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Conference Paper

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Beiträge zur Jahrestagung des Vereins für Socialpolitik 2021: Climate Economics

Provided in Cooperation with:

Verein für Socialpolitik / German Economic Association

Suggested Citation: Pagenhardt, Laura; Große Steffen, Christoph; Rieth, Malte (2021) : Committed to Flexible Fiscal Rules, Beiträge zur Jahrestagung des Vereins für Socialpolitik 2021: Climate Economics, ZBW - Leibniz Information Centre for Economics, Kiel, Hamburg

This Version is available at:

<https://hdl.handle.net/10419/242330>

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Committed to Flexible Fiscal Rules*

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February 26, 2021

Abstract

We study the impact of fiscal rules on macroeconomic performance following natural disaster shocks, using dynamic panel models and quarterly data for 89 countries. We find that countries with fiscal rules perform significantly better in the aftermath of such shocks than countries without rules. GDP, private consumption and investment are persistently higher. The superior performance is associated with more expansionary fiscal policy, which hinges critically on larger fiscal space and escape clauses. We rationalize the findings in a quantitative model of sovereign default. The model replicates the empirical dynamics and shows that tight fiscal rules create fiscal space in good times that can be used in bad times for deficit-spending.

Keywords: Fiscal policy; fiscal regimes; natural disasters.

JEL Classifications: E62, C32, E32, H50

**Acknowledgement:* We would like to thank Stéphane Guibaud and Alexander Kriwoluzky for useful discussions and suggestions.

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1 Introduction

The Covid-19 pandemic causes a deep global recession while in many countries monetary policy is constrained by the zero lower bound on policy rates. Hence, fiscal policy has to bear the brunt of supporting the economy and many, but not all governments around the world engaged in large-scale fiscal stimulus packages. In the European Union, public deficits widened massively, which led to a temporary suspension of the deficit criterion of the Stability and Growth Pact through the activation of a respective escape clause. The government of Indonesia has paused the 3% budget deficit cap for 2020 to 2022. In Brazil, exceptional central government transfers were made to sub-national governments. This raises the question whether fiscal rules are useless. Moreover, why do some countries implement large fiscal stimulus measures, while others do not, when all are faced with such a large adverse shock?

Fiscal rules are an increasingly important framework for fiscal policy around the globe and largely supported by international organizations and supranational institutions. In 2020, they are in place in 91 countries. They are defined as persistent constraints on fiscal policy in the form of numerical targets for budgetary aggregates, such as debt, deficits, expenditures or revenues. Their main aim is to restrict the secular increase in government debt, which normative macroeconomic theory is typically unable to explain and which is viewed as reflecting political economy factors, such as rising electoral uncertainty, political polarization, or an aging population. There is a growing consensus in the empirical literature that they 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 national policy makers, is that the commitment to stabilize debt involves a fundamental trade-off with the flexibility to respond to economic shocks.¹ This potentially undesirable effect of fiscal rules has received much less attention in the empirical literature. But faced with the largest adverse economic shock in modern peacetime history, the Covid-19 pandemic, it is arguably at least important.

In this paper, we address the trade-off argument and provide a new stylized fact. We document empirically that countries with fiscal rules perform significantly *better*, not worse, than countries under alternative fiscal regimes when hit by large adverse economic shocks. We use natural disasters as a measure of such shocks. They have a large impact on the macro-economy through the destruction of physical capital and durable consumption goods (Noy, 2009; Felbermayr and Gröschl, 2014). Moreover,

¹See, among others, Amador et al. (2006); Azzimonti et al. (2016); Battaglini and Coate (2008); Halac and Yared (2014, 2018).

windstorms and floods are increasingly important drivers of macroeconomic fluctuations as the global climate changes. At the same time, catastrophes are arguably exogenous to the decision whether to adopt a fiscal rule. This overcomes an endogeneity problem between the choice of adopting fiscal rules and macroeconomic shocks. Societies may introduce particular rules given their expectation about future shocks hitting the economy, or the identification of latent macroeconomic shocks can depend on the policy regime in place. Sovereign debt or financial crises, for example, are probably less likely under fiscal rules. Instead, natural disasters are largely unpredictable and not caused by economic conditions. Using such a measure of exogenous shocks allows identify the conditional effects of fiscal rules using relatively weak and verifiable assumptions about the distribution of the unobserved factors determining economic outcomes and about the systematic relation between catastrophes and fiscal regimes.

To measure the economic impact of natural disasters, we use the estimated damage to property, crops and livestock reported in the EM-DAT data set, which covers natural disasters globally. We match them with quarterly macroeconomic data for 89 countries over the period 1970Q1-2018Q4, and then estimate a set of dynamic panel models to trace out the macroeconomic responses. We find that, on average, disaster shocks are contractionary on impact, followed by booms in consumption and investment activity. The empirical patterns resemble adverse supply shocks in a New Keynesian model due to the destruction of physical capital and a decline in productivity. However, these average responses hide important differences. In countries with fiscal rules GDP, private consumption, and private investment are significantly higher than in countries without such rules following a shock. The superior performance is associated with different responses of fiscal policy. In response to the shock, countries with rules increase public expenditures—in particular transfers and other expenses, but also government consumption, investment and social benefits—significantly more. We show that two ingredients are key for the different policy responses: escape clauses and fiscal space. All in all, the results indicate that fiscal rules create *more*, not less, room for fiscal policy to actively buffer shocks.

We build a structural model with sovereign default to clearly trace out the response to a disaster shock in an economy with and without fiscal rules in place. We also compare alternative rules and their effectiveness. While natural disasters have served as an identification approach in the empirical section, we also consider it a useful approach for the quantitative-theoretic model. Natural disasters are easily observable and, thus, a prototype shock for which institutions can define a contractable exception from a fiscal rule that triggers an escape clause. This is not the case for regular productivity shocks also present in the model, which might be in part only be privately

observable (Halac and Yared, 2014). A natural disaster is modeled as a temporary exogenous reduction in the physical capital stock. This lowers output obtained 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 outstanding debt (Eaton and Gersovitz, 1981). As a result, the government decides optimally about spending, taxes, and foreign borrowing in response to natural disasters. The government is myopic, leading to higher than optimal borrowing (Laibson, 1997). To off-set the myopic behaviour, we consider different fiscal rules, specifically a debt rule and a deficit rule. If rules are tight enough and feature an escape clause, a combination of deficit-financed tax cuts and deficit-spending characterize the fiscal response to a disaster shock. These findings are in line with our empirical results and also with findings in the literature showing that deficit-financed tax cuts improve GDP (Mountford and Uhlig, 2009; Romer and Romer, 2010).

The paper relates to an empirical literature on fiscal rules, which can broadly be divided in two strands. In both strands, the identification of the impact of fiscal institutions on fiscal policy is the main challenge. The majority of papers investigates the benefits of fiscal rules, that is, their effectiveness at countering the present-bias in public budget policy (Wyplosz, 2012; Yared, 2019). In general, the evidence is supportive of the idea that rules are associated with lower deficits and debt, but earlier studies are plagued by the endogeneity between fiscal institutions and fiscal outcomes (Alesina et al., 1999; Alesina and Passalacqua, 2016; Heinemann et al., 2018). Both are likely to be shaped by similar factors, such as voter preferences for fiscal prudence. Moreover, economic conditions might themselves impact the decision whether to introduce a rule. More recent articles use instrumental variables or difference-in-difference type of strategies to address the problem that countries self-select into rule's adoption and largely document a positive causal effect of rules on fiscal discipline (Grembi et al., 2016; Asatryan et al., 2018; Combes et al., 2018).

A smaller set of articles analyzes the potential costs of fiscal rules, that is, whether they are associated with more procyclical fiscal policy. The standard approach is to estimate fiscal reaction functions and test whether they are different with fiscal rules. While some papers find that rules-based restrictions induce more procyclicality (Lane, 2003; Fatás and Mihov, 2006), others document that they are associated with a more countercyclical stance of fiscal policy (Galí and Perotti, 2003; Debrun et al., 2008). However, this relation, just as the one between fiscal rules and fiscal soundness, is subject to both reverse causality and omitted variables as well. The initial degree of fiscal cyclicity, just as the debt or expenditure level, can affect the choice of rules. Moreover, societies' preferences may determine simultaneously rule adoption, deficits,

and fiscal reaction functions. These problems may also explain the mixed empirical evidence.

To address the endogeneity problem, we follow the approach suggested by [Poterba \(1994\)](#), and more recently adopted by [Clemens and Miran \(2012\)](#). Both papers estimate the fiscal reaction to exogenous events, that is, shocks. Specifically, they use unexpected fiscal deficits and an annual sample from U.S. states. In contrast, we employ natural disasters and a quarterly sample from 68 countries. We share with these papers that conditioning on a specific type of shock comes at the cost of some loss of generality. The benefit of the approach is that it allows for causal inference. It reduces the risk of reverse causality by focusing on exogenous events. Furthermore, it attenuates the problem of omitted variables by netting out the linear (and potentially endogenous) relation between fiscal rules and macroeconomic performance. In the terminology of the treatment literature, we assume that the treatment in form of a catastrophe is random conditional on country characteristics. However, we are not interested in the treatment effect itself, but in whether fiscal rules change the responses to the treatment.

Fiscal rules have been analyzed before 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 et al. \(2015\)](#) 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 welfare implications of alternative fiscal rules in an endowment economy, finding sizeable welfare gains in the presence of government myopia. Our contribution to this literature is threefold. First, we model escape clauses, which are an important feature of existing fiscal rules. Escape clauses are making a large difference in the conditional dynamic response to large shocks. Second, we introduce natural disaster shocks into the analysis of sovereign debt sustainability. Third, we focus on the economic response conditional on disaster shocks and how they are affected by alternative fiscal rules.

2 Data and empirical strategy

2.1 Data on natural disasters and fiscal rules

We draw from a large number of data sources to create a comprehensive dataset that allows investigate the role of fiscal rules in macroeconomic stabilization. [Table A.2](#) in the appendix provides a detailed list of all variable definitions and the data sources.

2.1.1 Natural disasters

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

The database provides information on the human and economic impact, the start date and the duration of the shock. Following the literature on the macroeconomic consequences 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 to the economy, we limit the selection to those types of disasters which we assume to have a sudden and immediate impact (rather than a subtle and slow one). These disasters are earthquakes, landslides, floods and storms. To generate a quarterly shock variable, we take into account that events taking place earlier in the quarter are likely to have a larger impact on that quarter's output than shocks occurring towards the end of the quarter. We therefore weight the estimated damage (DAM) by the onset month (OM), that is, the month of the reported starting date of the disaster, such that $DAM_w = DAM(3-OM)/3$. Then, we sum the impact of all disasters that occurred in one country within one quarter. We standardize the disaster size by the quarterly nominal GDP in US dollars one year prior to the event to make the shocks 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 2,061 disaster shocks. To investigate the effects of large, that is, nationally relevant, natural 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. 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 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 whether they include escape clauses. The latter determine and define situations in which a deviation from the rule is admissible and may therefore be of particular importance in the case of natural disasters.

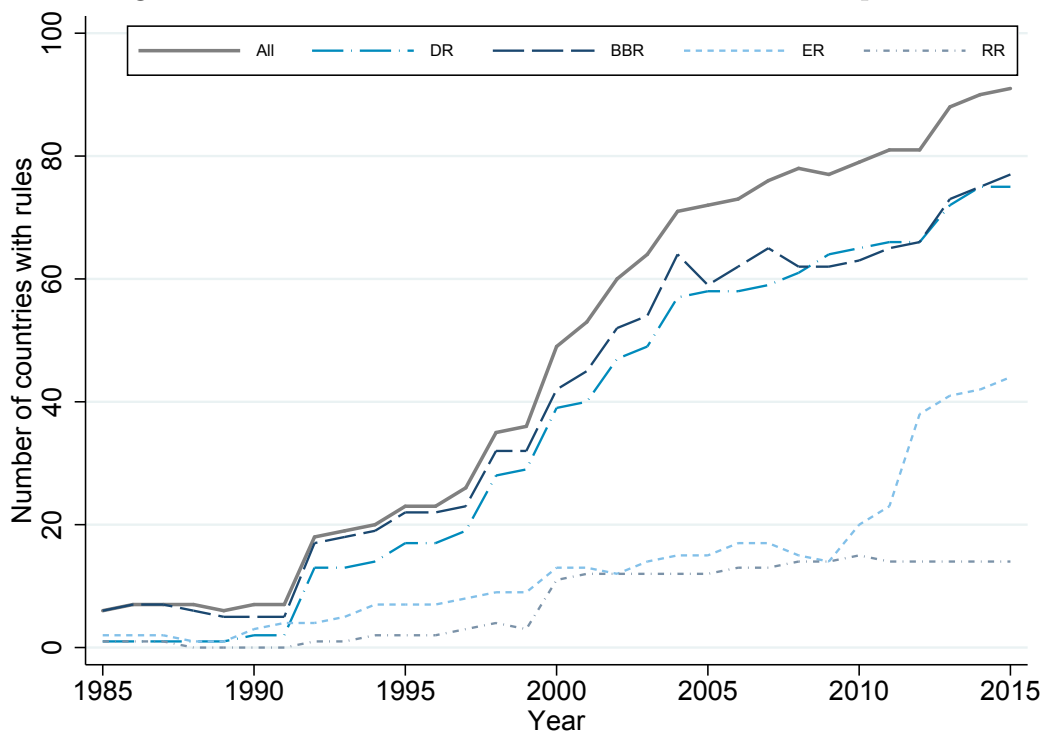
Four types of fiscal rules are distinguished, based on the budgetary aggregate they refer to. First, debt rules limit public debt in percent of GDP, providing a direct link to debt sustainability. However, they lack short-term policy guidance and may lead to procyclical fiscal policy when an economy is hit by a shock and the debt rule is binding. Second, budget balance rules constrain a government’s overall, structural, cyclically adjusted or “over the cycle” balance. While these rules entail more precise operational guidance, cyclical adjustment applied to prevent procyclicality is not straightforward and makes these rules more complex and thus more difficult to communicate and monitor. Finally, expenditure and revenue rules limit total, primary or current spending and set floors or ceilings on revenues, respectively. While not controlling debt directly, they can prevent procyclicality and target the size of the government. Given their various advantages and disadvantages, two or more fiscal rules are often combined. Furthermore, the rules may be instituted and enforced on both the national and supranational level. For example, the European Union imposed the Stability and Growth Pact, which constrains the debt and budget balance of its members, in 1992. Additionally, several European countries have rules in place at the national level, for example, the German “debt brake”.

As of 2015, the Fiscal Rules Database contains 95 countries. Figure 1 displays the number of fiscal rules over time. The figure shows that they have become increasingly popular over the past 30 years. In 1990, seven countries had some sort of fiscal rule in place; in 2015, that number had risen to 91. Four countries in the sample had retracted all rules by 2015: Argentina, Canada, Iceland and India. We extend the database by 24 countries that had no fiscal rule at any point in time. 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 Figure 1 also displays the number of countries that had 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

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

Figure 1: Number of countries that had a fiscal rule in place



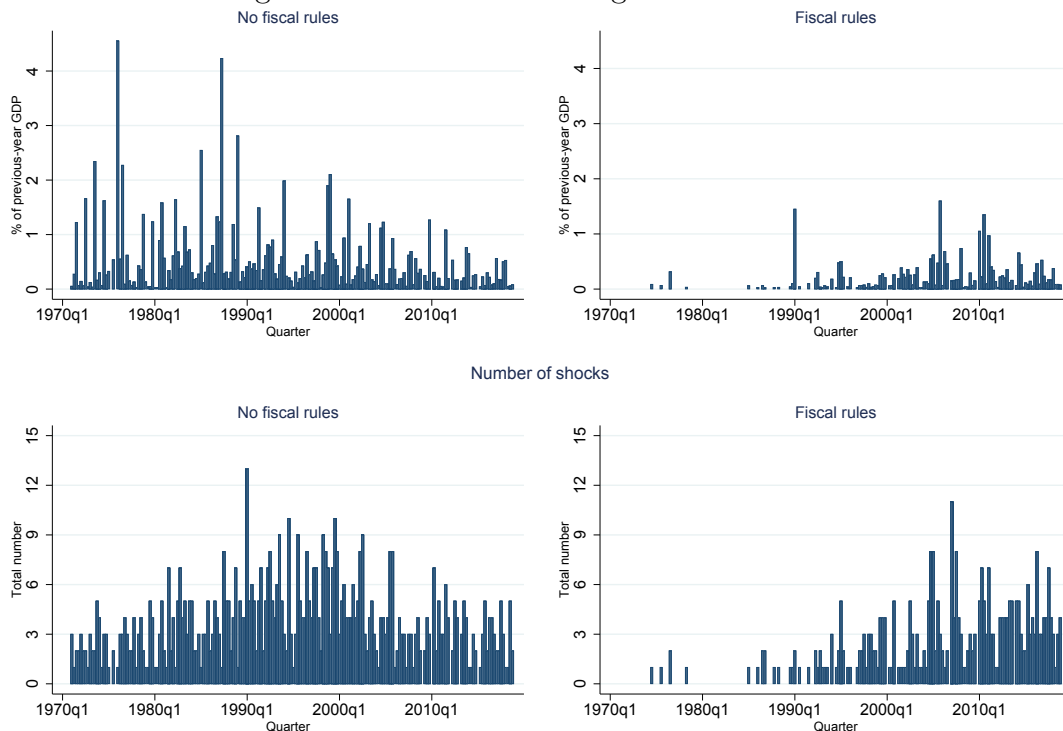
Notes: The figure shows the total number of countries that had any sort of fiscal rule, as well as the number of countries with different types of fiscal rules, in place each year. DR = Debt rule, BBR = Budget balance rule, ER = Expenditure rule, RR = Revenue rule.

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. We thereby aim to investigate whether the mere existence of any rule makes a country less or more resilient to shocks. A next step in future analysis would be discriminating between different degrees of stringency or *de facto* implementation. We interpolate the data to obtain a quarterly dataset. Since the exact dates of rule introduction are not given, we drop observations within the first year of rule introduction, that is, observations with rule value between 0 and 1. To analyze the mechanisms at place 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.

Figure 2 shows the mean size (upper panels) and the number of shocks (lower panels) for countries without fiscal rules (left panels) and with rules (right panels) over time. The figure indicates that both country groups have been significantly affected by

natural disasters. The comfortable number and size of shocks in each group suggests that we can reliably estimate their differential impact depending on fiscal regimes. The smaller number and later onset of disasters for fiscal rule countries reflects that most countries adopted fiscal rules after 1990. Furthermore, 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 an institutional quality indicator.

Figure 2: Distribution of large disaster shocks



Notes: The figure shows the average size of shocks in % of GDP (upper panel) and frequency of shocks (lower panel) per country group (countries with and without fiscal rules) per quarter. For each quarter, the mean and total number are computed from shock observations greater than zero.

2.1.3 Macroeconomic data, government and control variables

We collect macroeconomic data at a quarterly frequency for the period 1970Q1 to 2018Q4. We obtain real and seasonally adjusted data on output, private consumption and investment, exports and imports from the OECD national accounts statistics, as well as from national sources. If real or seasonally adjusted data are not available, we do these transformations ourselves. Data on government bond yields and credit default swap rates are obtained from Datastream. To proxy 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. Table 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 investigate the behavior of fiscal policy following the shocks. Those include the broader aggregates of total spending and revenue, as well as the following subcategories of government expenditure: social benefits, subsidies and employee compensation. Variables are obtained from Datastream, DBnomics and the IMF International Financial Statistics, depending on their respective availability. As government data are provided only in nominal levels, we use the Consumer Price Index (CPI) to deflate the numbers, seasonally adjust the data and compute quarterly growth rates.³ In the same way, we compute a structural government surplus variable as the difference between government revenue and spending, and divide 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 the 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:

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

where $\Delta y_{i,t}$ denotes the quarterly rate of change in the dependent variable for country i in quarter t . We use alternative endogenous variables, including changes in per capita output, private consumption and investment, imports, exports as well as government spending and interest rates. The natural disaster shock is captured by $S_{i,t-j}$. $FR_{i,t-j}$ is a dummy variable that captures the presence of a fiscal rule. We set $J = 15$ to compute impulse responses over four years. The central term in (1) is the interaction

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

between the shock and the rule dummy, which captures the difference between the dynamic effects of large real shocks under fiscal rules and without such rules. The main parameters of interest are thus the δ_j .

Fiscal rules may have an important impact on how quickly an economy recovers from 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 the aftermath of 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](#)).

To address the concern of omitted 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, $Goveff_{i,t-j}$) as possible alternative shock absorbing mechanisms. These country characteristics may affect $\Delta y_{i,t}$ beyond fiscal rules. The interaction terms also relax the standard assumption of common slopes across all panels. We investigate a variety of further shock absorbing mechanism in the sensitivity analysis. The vector $X_{i,t-4}$ contains the following control variables: the degree of urbanization, population density, a measure for the level of democracy and the exchange rate regime (fixed or floating). These enter at 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 growth and inflation or climate change).

To remove possible autocorrelation in the error term $\epsilon_{i,t}$, we include four lags of the dependent variable, $L = 4$. Depending on the variables included in the model, the regression contains up to 68 countries. To account for the heteroskedasticity in this large cross-section, we estimate (1) using 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

⁴We use a parametric bootstrap, applying the estimated covariance matrix of the coefficients to

Our identification strategy follows [Ramcharan \(2007\)](#). To illustrate it, consider the case of $J = L = \eta_0 = \theta_0 = 0$ and all control variables of model (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 this expression, 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 at some point abolished fiscal rules once they have been adopted. Furthermore, we find that just three countries have introduced a national fiscal rule in the aftermath (up to four years) of a large natural disaster (defined as an estimated economic damage of more than 0.5% of GDP). Excluding these countries does not change the results.⁵ Second, we assume the unobserved drivers of the dependent variables, captured by the residual $\epsilon_{i,t}$, to be 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 when hit by large disasters.

3 Fiscal rules and macroeconomic performance

This section contains the core results. Before we analyze whether fiscal rules change the response to natural disasters, we briefly develop a notion about the type of shocks that we use by describing their average macroeconomic impact. According to a linear

draw new coefficients from a multivariate normal distribution, to compute a distribution of impulse responses ([Romer and Romer, 2004](#)).

⁵We 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 excluding thirteen countries that introduced a national fiscal rule after any size of shock in the sample.

model, GDP declines upon impact. Thereafter, the economy starts recovering and GDP overshoots its pre-crisis level after one year. The shock has long-lasting and significant effects on essentially all components of GDP. While private consumption drops during the first two quarters, all demand components are above trend half a year after the shock. Private investment increases sharply as the disaster partially destroys the capital stock. It causes 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 generate catch-up demand and increase GDP. Finally, government spending increases significantly in an effort to stabilize the economy. Overall, these findings are in line with the literature.⁶ However, we show next that the average effects mask important differences in the responses of both fiscal policy and the economy across countries with and without fiscal rules such that we do not report them here.

3.1 The impact of fiscal rules on economic dynamics

We now assess whether and how fiscal rules change the adjustment to the shocks. Table 1 shows baseline regression results. The dependent variables in models 1-4 are changes in GDP, government spending, private consumption and private investment, respectively. The upper part contains the estimated δ_j s of model (1), which measure the differential effect of fiscal rules following a shock, and the associated standard errors in parentheses. The middle part focuses on selected additional coefficients. The bottom part contains summary statistics. The large χ^2 s 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, supporting the specification.

Model 1 shows that the estimated impact of fiscal rules on output growth is mostly positive. Out of the 16 parameters, 5 are negative but insignificant, while the remaining 11 are positive. 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 null is rejected at the 5% level (see bottom of the table). Similarly, the distributed impacts of the interaction terms on

⁶We do not aim at contributing to the literature on the growth effects of natural disasters, which has not come to a consensus (see Kousky (2014) for a literature survey). Figure A.4 in the Appendix summarizes the cumulative effects of the disasters on output and its components, on average across countries with and without fiscal rules. The estimates are derived from the β_j coefficients in (1) dropping all nonlinear terms and presented alongside their 68% and 90% confidence bands.

Table 1: Regression results for differential impact of fiscal rules.

	GDP		Priv. consumption		Gov. spending		Surplus/GDP ratio	
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 of observations	7,854		7,437		2,024		1,803	
Number of countries	68		61		39		32	
χ^2 of regression	2072.70		1408.70		997.22		1081.32	
Joint p -value of country FE	0.000		0.000		0.012		0.002	
Joint p -value of year FE	0.000		0.000		0.000		0.000	
Joint p -value interaction terms	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 dynamic differential effect of fiscal rules following large natural disasters on the quarterly percentage change in GDP, private consumption, government spending and the surplus-to-GDP ratio, respectively, for country i in quarter t . The estimates are based on model (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 significance at the .01/.05/.1 levels, respectively.

private consumption and government spending are predominantly positive, if they are individually significant (models 2 and 3), while they are mostly negative for the cyclically adjusted budget balance (model 4). Moreover, in each model, the 16 lag coefficients are highly significant jointly, as the p -values of the corresponding F -tests in the bottom of the table show. All in all, the results suggests that fiscal rules increase fiscal deficits, domestic demand and thereby output in the aftermath of the shocks.

The middle part of the table convey a high persistence in the dependent variables. Most of the lagged endogenous variables are significant. This implies that the autoregressive part of the model is an important determinant of the estimated dynamic effects of fiscal rules, which the tabular presentation of the individual effects neglects. Therefore, Figure 3 shows the dynamic adjustment of both country groups to the

shocks graphically. The responses are derived from the estimated coefficients β_j , γ_j , δ_j , and μ_l of (1).

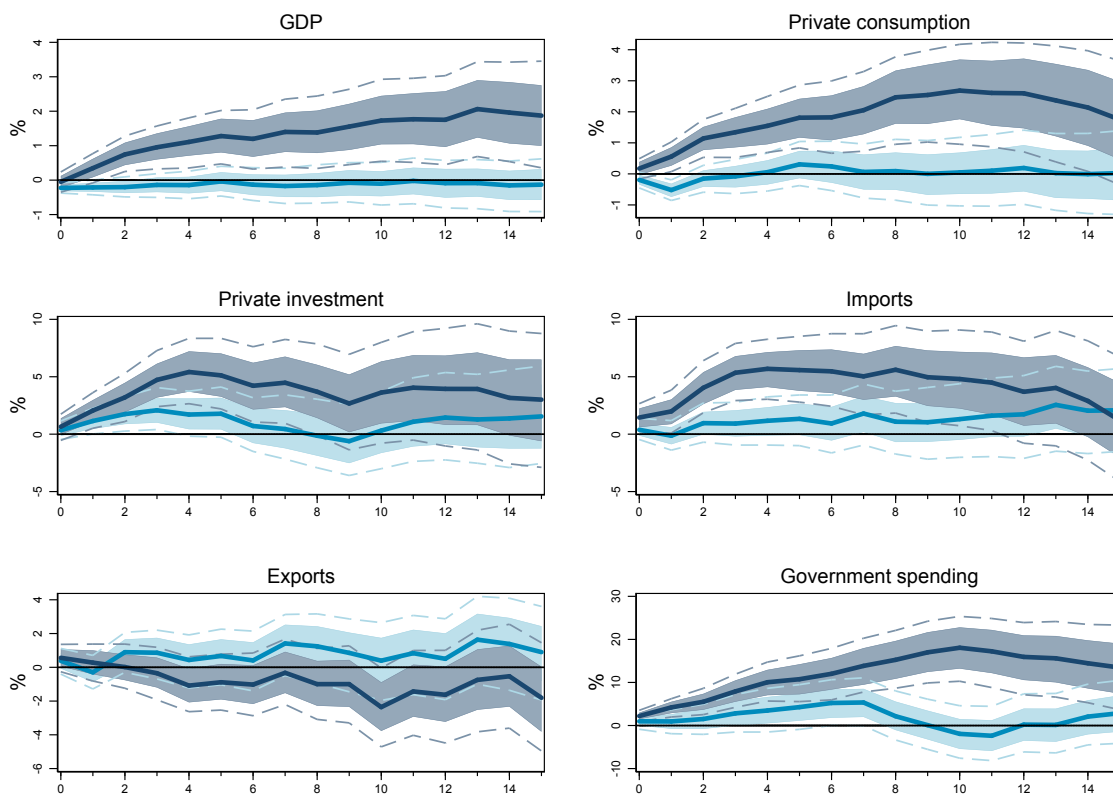
There are important differences between groups. First and foremost, output is higher in countries operating under fiscal rules. The initial drop is insignificant and the subsequent recovery is strong. Output persistently and significantly rises above the level prevailing in absence of the shock. In contrast, 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. A similar picture emerges for imports. Private investment rises in both groups, but the increase is stronger and longer-lasting in fiscal rule countries. The pattern is flipped for exports, which are below trend with rules and above trend without rules. Finally, public spending increases in both groups for about a year and a half. It then returns back to trend in countries without rules, whereas it keeps on rising in countries with fiscal rules. Together, the findings provide first support for the hypothesis that, measured by output or private consumption, fiscal rules enhance the absorption of adverse economic shocks.

To test whether the effects of fiscal rules on economic dynamics are statistically significant, we compute the cumulative differences between countries with and without rules. They are shown in Figure 4 and add to the initial evidence. GDP and, with the exception of exports, all of its components are significantly higher under fiscal rules. The differences are large and persistent. They range between 2% and 4%, and they last for 2-3 years. Bar the initial quarter, output is significantly higher when rules are in place. The cumulative difference after three years is roughly 2%. 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. A key driver of the positive impact of fiscal rules on output and private demand seems to be the response of fiscal policy to the shock. Total public spending is significantly and persistently higher in countries with fiscal rules. The difference is also economically significant. The maximum gap exceeds 10%. All in all, we conclude that fiscal rules support a recovery from large shocks significantly.

3.2 Detailed analysis of fiscal policy and rules

We now take a closer look at the fiscal response to the shocks to understand the mechanisms underlying the superior output performance of fiscal rule countries. Figure 5

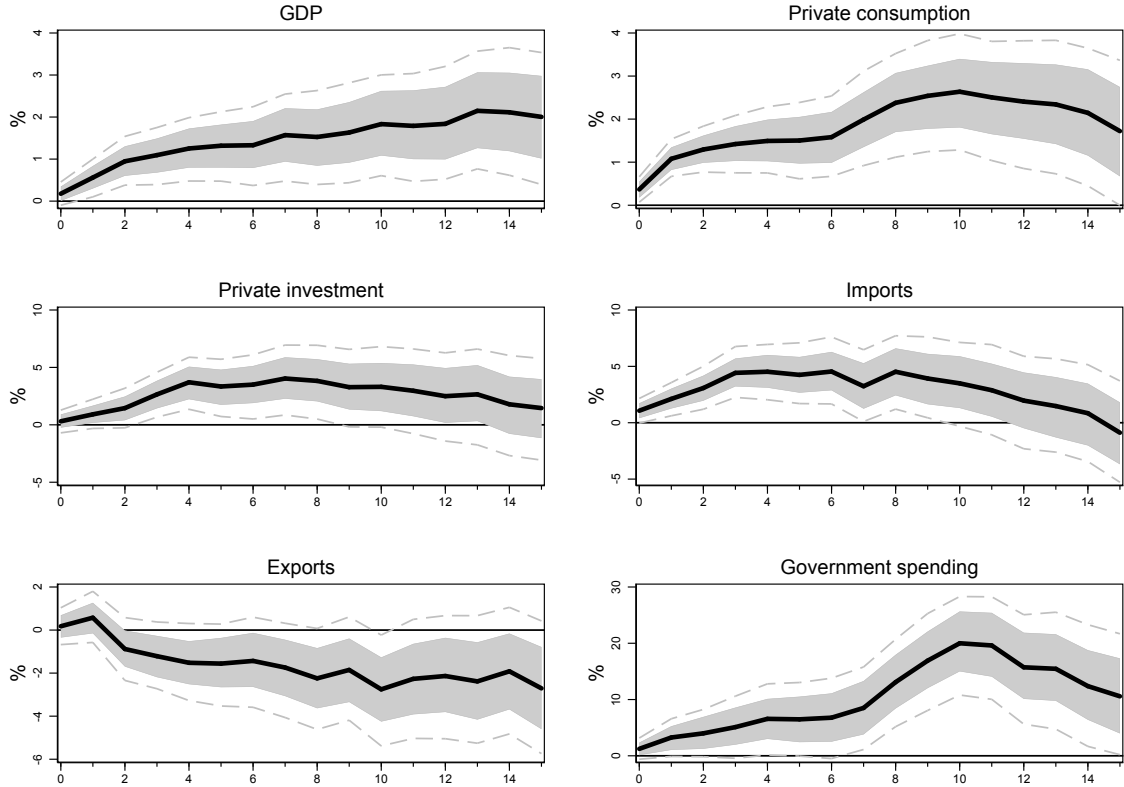
Figure 3: Cumulative effects of natural disasters in countries with and without fiscal rules



Notes: The figure shows the cumulative response of 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 period 1970Q1-2018Q4. The frequency is quarterly. Confidence bands refer to the 68% and 90% level and are based on 500 Monte-Carlo draws.

shows the differential evolution of selected government spending components and revenues following the shock. The drivers of the stronger fiscal expansion in rule countries seem to be government consumption (containing compensation of employees and the use of goods and services), investment, social benefits, subsidies, and other expenses. In particular the evolution of subsidies appears to contribute to the shape of the differential response of total government spending. This category accounts only for about 3% of total public expenses, but the differences between the two country groups is large, reaching 40%. Subsidies are transfers of government units to public and private firms and to other sectors, such as states or regions, for goods and services. Governmental transfers to households are usually not included, unless households act as producers. Instead, these are contained in social benefits and other expenses, which are higher in fiscal rule countries as well following the shock. Intergovernmental transfers are also partially attributed to the grants category.

Figure 4: Dynamic impact of fiscal rules in the aftermath of large adverse shocks.

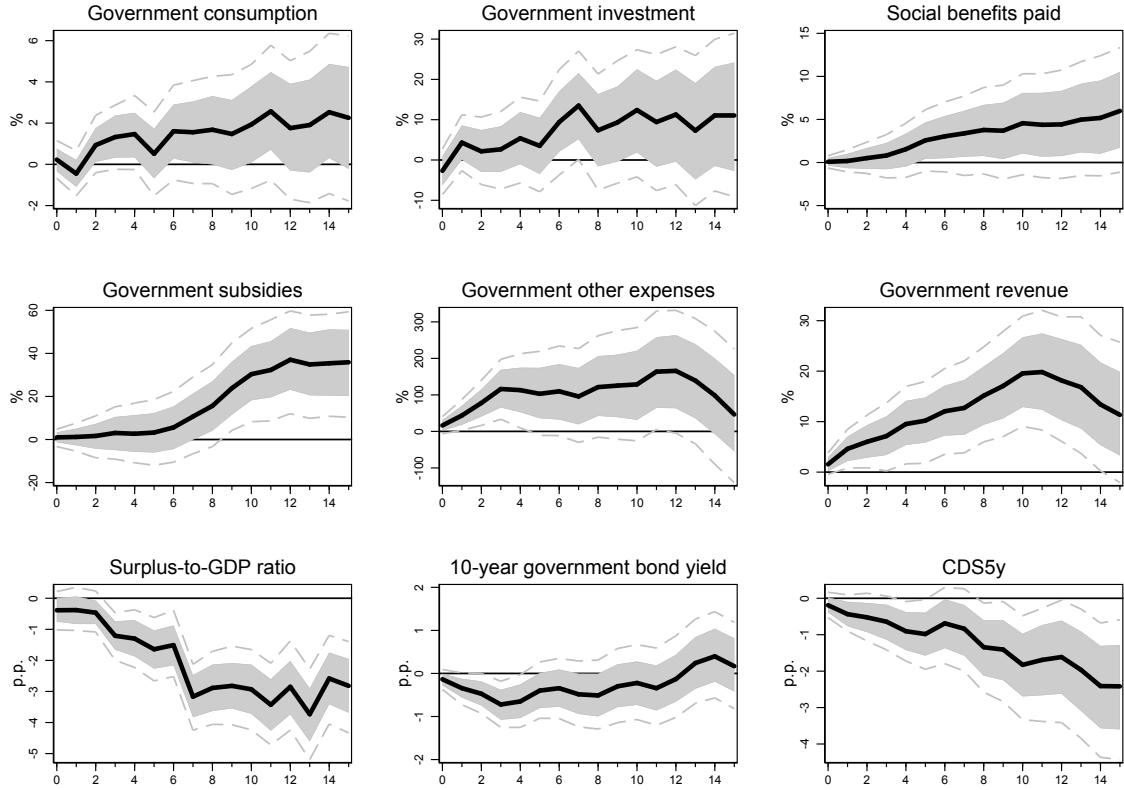


Notes: The figure shows the cumulative differential responses of output and its components between countries with and without fiscal rules to large natural disaster, based on model (1) over the period 1970Q1-2018Q4. The frequency is quarterly. Confidence bands refer to the 68% and 90% level and are based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

However, payments by the government for damages to, or losses of, capital goods due to natural disasters are mainly included in other expenses. This is an important category within total expenses. It represents up to 25% of total general government spending. Indeed, there is a large difference in the fiscal response regarding this category. It increase by about 100% in countries without rules, but rises by roughly 200% in countries with rules. The difference between both is 100%, and is mostly significant. These transfers include payments and gifts to individuals, private nonprofit institutions, nongovernmental foundations, corporations, or government units. In case of natural disasters, the category also includes 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.

Government consumption, investment and social benefits are also important cate-

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. The frequency is quarters. Confidence bands refer to the 68% and 90% level and are based on 500 Monte-Carlo draws.

gories, which together account for about two thirds of total government spending. The difference in the responses between groups are quantitatively important, but largely imprecisely estimated. Overall, these findings are consistent with a literature showing that there is a positive multiplier from deficit-financed government spending and that this multiplier is larger during recessions (Galí et al., 2010; Ramey, 2011, 2019; Auerbach and Gorodnichenko, 2012; Corsetti et al., 2012; Canzoneri et al., 2016). Regarding total revenues, they increase significantly more in countries with fiscal rules. We view this as reflecting automatic stabilizers since the tax base in these countries is significantly higher following the shock, and tax revenues increase with output.

The bottom panels in the figure suggest that and why fiscal policy is more expansionary in countries with fiscal rules. The surplus ratio is four percentage points lower in these countries. Moreover, the ten-year rate, a useful approximation of countries' financing conditions, is significantly lower as well. This rate reflects several components.

Next to credit risk, it comprises inflation and real growth expectations. To strip off the last 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 persistently and significantly negative as well. Together, the differential evolution of these three variables between country groups points to variation in public solvency and government's market access as potential explanations for the more expansionary policy response.

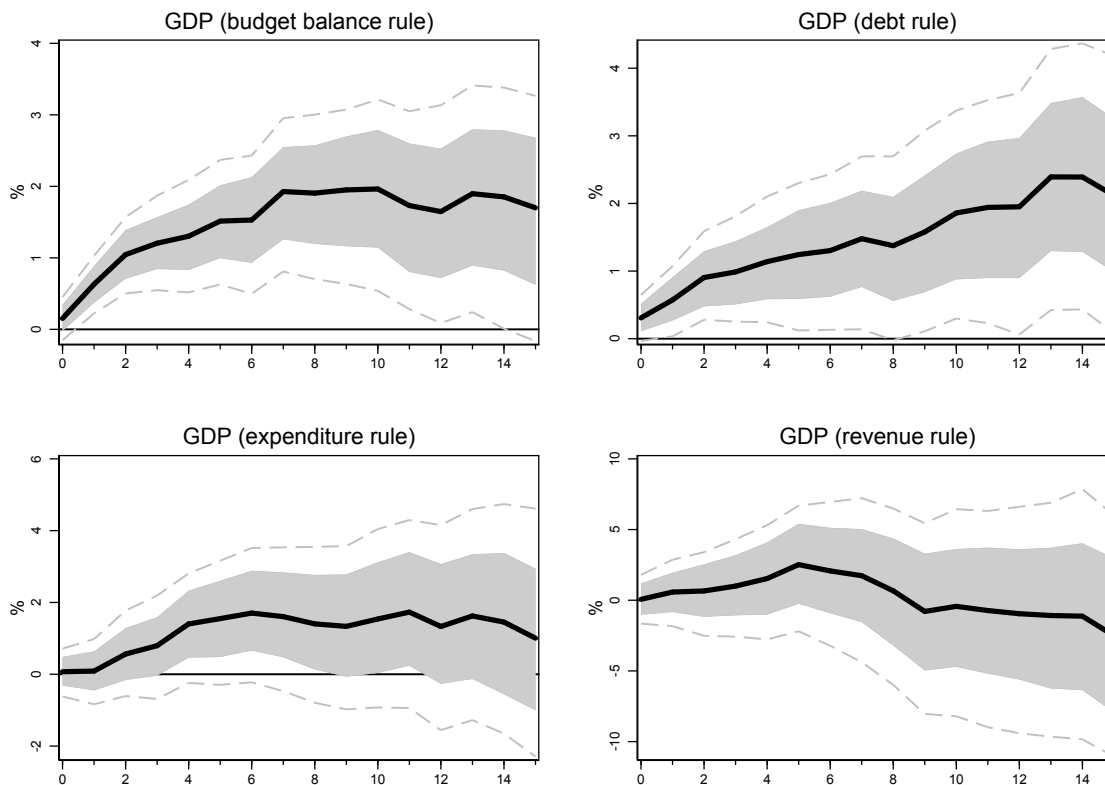
To investigate this issue further and to see which specific rules drive our main results, Figure 6 plots the differential GDP response between countries with and without fiscal rules, distinguishing between different types of rules. The fiscal rule dummy is now defined as equal to one whenever a country 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. 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.

The main result of a superior output performance under fiscal rules seems to be mainly driven by balanced budget rules and debt rules. For those two, the point estimates are roughly similar in size to the ones for the baseline definition of the fiscal rule dummy. The difference between countries with and without fiscal rules is statistically significant essentially for the full response horizon. For expenditure rules, the effect is still comparable in size but less statistically significant, while the impact of revenue rules is indistinguishable from zero. The last finding needs to be treated with caution, however, as the number of observations for countries with revenue rules hit by large disasters is small.

3.3 Empirical mechanisms

The finding that fiscal rules improve shock absorption is remarkable given a main contention in the literature and among policy makers that they constrain the possibility to respond to shocks (Azzimonti et al., 2016; Halac and Yared, 2018). The previous two figures combined raise two questions. How and why can countries with fiscal rules conduct more expansionary fiscal policy to buffer adverse shocks? To answer the how, understanding several technical characteristics of fiscal rules is crucial. 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 allow explicitly for temporary deviations from

Figure 6: The differential GDP response under alternative fiscal rules.



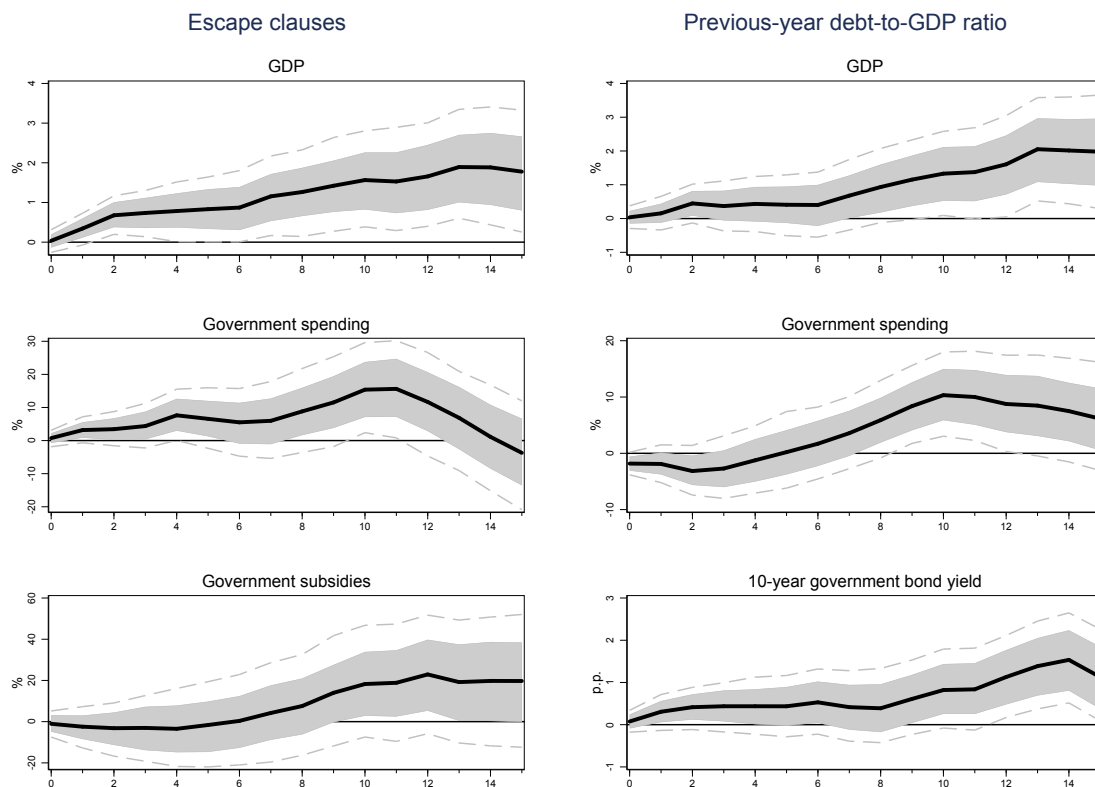
Notes: The figure shows the cumulative differential response of quarterly GDP between countries with and without different types of fiscal rules (budget balanced, debt rule, expenditure rule, revenue rule) following large natural disasters, based on model (1) over the period 1970Q1-2018Q4. Confidence bands refer to the 68% and 90% level and are based on 500 Monte-Carlo draws. Countries with the respective rule may still have other rules.

the rule in the event of natural disasters or other shocks outside of the control of the government. A recent example of such other shocks is the Covid-19 pandemic, which triggered an activation of the escape clause in the Stability and Growth Pact such that countries can temporarily exceed the deficit ceiling without entering an excessive deficit procedure.

The left column of Figure 7 shows the differential response of GDP, government spending and subsidies between countries with and without fiscal rules 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, the responses measure the dynamic differential impact of fiscal rules relative to countries without rules and countries with rules with escape clauses. The differences of both government spending variables between groups partly vanish and the impact on output decreases. This indicates that escape clauses are an important

determinant of the fiscal response to shocks because they generate the needed 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 previous year's debt-to-GDP ratio to control for fiscal space. 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.

At the same time, the 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 are often defined in terms of 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 (in absolute terms or growth rates) but are usually defined over

horizons of several years. Moreover, they often allow for economic stabilization by excluding cyclically sensitive items. Another reason why the impact does not vanish completely might be that governments comply with rules only about half of the time (Eyraud et al., 2018).

To understand why fiscal rule countries spend significantly more following adverse shocks, it is useful to look at existing empirical evidence. There is mounting evidence that, in the long-run, fiscal rules are successful in reducing sovereign deficits and debt (Alesina et al., 1999; Debrun et al., 2008; Grembi et al., 2016; Heinemann et al., 2018). Sustainable public finances, in turn, may allow governments to tap financial markets more easily in situations of stress. Romer and Romer (2018), for example, show that governments with more fiscal space, measured by the inverse debt/GDP ratio, respond more aggressively, that is, with more expansionary fiscal policy, to financial crises. Unfortunately, quarterly data on public debt are unavailable for a sufficiently long time span and broad country sample to estimate the differential response of debt to natural disasters depending on whether fiscal rules are in place.

But to assess the idea formally that debt may play a role, we conduct a similar regression to the one for escape clauses. The right column of Figure 7 shows the impact of fiscal rules on the reaction of output, government spending and the ten-year rate when conditioning on the initial level of debt in (1), measured by the previous year's debt/GDP ratio, instead of on government effectiveness. The picture is similar to the case of correcting for escape clauses. The effect of fiscal rules on the difference in GDP and government spending dynamics decreases, although it remains positive and partially significant. The difference in the ten-year rates tends to even reverse sign. These findings suggest that fiscal space is one important channel through which fiscal rules affect output dynamics following disaster shocks. By constraining the secular increase in deficits and debt, fiscal rules seem to generate the breathing space that fiscal policy needs to buffer shocks in the short-run.

Theoretically, there are at least two potential reasons why the debt level could affect market access. First, there can be a continuous (potentially highly nonlinear) relation between sovereign debt and interest rates, through either transaction costs or sovereign default risk premia. If fiscal rules lower long-run debt, they would also reduce the marginal cost of issuing additional debt in the case of an adverse economic shock. Second, fiscal rules might help prevent multiple equilibria. Calvo (1988), for example, shows that in sovereign debt markets there can be two equilibria: one with low interest and low repudiation, and one with high interest and high repudiation. If fiscal rules anchor expectations and rule out the second equilibrium, they may help ease market access when hit by an adverse shock. Finally, the debt channel is probably not the

only one. There are many other potential mechanisms through which fiscal rules could affect the policy response to shocks. For example, the implementation of rules might go along with enhanced fiscal governance in the form of greater accountability, more transparency, or leaner budgetary procedures.

4 Theoretical mechanisms

In this section, we present a theoretical model with endogenous fiscal space and natural disasters to shed further light on potential mechanisms through which fiscal rules shape the responses to such shocks. Natural disasters are modeled as a temporary exogenous reduction in the physical capital stock. This lowers output obtained 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 debt and provides a rationale to constrain borrowing.

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 and 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. Let $\zeta = 1$ denote 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 $u(\cdot)$ 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

$$E_0 \sum_{t=0}^{\infty} \delta^t u(c_t, g_t, 1 - l_t)$$

$$\text{s.t.} \quad (1 + \tau_t)c_t = z_t F(k_t, l_t), \quad (4)$$

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

$$\frac{u_l(c, g, 1 - l)}{u_c(c, g, 1 - l)} = \frac{z F_l(k, l)}{(1 + \tau)}, \quad (5)$$

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

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

where double discounting represents a present bias in government expenditures, leading to higher than optimal borrowing (Laibson, 1997). While the private sector discounts future utility with a rate $\delta < 1$, the government sector discounts the continuation value with an additional factor $\beta < 1$.

The markets for government assets b are incomplete and the government can only issue one-period discount bonds. The government 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} , where the government defaults when the value under default is strictly higher than under repayment

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

where superscript p denotes repayment and d default. The conditions for default imply

a default set across exogenous productivity and disaster states

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

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

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

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 :

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

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 adjustments in the tax rate, household consumption. The government problem in case of access to capital markets is

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

subject to the household and government budget constraint and 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

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

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

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

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

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

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

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

Given the evidence on the importance of escape clauses (Figure 7), we allow for deviations from the fiscal rule under certain conditions. We assume that this condition is a natural disaster. Escape clauses typically define a set of trigger events in order to limit discretion and preserve the credibility of the fiscal rule (Schaechter et al., 2012). In the model, if the fiscal rule contains an escape clause, the constraint (12) or (13) does not apply as long as the economy is in the disaster state, $\zeta = 1$, while it is enforced immediately after having returned to the normal state.

We now have the following definition:

Definition *The recursive equilibrium for this economy is defined as*⁷

⁷The Appendix provides more details on the implementation of the value functions taking into account the disaster state variable ζ .

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 Calibration

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

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

This specification of preferences leads to labor supply which is independent of current consumption (Greenwood et al., 1988). Table 4.2 contain 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 $\varphi = 1/6$ is calibrated to replicate the response of investment in Figure 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 Frish 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

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)

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 parameter values, 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 $\phi = 0.99$.

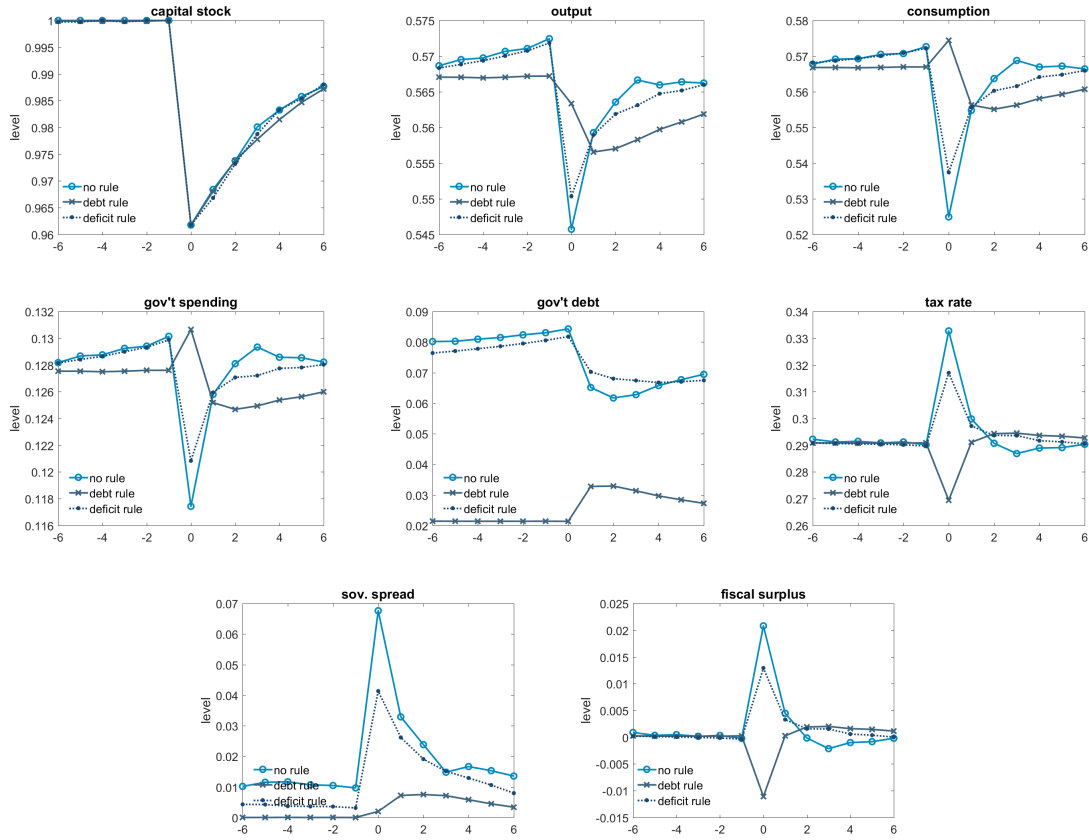
4.3 The theoretical impact of fiscal rules on dynamics

Figure 8 summarize the average responses of selected variables around disaster shocks.⁸ We show output, private and public consumption, the fiscal surplus and sovereign spreads to see whether the model can replicate the estimated dynamics presented in Figures 3 and 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 Figure 8 to understand the propagation of the shock and the policy response theoretically.

The solid lines with circles refer to a model without fiscal rule as a benchmark. There is an exogenous drop in the capital stock, which depresses output on impact.

⁸We 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. Output and consumption are therefore shown in productivity-adjusted terms, $\tilde{y}_t = y_t/z_t$, and $\tilde{c}_t = (y_t/z_t)/(1 + \tau_t)$.

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.

Given the persistence of the disaster state, a default in the consecutive periods becomes more likely, inducing a jump in the sovereign spread.⁹ 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, consistent with empirical findings (Klomp, 2017).¹⁰ To service outstanding debt in face of the contraction, the government hikes taxes, which lowers labor input further (see (5)). Taken together, the increase in the fiscal surplus suggests that initially high government debt compromise international risk sharing in case of natural disasters.

⁹The sovereign spread is defined over the risk-free rate as $s = 1/q(b', z, \zeta) - 1 - r^f$.

¹⁰This is further illustrated in the bond price functions and borrowing decisions in the disaster state in the Appendix, Figure B.5.

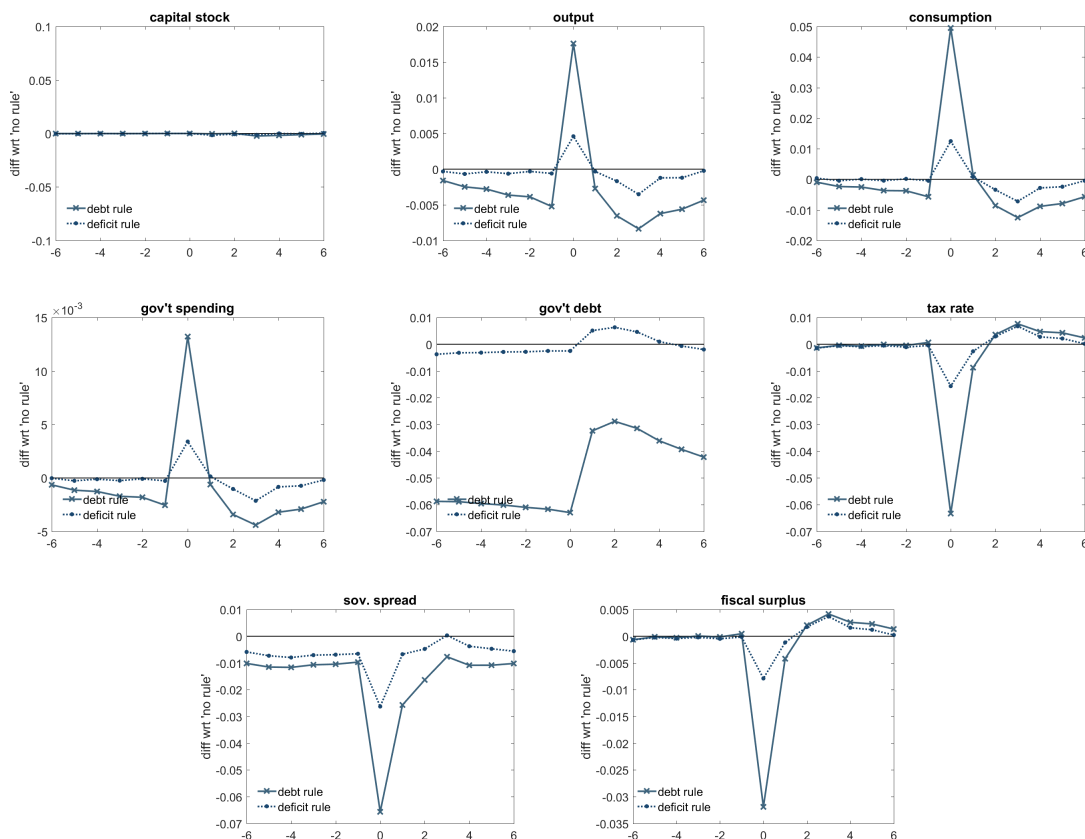
Next, we consider the effects of fiscal rules. First, the dashed lines with dots in Figure 8 show the average responses under a deficit rule with an escape clause. The rule (13) is calibrated to $\bar{\Delta} = -0.0015$. This value restricts the government to run the smallest possible non-zero deficit under the discretized state-space. Generally, the responses under a deficit rule are similar to those for the no-rule case, but 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, so 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). Now, fiscal policy is countercyclical. Since the debt rule is binding, 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. Moreover, government debt now actually rises, whereas it falls in the benchmark model. The international funds are used to increase government spending and lower taxes. All in all, labor, output and private consumption are all higher than in the no-rule case when the shock hits. In Figure B.7 of the Appendix, we show that the countercyclicality of the fiscal surplus depends critically on the existence of an escape clause. Without such an exemption, government debt and spending cannot be increased to buffer the shock.

Finally, Figure 9 shows the differences of the responses under a deficit rule and a debt rule, respectively, vis-à-vis an economy without a fiscal rule to see whether the model matches the estimated impact of fiscal rules on dynamics documented in Figures 4 and 5. The model predicts that output, private consumption and public expenditures are all higher under a fiscal rule when the shock hits, thereby 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, reflecting that there are no endogenous persistence features in the model, while such mechanisms are probably generating the persistence of the empirical responses. All in all, we conclude that fiscal space is one potential mechanism that can rationalize our empirical results.

¹¹(Figure B.6) 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.

5 Conclusions

We provide a novel stylized fact. Fiscal rules improve macroeconomic performance following large adverse economic shocks. To overcome the endogeneity between the choice of adopting fiscal rules and economic pre-conditions or social preferences, we use data on natural disasters. Catastrophes are exogenous with respect to the fiscal regime and not driven by macroeconomic conditions. We estimate a set of dynamic panel models and document that countries with fiscal rules enjoy significantly and persistently higher output, private consumption and investment in the four years following such shocks than countries without fiscal rules. The results are robust to a large number of sensitivity tests.

Several mechanisms seem important for understanding the stylized facts. First, balanced budget and debt rules provide the largest benefits. As they are typically either

combined with escape clauses, or defined in cyclically adjusted terms or over medium-term horizons, they provide sufficient flexibility to respond to shocks. At the same time, they seem to preserve fiscal space in the long-run, thereby giving governments sufficient room to maneuver to support economic recovery in the short-run. We document that governments with fiscal rules pursue more expansionary fiscal policy in the aftermath of disaster shocks. All in all, the results suggest that well-designed fiscal rules alleviate the fundamental trade-off between constraining fiscal policy to rein in public debt and deficits and the need for active fiscal policy to accommodate economic shocks. In fact, the results indicate that countries with fiscal rules are better able to respond to such shocks.

Our findings bear some implications for the future of fiscal rules after the covid pandemic. Fiscal deficits have been widened and public debt has increased considerably. As long as there is fiscal space, this is in line with an optimal fiscal response under a flexible fiscal rule. Our findings, however, suggest that bringing down the level of public debt in the aftermath of a large shock is equally important to be able to buffer future shocks.

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ONLINE APPENDIX

Committed to Flexible Fiscal Rules

by C. Grosse-Steffen¹, L. Pagenhardt² and M. Rieth³

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 adopt systematically also other specific policy frameworks, the previous results could still be affected by omitted nonlinearities.

To see whether this is the case, we first control for the foreign exchange 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. Second, we control for the monetary regimes. 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. Third, we control for the total damage caused

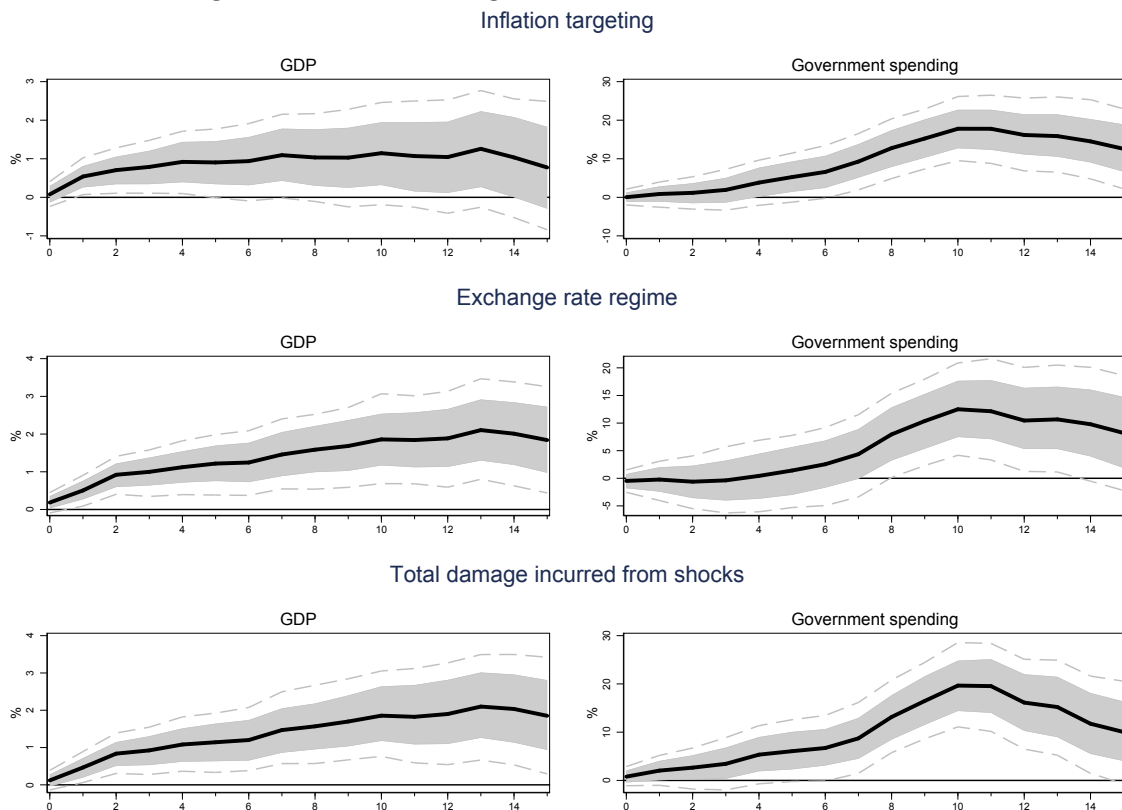
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by natural disasters within sample to capture countries' susceptibility to the shocks, which potentially affects both the choice of the fiscal regime and the adjustment to the shock. Each control variable, one at a time, replaces government effectiveness in (1). Figure 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.

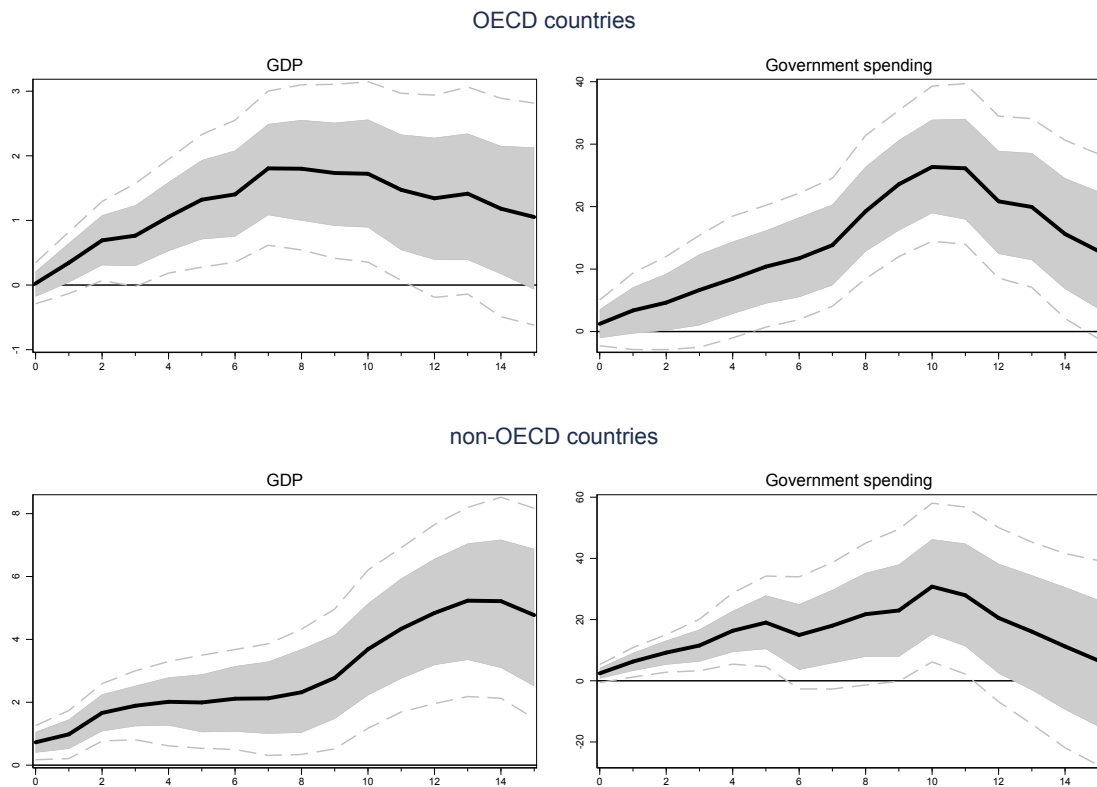


Notes: The figure shows the differential response of output and government spending between countries with and without fiscal rules to large natural disasters. In each specification, the respective control variable replaces government effectiveness as the alternative shock absorber. The estimation is 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. Figure 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.

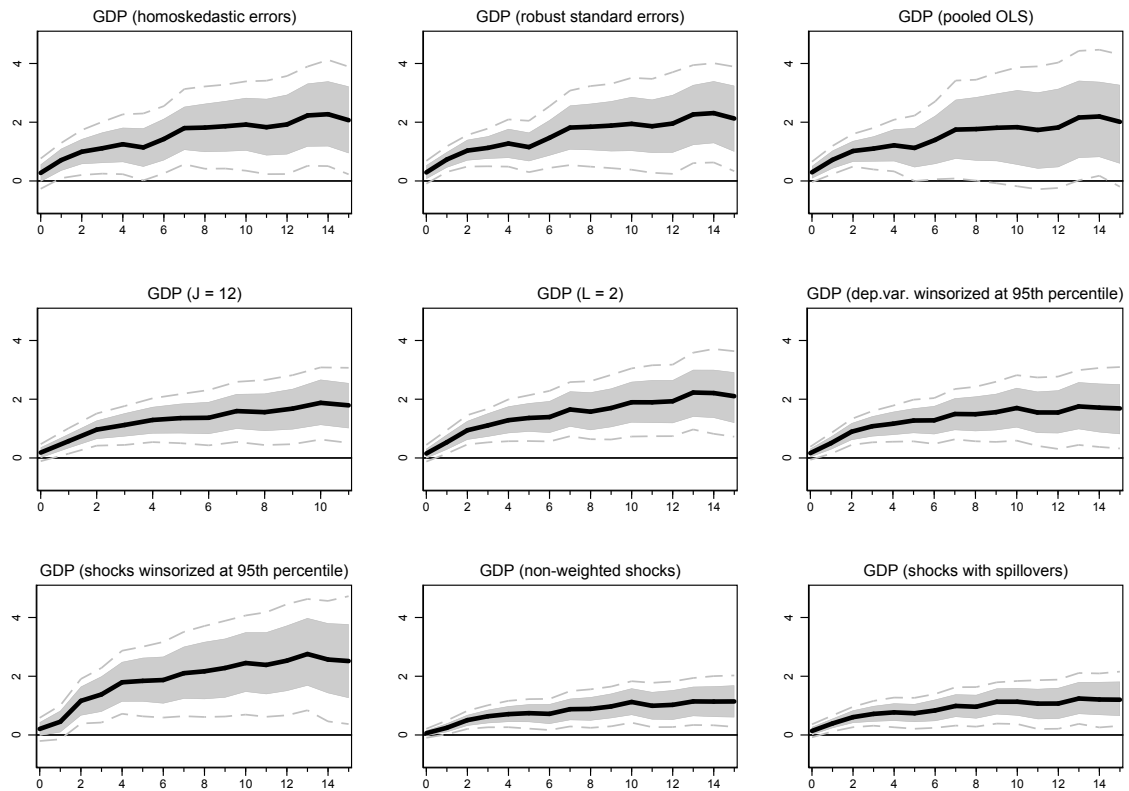


Notes: The figure shows the cumulative differential response of quarterly GDP and government spending between countries with and without fiscal rules following large natural disasters, based on model (1) over the period 1970Q1-2018Q4. The upper panel contains results for the subsample of OECD countries 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. 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

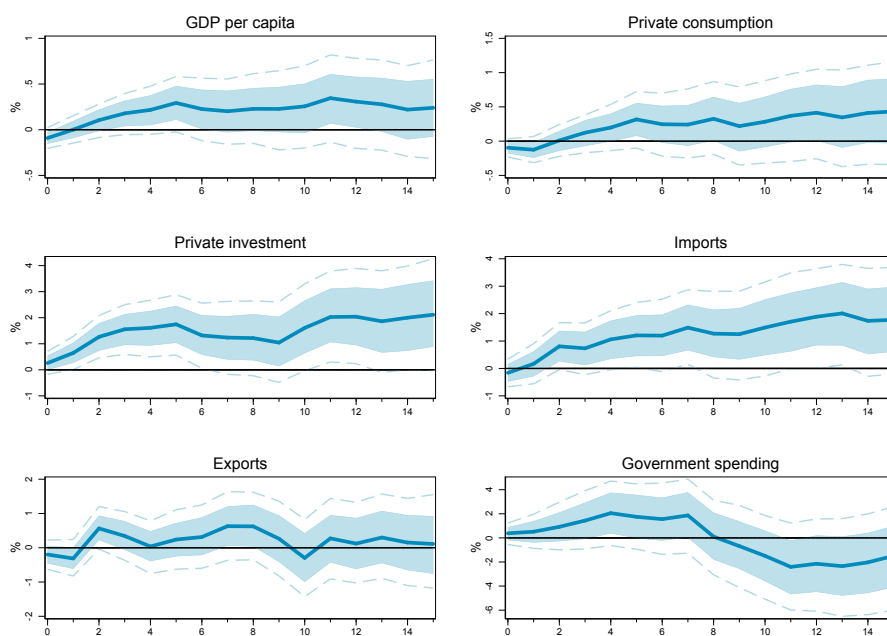
for spillovers from previous quarters. Figure A.3 shows that the impact of fiscal rules on the response of GDP is robust to all these alterations.

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. Confidence bands refer to the 68% and 90% level and are based on 500 Monte-Carlo draws.

Figure A.4: Macroeconomic effects of large natural disasters



Notes: The figure shows the cumulative impact of large natural disasters on GDP and its components in a sample of 68 countries over the period 1970Q1-2018Q4. 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)
GDP_{pc}^{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 values 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
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

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

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

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

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

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

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

This leads to the default set

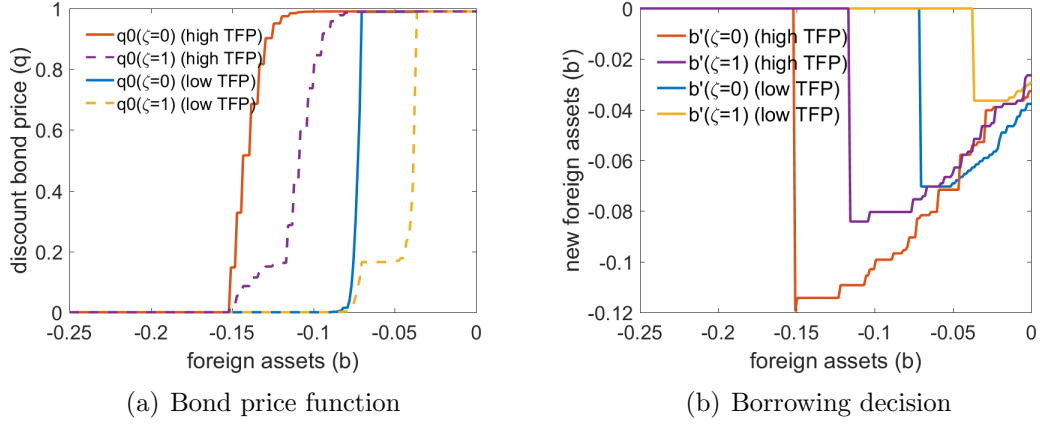
$$D(b, z, \zeta) = \begin{cases} z \in \mathcal{Z} : \mathcal{W}^{p^+}(b, z) < \mathcal{W}^{d^+}(z) & \text{if } \zeta = 0 \\ z \in \mathcal{Z} : \mathcal{W}^{p^-}(b, z) < \mathcal{W}^{d^-}(z) & \text{if } \zeta = 1 \end{cases}$$

with the respective set of default probabilities

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

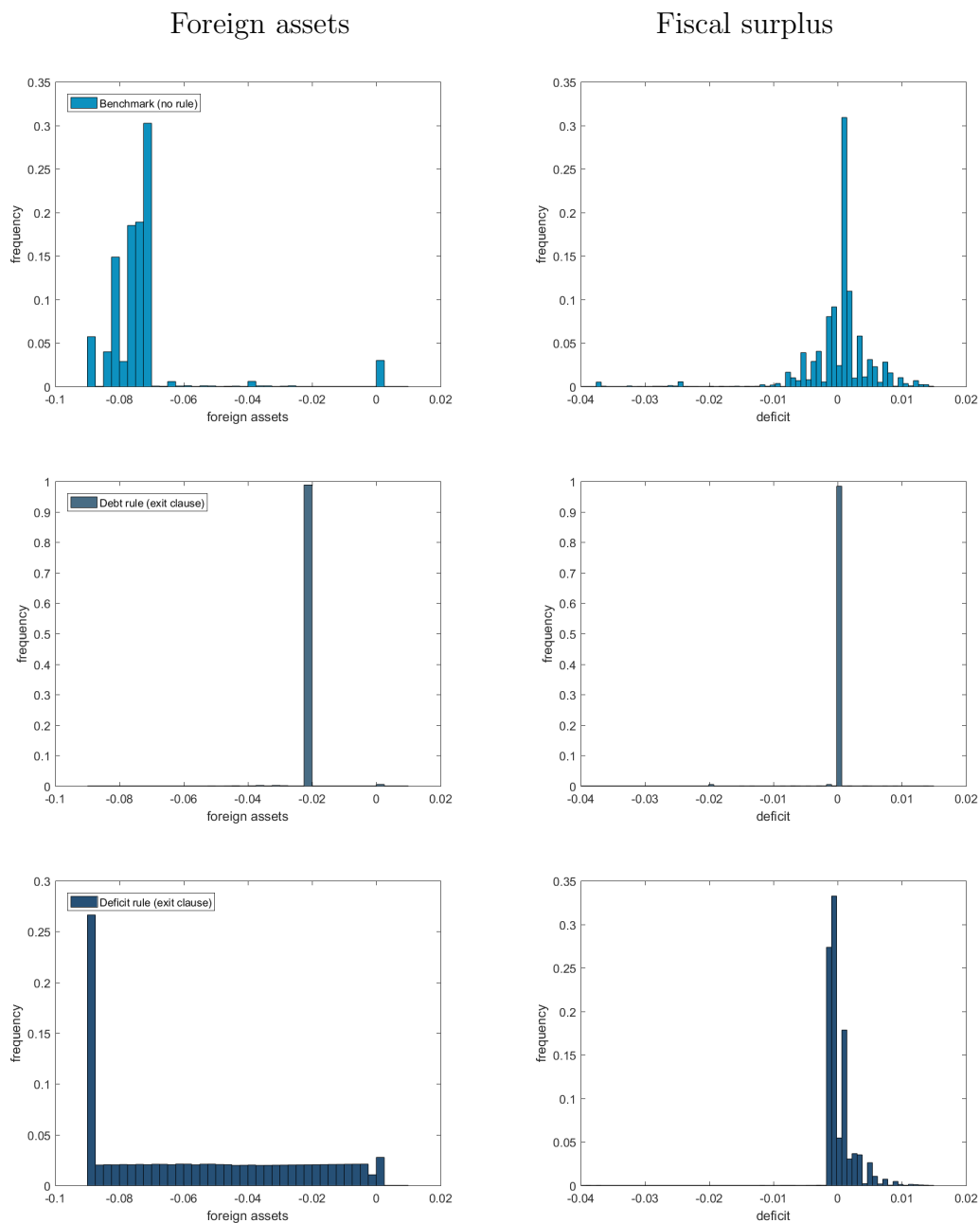
B.2 Additional model results

Figure B.5: Policy functions, model with natural disasters



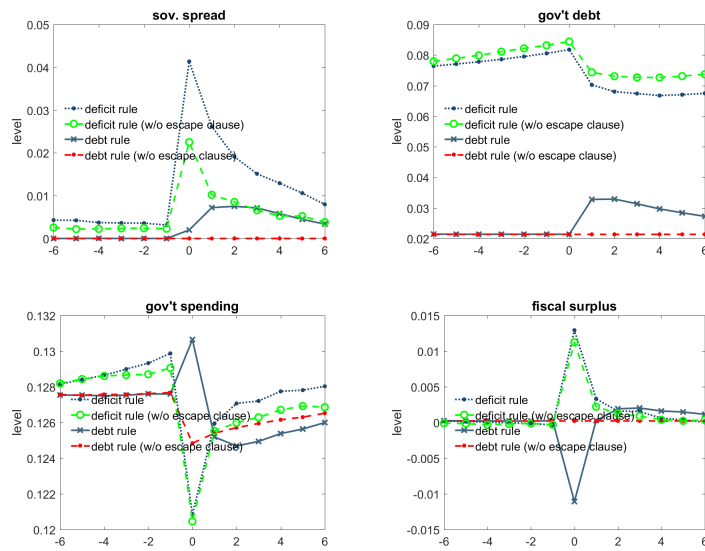
Note: Policy functions in the benchmark model with natural disaster risk. A natural disaster state has a similar effect as a bad productivity state on the bond price schedule. Given the high probability to exit from the disaster state and return to steady state levels of capital, the slope is much flatter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

Figure B.6: 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, discarding the first 50 periods as burnin.

Figure B.7: 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.