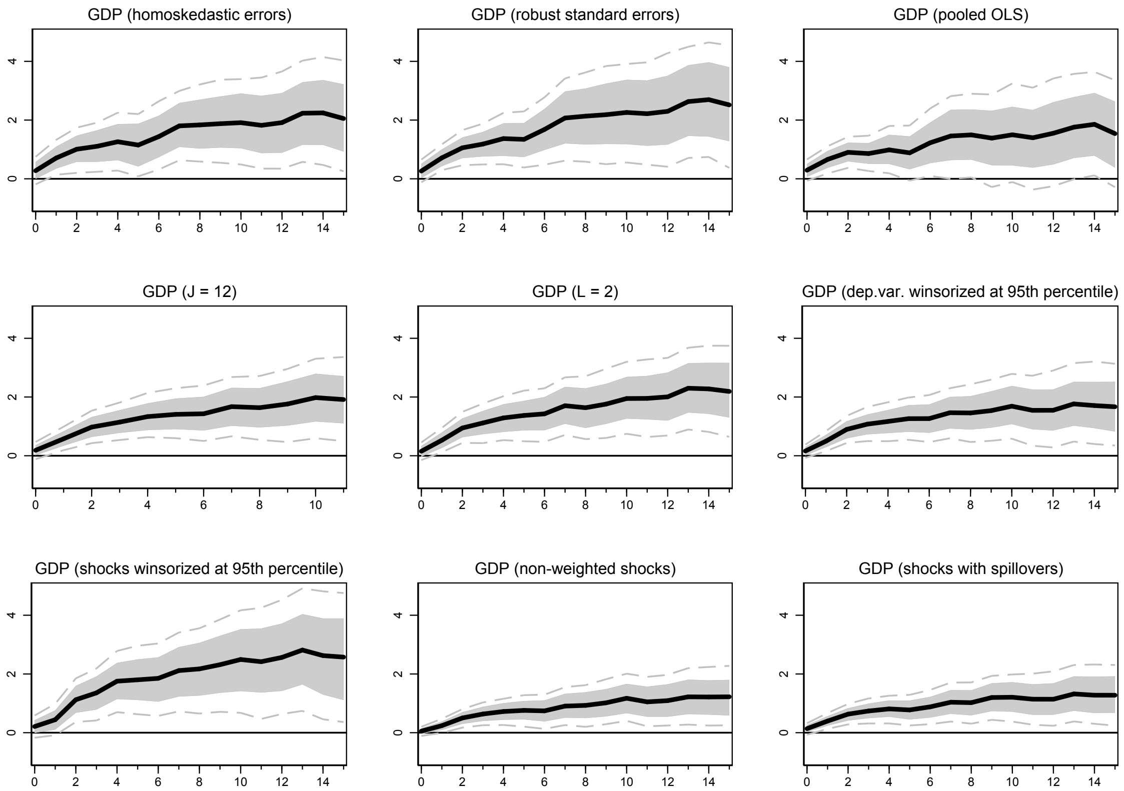
Figure A.2: Impact of fiscal rules in OECD and non-OECD countries.



Notes: The figure shows the cumulative differential response of quarterly GDP and government spending between countries with and without fiscal rules following large natural disasters, based on model (1) over the period 1970Q1-2018Q4. The upper panel contains results for the subsample of OECD countries and the lower panel for the complementary set of non-OECD countries. Confidence bands refer to the 68% and 90% level and are based on 500 Monte-Carlo draws.

Finally, we conduct several more technical robustness tests. First, we assume homoskedastic errors, or compute robust standard errors, instead of using feasible generalized least squares with panel heteroskedasticity. Then, we employ only 11 lags of the shocks instead of 15 for both the shock and interaction terms. We also reduce the number of lags of the endogenous variable from 4 in the baseline specification to 2. Furthermore, we either winsorize the shocks or output changes at the 95th percentile to remove disaster and growth outliers. In addition, we use unweighted shocks (not accounting for the onset months) or account for spillovers from previous quarters. Fig. A.3 shows that the impact of fiscal rules on the response of GDP is robust to all these alterations.

Figure A.3: Technical sensitivity tests.



Notes: The figure shows the cumulative differential response of quarterly GDP between countries with and without fiscal rules following large natural disasters, based on model (1) over the period 1970Q1-2018Q4, when using a fixed effects model with homoskedastic errors or with robust standard errors, respectively, when employing 11 lags of the shocks or 2 lags of the endogenous variable, when winsorizing the shocks or the output response at the 95th percentile, or when using alternative weighting schemes for the disaster shocks. All estimations are displayed in percentage points. Confidence bands refer to the 68% and 90% level and are based on 500 Monte-Carlo draws.

A.2 Data tables

Table A.1: List of countries.

Albania	Estonia	Kenya	Portugal
Algeria	Finland	Korea Rep	Romania
Argentina	France	Kyrgyzstan	Russia
Australia	Georgia	Latvia	Serbia
Austria	Germany	Lithuania	Singapore
Belarus	Ghana	Luxembourg	Slovakia
Belgium	Greece	Malaysia	Slovenia
Bolivia	Guatemala	Maldives	South Africa
Botswana	Honduras	Malta	Spain
Brazil	Hong Kong	Mauritius	Sri Lanka
Bulgaria	Hungary	Mexico	Sweden
Canada	Iceland	Morocco	Switzerland
Chile	India	Namibia	Thailand
China	Indonesia	Netherlands	Trinidad and Tobago
Colombia	Iran	New Zealand	Tunisia
Costa Rica	Ireland	Nigeria	Turkey
Croatia	Israel	Norway	Ukraine
Cyprus	Italy	Pakistan	United Kingdom
Czech Republic	Jamaica	Paraguay	United States
Denmark	Japan	Peru	Uruguay
Ecuador	Jordan	Philippines	Venezuela
Egypt	Kazakhstan	Poland	Vietnam
El Salvador			

Note: The table lists the countries whose data are used in the empirical analysis.

Table A.2: Variable description and sources.

Variable	Definition	Source
Shock	Damage from natural disasters incurred within one quarter, in % of GDP; upper 50th percentile of reported damage; winsorized at the 99th percentile	EM-DAT, IMF-IFS, OECD, national sources
Fiscal Rules	Dummy indicating any type of fiscal rule in place on national or supra-national level	IMF Fiscal Rules Database, Schaechter et al. (2012)
$GDPpc^{1990q1}$	GDP per capita in 1990Q1, nominal, in USD	World Bank
Government effectiveness	Institutional quality indicator, defined over the interval [-2.5,2.5], with higher calues indicating higher effectiveness, available from 1996-2016, extrapolated	World Bank, The Worldwide Governance Indicators
GDP	Real per capita GDP growth, seasonally adjusted	OECD, national sources, WDI
Private consumption	Real private consumption growth, seasonally adjusted	OECD, national sources
Private investment	Gross capital formation, seasonally adjusted	OECD, national sources
Imports	Real import growth, seasonally adjusted	OECD, national sources
Exports	Real export growth, seasonally adjusted	OECD, national sources
Government spending	Total government expenditure growth, CPI deflated & seasonally adjusted	Datastream
Government consumption	Real government consumption growth, seasonally adjusted	Datastream
Government investment	Government gross fixed capital formation, seasonally adjusted	Ilzetzki et al. (2013)
Social benefits paid	Current transfers by the government to households, CPI deflated & seasonally adjusted, QoQ growth	IMF-GFS
Government subsidies	Transfers of government units to public and private firms and other public sectors for goods and services, CPI deflated & seasonally adjusted, QoQ growth	IMF-GFS
Government other expenses	Comprises property expense other than interest, transfers not elsewhere classified and amounts payable in respect of e.g. fees related to nonlife insurance, CPI deflated & seasonally adjusted, QoQ growth	IMF-GFS
Government revenue	Real total government income from taxes, social contributions, grants and other sources, seasonally adjusted, QoQ growth	Datastream
Surplus-to-GDP ratio	Real government budget balance (revenue minus expenditure) divided by real GDP, netted of automatic stabilizers following the approach suggested by Romer and Romer (2018), QoQ growth	Datastream, OECD
10-year government bond yield	QoQ change in the yield on 10-year government bond, in percentage points	IMF-IFS
CDS5y	QoQ change in 5-year credit default swaps, in percentage points	Datastream
Democracy	Democracy index on the interval [-1,1], with 1 indicating a high level of democratic institutions	Center for Systemic Peace
Urbanization	Urban population in percent of total population, annual frequency, interpolated	World Bank/WDI
Density	Population (thousand) per land area (square kilometers), annual frequency, interpolated	World Bank/WDI
FX index	Official exchange rate, national currency to USD, index: 2000 = 100	Datastream

Note: The table lists the variables, definitions and data sources used in the empirical analysis.

B Appendix. Quantitative-theoretic model

B.1 Note on implementation of disaster risk

Technically, we exploit the fact that the disaster variable features only two distinct states in order to rewrite the value under repayment conditional on the disaster state as

$$\underbrace{V^p(b,z,\zeta=0)}_{\equiv V^{p^+}(b,z)} = \max_{\{\tau_{p^+},b'_{p^+}\}} \left\{ u(c^*,g,1-l^*) + \beta\left[(1-\eta)\int_z V^p(b',z',\zeta'=0)dz + \eta\int_z V^p(b',z',\zeta'=1)dz\right]\right\}$$

$$\underbrace{V^p(b,z,\zeta=1)}_{\equiv V^{p^-}(b,z)} = \max_{\{\tau_{p^-},b'_{p^-}\}} \left\{ u(c^*,g,1-l^*) + \beta\left[\varphi\int_z V^p(b',z',\zeta'=0)dz + (1-\varphi)\int_z V^p(b',z',\zeta'=1)dz\right]\right\}$$

This makes clear that the policy functions differ in the two disaster states, which is captured in the notation with a minus sign in case of a disaster ($\zeta = 1$) and with a plus sign in the absence of a disaster ($\zeta = 0$). We also rewrite the value function under default conditional on the disaster state as

$$\begin{aligned}
\underbrace{V^d(z,\zeta=0)}_{\equiv V^{d^+}(z)} = \max_{\{\tau_{d^+}\}} \Bigg\{ & u(c^*_{d^+}, g_{d^+}, 1-l^*_{d^+}) \\
& + \beta\Bigg[\eta\left(\nu\int_z V_p(0,z',\zeta'=1)dz + (1-\nu)\int_z V_d(z',\zeta'=1)dz\right) \\
& + (1-\eta)\left(\nu\int_z V_p(0,z',\zeta'=0)dz + (1-\nu)\int_z V_d(z',\zeta'=0)dz\right)\Bigg]\Bigg\} \\
\underbrace{V^d(z,\zeta=1)}_{\equiv V^{d^-}(z)} = \max_{\{\tau_{d^-}\}} \Bigg\{ & u(c^*_{d^-}, g_{d^-}, 1-l^*_{d^-}) \\
& + \beta\Bigg[(1-\varphi)\left(\nu\int_z V_p(0,z',\zeta'=1)dz + (1-\nu)\int_z V_d(z',\zeta'=1)dz\right) \\
& + \varphi\left(\nu\int_z V_p(0,z',\zeta'=0)dz + (1-\nu)\int_z V_d(z',\zeta'=0)dz\right)\Bigg]\Bigg\}
\end{aligned}$$

The government's present bias is taken into account through additional discounting in the repayment and the default states

$$\underbrace{\mathcal{W}^p(b,z,\zeta=0)}_{\equiv \mathcal{W}^{p^+}(b,z)} = \max_{\{\tau_{p^+},b'_{p^+}\}} \left\{ u(c^*,g,1-l^*) + \beta\delta\left[(1-\eta)\int_z V^p(b',z',\zeta'=0)dz + \eta\int_z V^p(b',z',\zeta'=1)dz\right]\right\}$$

$$\underbrace{\mathcal{W}^p(b,z,\zeta=1)}_{\equiv \mathcal{W}^{p^-}(b,z)} = \max_{\{\tau_{p^-},b'_{p^-}\}} \left\{ u(c^*,g,1-l^*) + \beta\delta\left[\varphi\int_z V^p(b',z',\zeta'=0)dz + (1-\varphi)\int_z V^p(b',z',\zeta'=1)dz\right]\right\}$$

$$
\begin{aligned}
\underbrace{\mathcal{W}^d(z,\zeta=0)}_{\equiv \mathcal{W}^{d^+}(z)} = \max_{\{\tau_{d^+}\}} \Bigg\{ & u(c^*_{d^+}, g_{d^+}, 1-l^*_{d^+}) \\
& + \beta\delta \Bigg[\eta \left(\nu \int_z V_p(0,z',\zeta'=1)dz + (1-\nu) \int_z V_d(z',\zeta'=1)dz \right) \\
& + (1-\eta) \left(\nu \int_z V_p(0,z',\zeta'=0)dz + (1-\nu) \int_z V_d(z',\zeta'=0)dz \right) \Bigg] \Bigg\} \\
\underbrace{\mathcal{W}^d(z,\zeta=1)}_{\equiv \mathcal{W}^{d^-}(z)} = \max_{\{\tau_{d^-}\}} \Bigg\{ & u(c^*_{d^-}, g_{d^-}, 1-l^*_{d^-}) \\
& + \beta\delta \Bigg[(1-\varphi) \left(\nu \int_z V_p(0,z',\zeta'=1)dz + (1-\nu) \int_z V_d(z',\zeta'=1)dz \right) \\
& + \varphi \left(\nu \int_z V_p(0,z',\zeta'=0)dz + (1-\nu) \int_z V_d(z',\zeta'=0)dz \right) \Bigg] \Bigg\}
\end{aligned}
$$

This leads to the default set

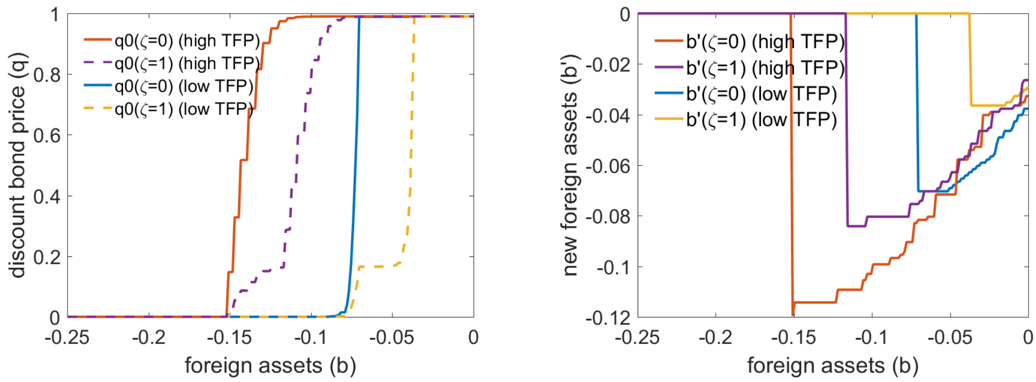
$$
D(b,z,\zeta) = \begin{cases} z \in \mathcal{Z} : \mathcal{W}^{p^+}(b,z) < \mathcal{W}^{d^+}(z) & \text{if} \quad \zeta = 0 \\ z \in \mathcal{Z} : \mathcal{W}^{p^-}(b,z) < \mathcal{W}^{d^-}(z) & \text{if} \quad \zeta = 1 \end{cases}
$$

with the respective set of default probabilities

$$
\begin{aligned}
\lambda^+(b',z \mid \zeta=0) &= \eta \int_{D^-(b)} f(z',z)dz' + (1-\eta) \int_{D^+(b)} f(z',z)dz' \\
\lambda^-(b',z \mid \zeta=1) &= (1-\varphi) \int_{D^-(b)} f(z',z)dz' + \varphi \int_{D^+(b)} f(z',z)dz'
\end{aligned}
$$

B.2 Additional model results

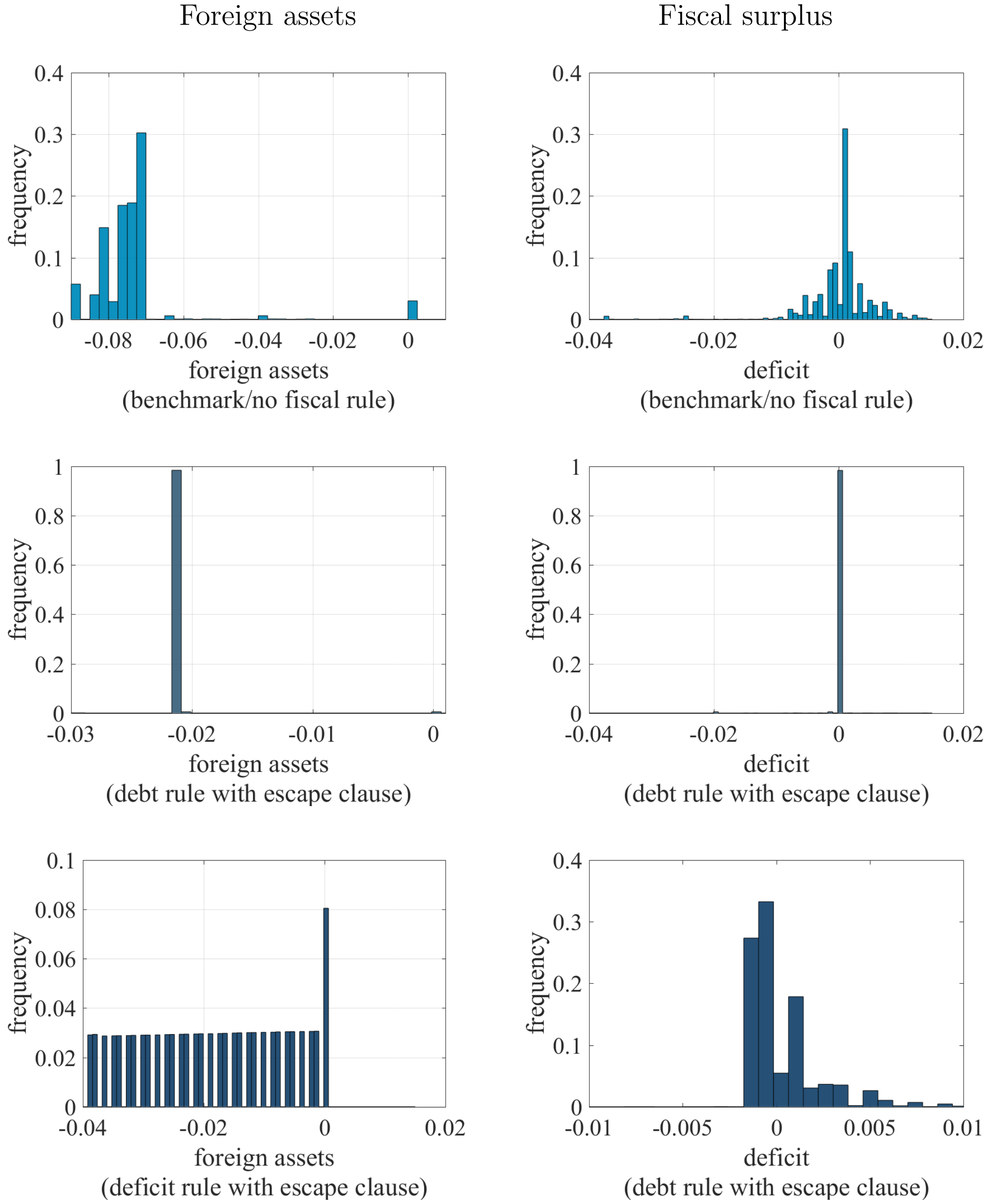
Figure B.4: Policy functions, model with natural disasters



(a) Bond price function (b) Borrowing decision

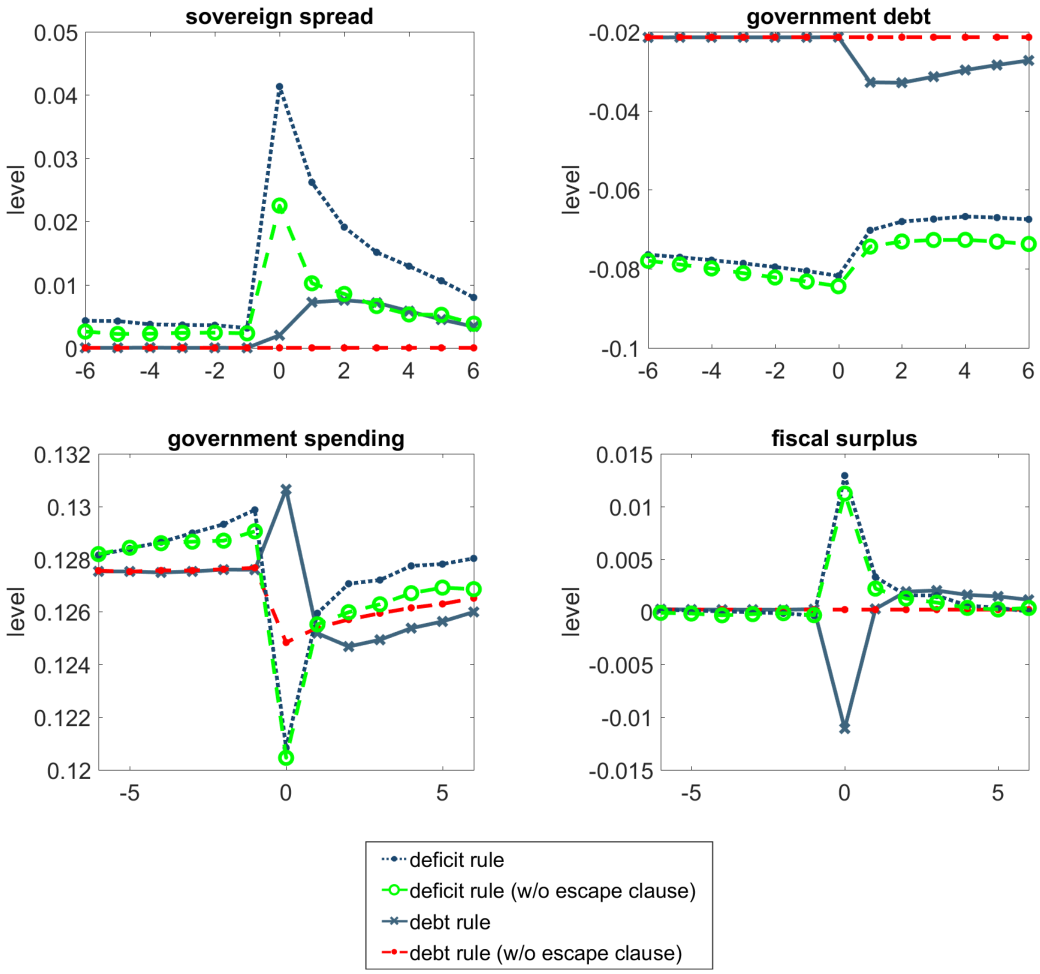
Note: Policy functions in the benchmark model with natural disaster risk. A natural disaster state has a similar effect as a bad productivity state on the bond price schedule. Given the high probability to exit from the disaster state and return to steady state levels of capital, the slope is much flatter in the disaster state ($\zeta = 1$).

Figure B.5: Ergodic distribution, benchmark vs. fiscal rules



Note: Ergodic distributions of model variables from the simulated paths. Shown are the histograms of the benchmark model (no fiscal rule) in comparison with models that have a fiscal rule in place. The distributions are formed from 1000 simulations with 200 periods each, discarting the first 50 periods as burnin.

Figure B.6: Role of escape clause for disaster response



Note: Event windows from model simulations comparing fiscal rules with and without escape clauses. Shown are the model averages (in levels) across simulation paths centered at the occurrence of a natural disaster shock. The event windows are computed from 3000 simulations with 200 periods each, discarding the first 50 periods as burn-in. Default events and periods of financial autarky are excluded. This leads to different average trajectories of TFP across models.