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Government Spending and Tax Revenue Decentralization and Public Sector Efficiency: Do Natural Disasters matter?*

António Afonso[$.] João Tovar Jalles[#] Ana Venâncio[±]

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Abstract

We assess notably how do extreme events affect the public sector efficiency of decentralized governance. Hence, we empirically link the public sector efficiency scores, to tax revenue and spending decentralization. First, we compute government spending efficiency scores via data envelopment analysis. Second, relying on panel data and impulse response approaches, we estimate the effect of decentralization on public sector efficiency and how extreme natural disasters mediate this relationship. The sample covers 36 OECD countries between 2006 and 2019. Our results show that tax revenue decentralization decreases public sector efficiency, while spending decentralization and a regional authority index are positively related to public sector efficiency, both for local projections and panel analysis. For instance, efficiency rises by 10 percent following a spending decentralization shock (reaching over 20 percent after 4 years). Nevertheless, in cases of natural disasters, spending decentralization reduces public sector efficiency. Specifically, in the presence of most extreme natural disasters, the improvement in public sector efficiency after a spending decentralization shock is smaller than in their absence. Moreover, extreme natural disasters also deteriorate the negative effect of tax revenue decentralization on public sector efficiency. These results suggest that sub-national discretionary spending and tax revenue responses might be less fruitful when such extreme events occur.

JEL: C14, C23, E62, H11, H50

Keywords: public sector efficiency; data envelopment analysis; local projections; revenue decentralization; spending decentralization; natural disasters; OECD

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1. Introduction

Typically, governments intervene in the economy to deal with: pure public goods and quasi-public goods; various market failures; negative externalities; business cycles; income maintenance for individuals and families unable to earn a living; and to make the income distributions closer to what voting societies expected them to be (see Afonso et al., 2023). In many countries, subnational and local governments have turned into key actors in the mobilization of revenues and provision of public goods and services to their citizens. This in turn led to rising demand from policymakers, policy analysts, and academics for assessing the efficiency and the trend of fiscal and spending decentralization and its impact on the economy.

Centralization might cope better with unforeseen events, such as disasters, and may as well rip the benefits of scale economies in the provision of public goods and services, hence, there would be efficiency gains. On the other hand, the proximity to citizens, notably in terms of the provision of services, and on the spending side of the budget, might also contribute to increase efficiency, even if that may not be true from a tax collection perspective. Therefore, spending and tax decentralization may well impinge differently on government spending efficiency. Still, and in spite of efficiency assessments, one could think that in a more centralised country, where most of the government spending occurs at the central government level, may perhaps be less difficult to reign in the budget deficit. In other words, in more decentralised institutional fiscal settings, the less significant could be the responses and improvements in the primary balance, since the coordination/control of the sectors/entities responsible for the final spending actions can be more difficult.

In this paper we are interested in assessing notably how do extreme events affect the public sector efficiency of decentralized governance. Therefore, we study the potential links between the efficiency of the general government, proxied by efficiency scores, and the level of fiscal and government spending decentralization. Therefore, we are bridging two topical areas of relevance notably for policy makers: are public resources more efficiently used depending on the degree of government decentralisation? How extreme natural disasters affect the relationship between efficiency and the degree of government decentralization?

The main findings of our empirical analysis are as follows. Regarding input efficiency scores, the average scores of our baseline model ranged between 0.58 to 0.68, which means that with the same level of outputs, inputs could decrease between 32% and 42%. Regarding the core research questions of the paper, we find that tax revenue decentralization is negatively related to public sector efficiency, while spending decentralization and regional authority index are positively related to public sector efficiency. These results hold for both input and output-oriented efficiency scores. For instance, public sector efficiency rises by 10 percent in the first year, following a spending decentralization shock (reaching over 20 percent 4 years after the shock). In addition, in cases of natural disasters expenditure decentralization reduces public sector efficiency. In fact, in the presence of most extreme natural disasters, the improvement in public sector efficiency after a spending decentralization shock is smaller than in their absence. Moreover, extreme natural disasters also deteriorate the negative effect of tax revenue decentralization on public sector efficiency. These results suggest that sub-national discretionary spending and tax revenues responses might not be fruitful when these extreme events occur.

The remainder of the paper is organized as follows. Section 2 discusses the related literature. Section 3 presents the data and the methodology used in the paper. Section 4 reports the empirical analysis. The last section concludes.

2. Literature

The primary goal of public economics and finance is to align the government revenues with the preference of citizens in delivering a range of services efficiency. To this end, governments have to decide the best mode of delivery of services. For example, they have to decide if they prefer to deliver a particular service centrally or locally or deliver it themselves (public) or outsource or partner with a private entity. These decisions are mostly driven by efficiency considerations.

Several studies have assessed public sector efficiency looking at different sample and time spans, notably for OECD and European countries (Adam at al., 2011; Duti and Sicari, 2016; Afonso and Kazemi, 2017; Antonelli and de Bonis, 2019). Still, empirical evidence is also available in other regions of the world such as in African (see e.g. Olanubi and Olanubi, 2023), Asian (see e.g. Mohanty et al., 2023; Song, et al., 2023) and Latin American and Caribbean countries (see e.g. Afonso et al., 2013; Gutiérrez-Arango, et al., 2023).

Regarding commonly used methods, a number of studies applied non-parametric techniques to measure public sector performance and efficiency (Afonso, et al., 2005, 2010a, 2010b; Afonso and Aubyn, 2006, 2011; Sutherland et al., 2009; Adam, et al., 2011; Afonso, et al., 2013; Afonso and Kazemi, 2017; Herrera and Ouedrago, 2018). The underlying idea is simple: one or several expenditure inputs can affect one or several performance indicators.

Two key results emerge from this literature: i) public spending efficiency can be improved; and ii) specific factors are associated with efficiency. These cross-country aggregated efficiency studies are very useful to compare the performance of different countries, nevertheless it is important to account for the underlying institutional, cultural, political, and economic factors. To account for these issues, studies have resorted to two-stage models.[1] Results suggest that education, income level, quality of the institutions and country's governance are positively and statistically significantly associated with performance (Hauner and Kyobe, 2008; Antonelli and de Bonis, 2019). Others report that political variables, such as having a right-wing and a strong government, and a high voter participation rates and decentralization of the fiscal systems, are positively associated with more efficient public sectors (Adam et al., 2011). More recently, Afonso et al. (2021a, 2021b) evaluated the role of tax structures and tax reforms on explaining cross-country efficiency differences. In addition, Afonso et al. (2022) reported that capital markets do reward better public sector efficiency.

For a discussion on financial and spending decentralisation and fiscal federalism see notably the seminal work by Tiebout (1956) and Oates (1999). In that vein, there are several arguments in favour of the benefits attributable to decentralization that potentiate the responsiveness of governments to local needs and more homogeneous groups of citizens. Hence, one would want to understand how governments should allocate efficiently public goods and how the costs of such provision should be shared across the several tiers of government. Proximity to economics agents and households, might improve performance in the provision of public goods and services (see Musgrave, 1969). For instance, Shah (2006) argues that fiscal decentralization can improve government efficiency by promoting competition among local governments, increasing accountability, and enhancing the responsiveness of government services to local needs. On the other hand, Sow and Razafimahefa (2015) report that fiscal decentralization can improve the efficiency of public services only when a sufficient degree of expenditure decentralization occurs.

When addressing the issue of government decentralisation, the most common gauge for measuring fiscal decentralisation is the sub-national share of government spending and revenue, which varies considerably across countries (see, for instance, OECD, 2003). For instance, Stegarescu (2005) uses different measures of tax autonomy and revenue decentralisation to conduct revenue-based assessment of public sector decentralisation in OECD countries, while von Hagen and Eichengreen (1996) used the share of sub-central government spending financed by revenues from own taxes.

[1] See, for instance, Simar and Wilson (2007) provide an overview of this issue.

More connected with our study, Balaguer-Coll et al., (2010) study the link between efficiency and decentralization in Spanish local governments in the period 1995-2000. They use a two-stage analysis: first, compute non-parametric measures of the performance of each municipality and, in a second stage, compare municipalities for which decentralization remained less prominent. Results suggest that some municipalities could manage their resources more efficiently if they were granted more power. Nevertheless, fiscal decentralisation might also hinder efficiency and macroeconomic performance, as mentioned for instance by Zhang and Zou (1998) and Gonzalez Alegre (2010).

3. Methodology and Data

3.1. Public Sector Performance and Efficiency Scores

Frontier approaches have been widely used to evaluate the public sector performance. Stochastic frontier analysis (SFA) and data envelopment analysis (DEA) are the most widely used frontier techniques. In this study, we compute government spending efficiency scores using DEA due to its modelling flexibility and lack of functional restrictions. DEA is a non-parametric technique that uses linear programming to compute the production frontier (see Farrell, 1957; Charnes et al., 1978; Coelli et al., 2002). It compares the performance of a country with a frontier composed by the best performing countries. Therefore, DEA is modelled under the assumption that countries produce similar sets of outputs, have similar resources, and operate in similar environments.

Below we summarize the DEA technology used in this study. For each country i, we consider the following function:

$$Y_i = f(X_i),\ i = 1, \dots, 36 \qquad (1)$$

where Y (Public Sector Performance, PSP) is the composite output measure, and X is the input measure, namely government spending-to-GDP ratio for 36 OECD member countries[2] between the period of 2006 and 2019.

[2] The 36 OECD member countries are: Australia, Austria, Belgium, Canada, Chile, Colombia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States. We were not able to compute the efficiency scores for Mexico and Costa Rica, due to data unavailability.

The output indicator for Public Sector Performance (PSP), as suggested by Afonso et al. (2005, 2022, 2023), includes two main components: opportunity and the traditional Musgravian indicators. The opportunity indicators evaluate the performance of the government in administration, education, health, and infrastructure sectors. The Musgravian indicators includes three sub-indicators: distribution, stability, and economic performance. Table 1 summarizes the variables used to construct the PSP indicators. PSP is the average between the opportunity and Musgravian indicators. Accordingly, the opportunity and Musgravian indicators result from the average of the measures included in each sub-indicator. To ensure a convenient benchmark, each sub-indicator is first normalized by dividing the value of a specific country by the average of that measure for all the countries in the sample.

Table 1 – Total Public Sector Performance (PSP) Indicator

Sub Index	Variable
Opportunity Indicators	
Administration	Corruption
	Red Tape
	Judicial Independence
	Property Rights
	Shadow Economy
Education	Secondary School Enrolment
	Quality of Educational System
	PISA scores
Health	Infant Survival Rate
	Life Expectancy
	CVD, cancer, diabetes or CRD Survival Rate
Public Infrastructure	Infrastructure Quality
Standard Musgravian Indicators	
Distribution	Gini Index
Stabilization	Coefficient of Variation of Growth
	Standard Deviation of Inflation
Economic Performance	GDP per Capita
	GDP Growth
	Unemployment

Source: authors' elaboration.

Our input measure, Public Expenditure (PE), is lagged one year and expressed as a percentage of GDP in several government expenditure areas. More specifically, we consider government consumption as input for administrative performance, government expenditure in education as input for education performance, health expenditure as input for health performance and public investment as input for infrastructure performance. For the distribution indicator, we consider expenditures on transfers and subsidies. The stability and economic performance are related to the total expenditure. Again, each sub-indicator is first normalized.

Table A1 and A2 in Appendix A provide further information on the sources and variable construction.

We adopt an input orientation and assume variable-returns to scale (VRS), to account for the fact that countries might not operate at the optimal scale. The input-oriented approach allows us to evaluate by how much input quantity can be proportionally reduced without changing the output quantities. Alternatively, an output-oriented approach allows us to assess how much output quantities can be proportionally increased without changing the input quantities. In this study, we use an input-oriented setup since the focus of our analysis relies on decreasing inputs (via decentralization).

Formally, efficiency scores are computed solving the following linear programming problem:

$$\begin{aligned} &\min_{\theta,\lambda} \theta \\ s.t.\ \ & -y_i + Y\lambda \geq 0 \\ &\theta x_i - X\lambda \geq 0 \\ &I1'\lambda = 1 \\ &\lambda \geq 0 \end{aligned} \tag{2}$$

where y_i is a vector of outputs, x_i is a vector of inputs, θ is the efficiency scores, λ is a vector of constants, $I1'$ is a vector of ones, X is the input matrix and Y is the output matrix.

The efficiency scores, θ, range from 0 to 1, such that countries performing in the frontier score 1. More specifically, if θ<1, the country is inside the production frontier (i.e., it is inefficient), and if θ=1, the country is at the frontier (i.e., it is efficient).

3.2. Shorter-term Local Projections

In this first part of the analysis, we look at the short to medium-term effects of fiscal decentralization on public sector efficiency. We apply the local projection (LP) method proposed by Jordà (2005) to derive impulse response functions (IRFs) in a panel setting. This approach estimates a sequence of regressions of the dependent variable (a proxy of public sector efficiency) shifted several periods ahead instead of a recursive use of the initial set of estimated coefficients. As a result, the LP technique does not constrain the shape of the IRFs and therefore become less sensitive to potential misspecification compared to conventional vector autoregressions (VAR) models (Auerbach and Gorodnichenko, 2013; Jordà and Taylor, 2016). This approach has also been advocated by Romer and Romer (2019) as a flexible alternative to VAR for estimation purposes while being on similar footing in terms of identification. Given our panel data setting, we adopt the LP method over commonly used VAR models for the following specific reasons. First, our fiscal decentralization shocks are orthogonal to contemporaneous and expected future macroeconomic conditions. For this reason, we do not need to further identify shocks using restrictions in VAR models. Second, our estimation entails a relatively large panel dataset with a constellation of fixed effects, which makes a direct application of standard VAR models more difficult.[3] In addition, the LP method obviates the need to estimate the equations for dependent variables other than the variable of interest, thereby significantly economizing on the number of estimated parameters. All else equal, in finite samples local projections tend to do better at estimating the shorter horizons of impulse responses, as it is our case with a time span up to 4 years, while VARs tend to do a better job at estimating the longer horizons of impulse responses. Third, the LP method is particularly suited to estimating nonlinearities (such as, in our context, the interactions between fiscal decentralization shocks and the occurrence of natural disasters—see below), as its application is much more straightforward compared to non-linear structural VAR models, such as Markov-switching or threshold-VAR models.[4] Moreover, it allows for incorporating various time-varying features of source (recipient) economies directly and allow for their endogenous response to fiscal decentralization shocks. In fact, LPs tend to be easier to implement relative to VARs when a specified nonlinearity would make the inversion of the VAR form into the VMA form difficult (Plagborg-Møller and Wolf, 2021). Lastly, the error term in the following panel estimations is likely to be correlated across countries. This correlation would be difficult to address in the context of VAR models, but it is easy to handle in the LP method by either clustering standard errors or using the Driscoll-Kraay (1998) standard errors allowing for arbitrary correlations of the errors across countries and time.

Against this background, we estimate the following baseline specification:

$$PSE_{t+k,i} - PSE_{t-1,i} = \alpha_i + \tau_t + \beta_k D_{i,t} + \theta X_{i,t} + \varepsilon_{i,t} \quad (3)$$

where PSE is a measure of public sector efficiency (cf. section 3.1 for the efficiency scores, θ); the coefficients α_i and τ_t are country and time fixed effects, respectively, accounting for

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[3] If one wishes to include fixed effects for a VAR in a panel environment that is possible. Often the easiest way is to simply demean each of the variables over time for each country before entering them into the VAR.

[4] See Choi et al. (2018) and Miyamoto et al. (2019) for the recent application of local projections to the estimation of nonlinearities and interaction effects of exogenous shocks using a large panel dataset.

cross-country heterogeneity and global shocks; β_k denotes the cumulative response of public sector efficiency in each k year after a decentralization shock; $D_{i,t}$ denotes the decentralization shock variable (see below) treated as exogenous. $X_{i,t}$ is a set a of control variables including up to two lags of the relevant dependent variable and two lags of real GDP growth.

This equation (3) is estimated for alternative input and output PSE proxies using Ordinary Least Squares (OLS) with standard errors clustered at the country level. IRFs are then obtained by plotting the estimated β_k for $k = 0,1,\ldots,4$ with 90 (68) percent confidence bands computed using the standard errors associated with the estimated coefficients β_k over a four-year period.[5] According to Sims and Zha (1999), "the conventional pointwise bands common in the literature should be supplemented with measures of shape uncertainty." Hence, for characterizing the likelihood shape, bands that correspond to a 68 percent posterior probability – or one standard deviation shock – provide a more precise estimate of the true probability.[6]

The decentralization variables are of two types, namely:

- Composition of tax revenue and expenditure across local and subnational governments. In this case, D includes two continuous variables defined as the share of sub government tax revenues to general government tax revenue (tax revenue decentralization) and the share of sub government expenditure over the share of general government expenditure (spending decentralization). Data are available from Lledó et al. (2022) and cover 86 OECD and non-OECD countries over the period 1970-2020.[7]
- Subnational authority in policy-making and fiscal–financial management. The composite index (aggregated authority index) includes several indicators related to changes in the assignment of policy-making authority and responsibilities across the different levels of administration, the executive and law-making prerogatives of the subnational governments, as well as inter-jurisdictional coordination mechanisms. Data are available from Shair-Rosenfield et al. (2021) Hooghe et al. (2016) and cover 95 countries over the period 1950–2018. Several individual indicators are also used to construct a composite indicator of self- and shared-rule. The self- and shared rule measure two broad aspects of subnational

[5] Another advantage of the LP method compared to vector autoregression (autoregressive distributed lag) specifications is that the computation of confidence bands does not require Monte Carlo simulations or asymptotic approximations. One limitation, however, is that confidence bands at longer horizons tend to be wider than those estimated in vector autoregression specifications.
[6] Other papers that have employed one standard deviation bands include Giordano et al. (2007), Romer and Romer (2010) and Bachmann and Sims (2012), among others.
[7] Data were collected from the IMF's Government Finance Statistics and World Economic Outlook databases, the World Bank's World Development Indicators, as well as Eurostat and OECD databases.

authority. The self-rule indicators are based on the policy, fiscal–financial and representation autonomy of the subnational governments within their own jurisdictional borders.[8] The shared-rule indicators measure the extent of joint prerogatives of subnational governments based on their capacity to influence national legislation and policy.[9]

Additionally, we also explore whether initial climate-related conditions at the time of the shock influence the effect of decentralization on public sector efficiency scores. The LP framework is especially useful in estimating nonlinear dynamic responses.[10] The augmented LP model takes the following form:

$$PSE_{i,t+k} - PSE_{i,t-1} = \alpha_i + \tau_t + \beta_k^L ND_{i,t} \times D_{i,t} + \beta_k^H (1 - ND_{i,t}) \times D_{i,t} + \theta X_{i,t} + \varepsilon_{i,t} \qquad (4)$$

in which $ND_{i,t}$ captures climate-related shocks as measured by the occurrence of weather-driven natural disasters by taking the value of 1 when a climate-related disaster occurs in a country in a given year and zero otherwise. The coefficients β_L^k and β_H^k capture the impact of the decentralization shocks at each horizon k in cases of natural disasters and in the absence of natural disasters, respectively. Large-scale natural disaster events featured in our analysis are country-wide shocks for two reasons: either because the shock itself is widespread or because economic relationships related to trade and/or market integration eventually propagate the shock throughout the country. This natural disaster data is retrieved from the Emergency Events Database (EM-DAT). The EM-DAT database, compiled by the Centre for Research on the Epidemiology of Disasters (CRED) at the Université Catholique de Louvain in Belgium, offers information on different categories of climate-induced events including droughts, extreme

[8] The self-rule indicators include the institutional autonomy (depth) of regional governments (measured on a 0–3 scale with increasing level of authority), their policy scope (or range of policies under regional government authority, measured on a 0–4 scale with increasing breadth of policy areas, including economic affairs, education and welfare, etc.), their fiscal autonomy (measured on a 0–4 scale of increasing regional autonomy to set tax bases and rates), and their borrowing autonomy (measured on a 0–3 scale of decreasing central government control over subnational borrowing), and their representation independence (measure on a 0–4 scale identifying the existence of an independent executive branch and a legislature at the subnational level).

[9] The shared-rule indicators include the ability of the subnational governments to influence national legislation (law-making, measured on a 0–2 scale of increasing level of law-making co-determination between subnational and national governments) and co-set national policy in intergovernmental fora (executive control, measured on a 0–2 scale of increasing ability), the distribution of national tax revenue (fiscal control, measured on a 0–2 scale of increasing ability), subnational and national borrowing constraints (borrowing control, measured on a 0–2 scale of increasing ability), and constitutional change (constitution reform, measured on a 0–4 scale of increasing ability).

[10] LPs have been widely adopted in the recent literature to analyze the nonlinear effects: for instance looking for nonlinear effects of monetary policy shocks (Jeenas, 2018); or nonlinear effects of fiscal policy shocks (Ramey and Zubairy, 2018; Romer and Romer, 2019).

temperatures, and storms.[11] The EM-DAT database defines droughts as "an extended period of unusually low precipitation that produces a shortage of water for people, animals and plants"; extreme temperatures as "a general term for temperature variations above (extreme heat) or below (extreme cold) normal conditions"; wildfires as any uncontrolled and non-prescribed combustion or burning of plants in a natural setting such as a forest, grassland, brush land or tundra, which consumes the natural fuels and spreads based on environmental conditions (e.g., wind, topography); landslides as any kind of moderate to rapid soil movement including lahar, mudslide, debris flow; and storms as meteorological events including extra-tropical, tropical and convective storms. The EM-DAT provides data on the occurrence and effects of over 22,000 large-scale natural disasters across the world from 1900 to the present day. The database is compiled from various sources, including UN agencies, non-governmental organizations, insurance companies, research institutes and press agencies. All other variables are as before.

Figure A.1, in Appendix A, shows the number of natural disasters by type. For our sample of 36 OECD countries between 2006 and 2019, there has been a larger prevalence of floods and storms than other categories of natural disasters. Note that these statistics have implications later on for the empirical analyses disaggregating by type of disaster.

3.3. Longer-term Panel Analysis

The effect of decentralization can be gauged by regressing the input efficiency score ($PSE_{i,t}$) on a set of variables capturing different aspects of decentralization. In particular, we run the following reduced-form panel regression:

$$PSE_{i,t} = \alpha_i + \delta_t + \beta \boldsymbol{D'}_{i,t} + \gamma \boldsymbol{X}'_{i,t-1} + \varepsilon_{i,t} \quad (5)$$

where $PSE_{i,t}$ is the input efficiency scores (cf. section 3.1 for the efficiency scores, θ); $\boldsymbol{D_{i,t}}$ is the decentralization variables (cf. section 3.2 for the decentralization variables); $\boldsymbol{X_{i,t}}$ is a vector of relevant drivers of public sector performance; α_i are country-fixed effects to capture unobserved heterogeneity across countries, and time-unvarying factors such as geographical variables which may affect the degree of public sector efficiency; δ_t are time effects to control

[11] The difference between extreme temperatures and droughts is that the former is the result of a short-lived meteorological hazard, while the latter is the result of a long-lived climatological hazard.

for global shocks; ε_{it} is an i.i.d. error term satisfying the usual assumptions of zero mean and constant variance. Countries and years are identified by subscripts i and t, respectively.

The vector $\boldsymbol{X}_{i,t}$ includes several determinants of public sector performance, lagged one year.[12] This vector includes the following variables: the logarithm of population and the age dependency ratio (as percentage of working-age population), included to control for the size of the social benefits, both variables retrieved from World Bank´s World Development Indicators; the debt-to-GDP ratio to control for the size of government retrieved from the IMF´s World Economic Outlook; a dummy variable equaling one for single-party majority government to control for political cohesion and government fragmentation retrieved from the Database of Political Institutions (Cruz et al., 2021).[13] We also include the government effectiveness and voice and accountability scores from the World Bank´s Governance Indicators.

To test the extent to which the existence of extreme natural disasters increases or decreases the role attributed to decentralization in affecting public sector efficiency at the central level, we estimate instead the following alternative specification:

$$PSE_{i,t} = \alpha_i + \delta_t + \beta_1 \boldsymbol{D'}_{i,t} + \beta_2 \boldsymbol{ND'}_{i,t} + \boldsymbol{\beta_3}[\boldsymbol{D'}_{i,t} \times \boldsymbol{ND'}_{i,t}] + \gamma \boldsymbol{X}'_{it-1} + \varepsilon_{it} \tag{6}$$

where everything is as before: $\boldsymbol{D}_{i,t}$ is the decentralization variables; $\boldsymbol{ND'}_{it}$ is climate-related shocks variables and $\boldsymbol{X}_{i,t}$ is the drivers of public sector performance.

4. Empirical Results

4.1. Government Efficiency: Stylized Facts

We performed DEA for different models regarding inputs and outputs: the baseline model (Model 0) includes only one input (PE as percentage of GDP) and one output (PSP); Model 1 uses two inputs, governments' normalized spending on opportunity and on "Musgravian" indicators and one output, total PSP scores; and Model 2 assumes one input,

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[12] Similar results are obtained using contemporaneous regressors instead (not shown, but available from the authors upon request).

[13] Summary statistics of these variables are provided in Table B.1 in Appendix B. Note that the ideology variable available in the Database of Political Institutions is often incorrect. For this reason the Comparative Political Data set was used which more accurately displays the nature of the ideological streams in power across countries and over time.

governments´ normalized total spending (PE) and two outputs, the opportunity PSP and the "Musgravian" PSP scores. Detailed results of public sector efficiency scores are available in the Appendix E. Table 2 provides a summary of the DEA results for the period 2006-2019 using input-oriented models.

The purpose of an input-oriented approach is to assess by how much input quantities can be proportionally reduced without changing the output quantities produced, which can be perceived as a more feasible policy-oriented prescription, if supported by the analysis. Alternatively, and by computing output-oriented measures, one can assess how much output quantities can be proportionally increased without changing the input quantities used.

The average input efficiency scores for our baseline model, Model 0, ranged between 0.58 to 0.68, suggesting that with the same level of outputs, inputs could decrease between 32% and 42%. For Models 1 and 2 the average scores ranged between 0.63 to 0.71 and between 0.61 and 0.69, respectively. Overall, the more efficient countries, those located in the production possibility frontier, for Model 0 were: Australia (2009-2011; 2013; 2019), Chile (2007-2016; 2019); Ireland (2015; 2019), New Zealand (2018), South Korea (2006-2018), and Switzerland (2006-2009; 2014-2016; 2019).

Table 2 – Summary of DEA input efficiency scores

		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Model 0	Efficient	2	3	3	4	3	3	2	3	3	4	3	1	2	3
	Name	CHE; KOR	CHE; CHL; KOR	CHE; CHL; KOR	AUS; CHE; CHL; KOR	AUS; CHL; KOR	AUS; CHL; KOR	CHL; KOR	AUS; CHL; KOR	CHE; CHL; KOR	CHE; CHL; IRL; KOR	CHE; CHL; KOR	KOR	KOR; NZL	AUS; CHL; IRL
	Average	0.61	0.60	0.59	0.61	0.58	0.58	0.58	0.58	0.63	0.63	0.65	0.65	0.68	0.66
	Median	0.57	0.56	0.55	0.56	0.53	0.53	0.53	0.54	0.59	0.60	0.62	0.63	0.64	0.64
	Min	0.44	0.43	0.41	0.44	0.41	0.40	0.39	0.39	0.42	0.42	0.46	0.45	0.48	0.47
	Max	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Stdev	0.15	0.15	0.15	0.16	0.16	0.16	0.16	0.16	0.15	0.16	0.15	0.14	0.15	0.14
Model 1	Efficient	2	3	3	4	3	3	3	3	4	4	4	2	4	3
	Name	CHE; KOR	CHE; CHL; KOR	CHE; CHL; KOR	AUS; CHE; CHL; KOR	AUS; CHL; KOR	AUS; CHL; KOR	AUS; CHL; KOR	AUS; CHL; KOR	CHE; CHL; KOR; USA	CHE; CHL; IRL; KOR	CHE; CHL; IRL; KOR	CHL; KOR	CHL; IRL; KOR; NZL	AUS; CHL; IRL
	Average	0.65	0.64	0.63	0.67	0.66	0.65	0.65	0.65	0.70	0.71	0.71	0.69	0.71	0.71
	Median	0.63	0.60	0.58	0.62	0.60	0.61	0.62	0.64	0.67	0.70	0.70	0.69	0.69	0.69
	Min	0.50	0.48	0.47	0.53	0.51	0.49	0.48	0.48	0.50	0.52	0.52	0.46	0.48	0.48
	Max	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Stdev	0.14	0.14	0.13	0.14	0.14	0.14	0.14	0.14	0.14	0.13	0.13	0.13	0.14	0.13
Model 2	Efficient	3	3	3	4	4	4	3	4	3	4	4	2	4	5
	Name	CHE; ESP; KOR	CHE; CHL; KOR	CHE; CHL; KOR	AUS; CHE; CHL; KOR	AUS; CHE; CHL; KOR	AUS; CHE; CHL; KOR	AUS; CHE; CHL	AUS; CHE; CHL; KOR	CHE; CHL; KOR	CHE; CHL; IRL; KOR	CHE; CHL; IRL; KOR	CHE; KOR	CHE; IRL; KOR; NZL	AUS; CHE; CHL; DNK; IRL
	Average	0.66	0.63	0.63	0.64	0.61	0.62	0.63	0.64	0.66	0.67	0.68	0.69	0.69	0.69
	Median	0.64	0.60	0.59	0.59	0.56	0.57	0.59	0.60	0.64	0.67	0.68	0.67	0.65	0.64
	Min	0.46	0.44	0.47	0.48	0.47	0.46	0.46	0.44	0.46	0.50	0.51	0.50	0.48	0.48
	Max	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Stdev	0.15	0.15	0.14	0.15	0.16	0.16	0.15	0.16	0.15	0.15	0.14	0.14	0.15	0.16

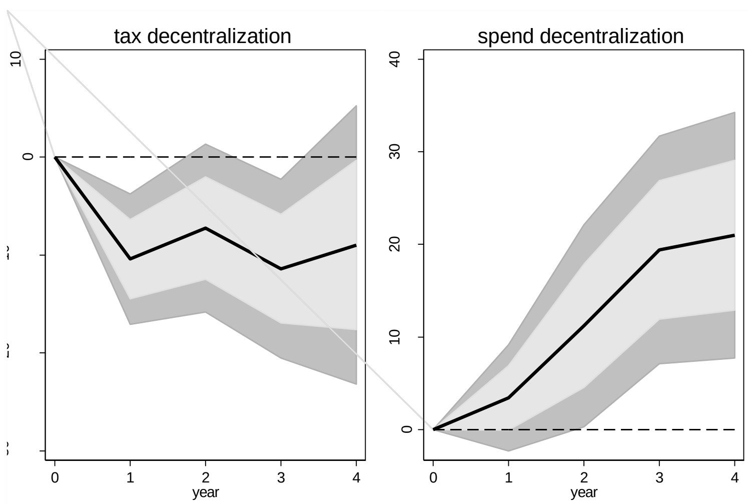
Note: Summary of the DEA results for the periods 2006-2019 using input-oriented models. Model 0 uses one input, government' normalized total spending and one output, the total PSP. Model 1 uses two inputs, governments' normalized spending on opportunity and on "Musgravian" indicators and one output, total PSP. Model 2 assumes one input, government' normalized total spending and two outputs, the opportunity PSP and the "Musgravian" PSP scores. The results obtained from the three models are illustrated on Tables E.1, E.2. and E.3 of the online Appendix E.

4.2. Effects of Fiscal Decentralization on Government Efficiency

4.2.1. Local Projections

The starting point of our analysis is the estimation of the baseline equation for the entire sample spanning the period 2006-2019 that will underpin the computation of the IRFs. The estimated coefficient for the fiscal decentralization shocks to efficiency scores are scaled by multiplying the obtained coefficient estimate by the one standard deviation of the respective fiscal decentralization indicator to provide a scale in the IRFs and a more direct interpretation. The impulse responses can then be interpreted as indicating the effect of a one standard deviation increase in efficiency in year 0 on the (percent) level of efficiency over a period of 4 years (in cumulative terms).

Figure 1 – Baseline Effects of Fiscal Decentralization on Public Sector Efficiency



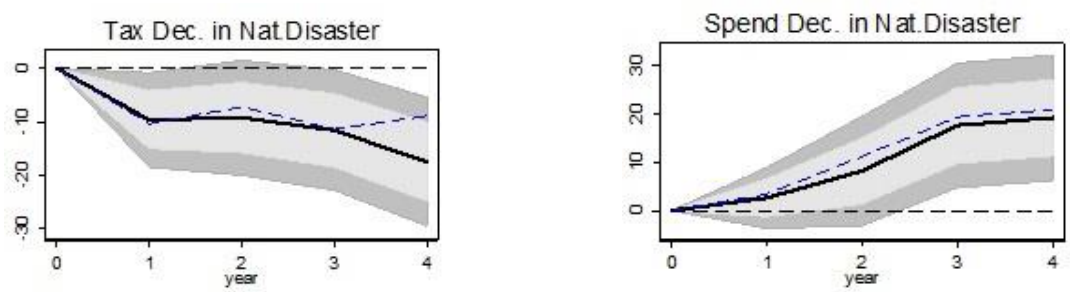
Note: Impulse response functions are estimated using a sample of 36 OECD member countries between the period of 2006 and 2019. The graph shows the response on PSE_0 input score and both the 90 and 68 percent confidence bands. The x-axis shows years (k) after fiscal decentralization shocks; t = 0 is the year of the fiscal decentralization shock. Estimates based on equation (3). Standard errors in parentheses are clustered at the country level.

Figure 1 shows the results of estimating equation (3) for PSE_0 (Model 0) using alternative decentralization variables. Both the 90 and 68 percent confidence bands are shown together with the response. Efficiency drops more than 10 percent in the first year after the tax decentralization shock, it then recovers slightly, but ends up reaching a cumulative of -12 percent after 3 years, meaning that the tax revenue decentralization impact is non-negligible and long-lasting.

Conversely, efficiency seems to rise following a spending decentralization shock. This effect is more precisely estimated than the tax decentralization as the horizon progresses. Efficiency rises by 10 percent in the first year and continues to rise in the medium term (reaching over 20 percent 4 years after the shock).

Next, we focus on the non-linear specification described by equation (4). Results in Figure 2 suggest that the response of efficiency to decentralization shocks does not vary much with the occurrence of natural disasters compared with the baseline unconditional result.

Figure 2 – Nonlinear-Effects of Fiscal Decentralization on Public Sector Efficiency, conditioned on the occurrence of natural disasters



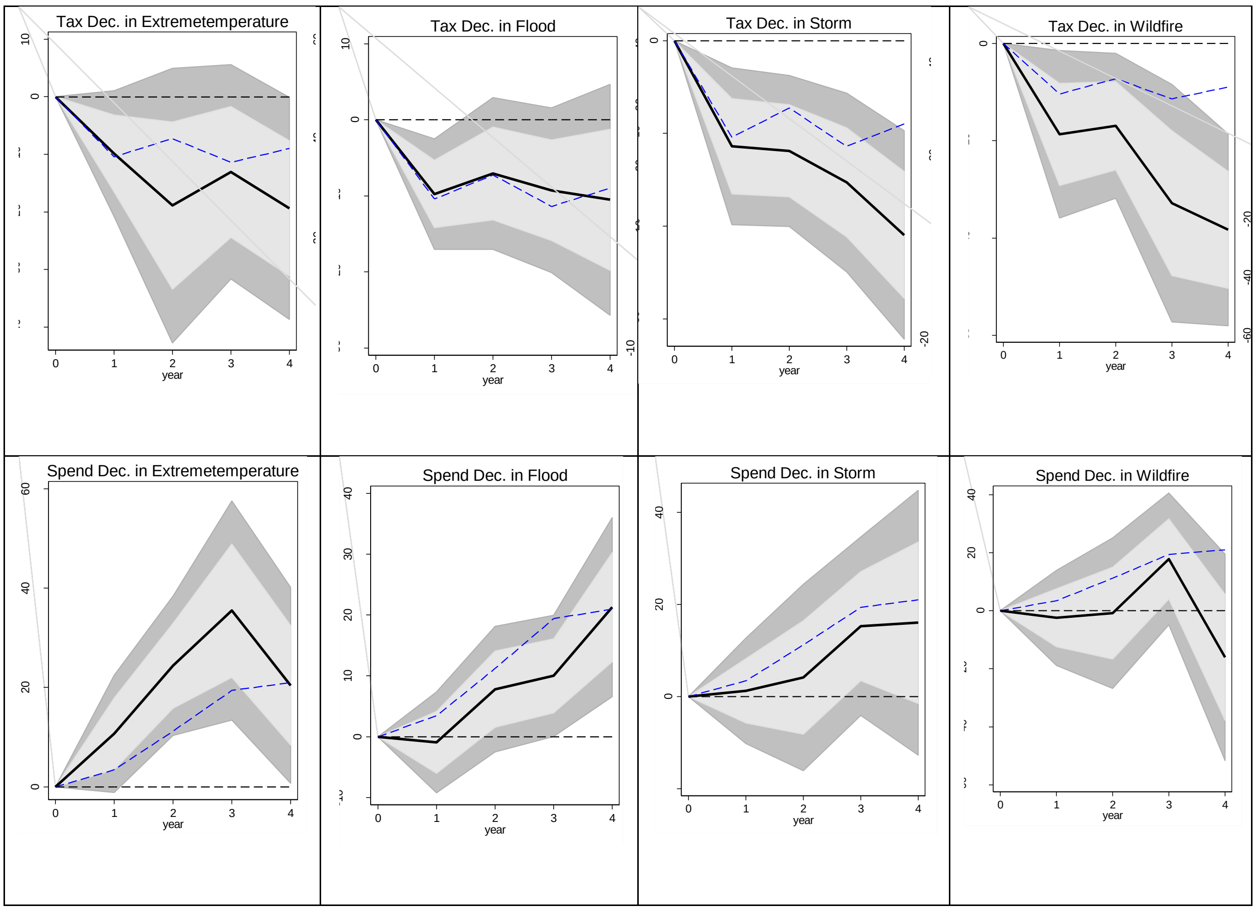
Note: Impulse response functions are estimated using a sample 36 OECD member countries between the period of 2006 and 2019. The graph shows the response on PSE_0 input score and both the 90 and 68 percent confidence bands. The x-axis shows years (k) after fiscal decentralization shocks; t = 0 is the year of the fiscal decentralization shock. Estimates based on equation (3). Baseline unconditional response depicted in dashed blue. Standard errors in parentheses are clustered at the country level.

However, the exact category of natural disasters matters. Figure 3 shows similar results to those presented in Figure 2, but they should be interpreted with care due to the limited degrees of freedom in estimating the IRFs (cf. Appendix Figure A.1)[14]. We can observe some highlights as follows. After extreme temperature disasters, the degree of improvement in public sector efficiency after a spending decentralization shock is larger than in their absence, suggesting that a more regional discretionary response of spending is warranted and fruitful. Nonetheless, for most types of natural disasters (floods, storms, and wildfires), the degree of improvement in public sector efficiency after a spending decentralization shock is smaller than in their absence. On the other hand, and following wildfires and storm disasters, the degree of deterioration in public sector

[14] For this reason, we dropped droughts and landslides from the analysis.

efficiency after a tax decentralization shock is larger (in absolute value) than in their absence. All this suggests, again, that tax and spending decentralization hampers efficiency when such events take place, supporting the relevance of some more national use of fiscal measures.

Figure 3 – Nonlinear-Effects of Fiscal Decentralization on Public Sector Efficiency, conditioned on the occurrence of natural disasters, by category



Note: Impulse response functions are estimated using a sample 36 OECD member countries between the period of 2006 and 2019. The graph shows the response on PSE_0 input score and both the 90 and 68 percent confidence bands. The x-axis shows years (k) after fiscal decentralization shocks; t = 0 is the year of the fiscal decentralization shock. Estimates based on equation (3). Baseline unconditional response depicted in dashed blue. Standard errors in parentheses are clustered at the country level.

4.2.2. Panel

4.2.2.1. The effect of decentralization

In this section, we assess the standalone (unconditional) link between the decentralization and input spending efficiency for Model 0 (Columns (1)-(3)), Model 1 (Columns (4)-(6)) and Model 2 (Columns (7)-(9)).[15] For decentralization, we consider three variables: tax revenue decentralization and expenditure decentralization (Columns (1), (4), (7)) and regional authority index (Columns (2), (5), (8)). The results reported in Table 3 confirm the local projections evidence and show that tax revenue decentralization is negatively related to public sector efficiency while spending decentralization and regional authority index are positively related to higher government efficiency. This baseline result holds for all input efficiency scores, except for spending decentralization in Model 2. Then, we divide the regional authority index into two domains: self-rule and shared rule (Columns (3), (6), (9)). We find a positive effect of self-rule and negative effect of shared rule in government efficiency.

Table 3. Baseline regression on input efficiency scores

Dependent Variable	PSE_0			PSE_1			PSE_2		
Specification	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Tax dec.	-0.671***			-0.791***			-0.836***		
	(0.152)			(0.200)			(0.177)		
Spend dec.	0.231**			0.242*			0.173		
	(0.109)			(0.132)			(0.111)		
Regional authority index		0.020***			0.018***			0.020***	
		(0.006)			(0.005)			(0.006)	
Self-rule			0.021***			0.019***			0.021***
			(0.006)			(0.005)			(0.006)
Shared rule			-0.032			-0.045***			-0.021**
			(0.028)			(0.016)			(0.010)
Country effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	295	432	432	295	432	432	295	432	432
R-squared	0.884	0.876	0.877	0.856	0.834	0.836	0.909	0.880	0.881

Note: The models include country and year fixed effects. Constant term included but omitted. Standard errors in parenthesis. The symbols *, **, and *** denote significance levels at 10%, 5%, and 1%, respectively.

[15] Recall that Model 0 (baseline model) includes one input, governments' normalized spending, and one output, total PSP scores, Model 1 includes two inputs and one output, and Model 2 includes one input and two outputs.

As a next step, we estimate the initial specification augmented with a set of control variables, notably: logarithm of population, age dependency ratio, debt-to-GDP, majority government, government effectiveness index and voice and accountability. Table 4 reports the new set of results again for alternative dependent variables. We continue to find a negative effect of tax revenue decentralization and positive effect of spending decentralization and regional authority index on government efficiency. In terms of regional authority domains, we find a positive effect of self-rule and negative effect of shared rule in government efficiency, although not statistically significant in Model 0.

Regarding the control variables, we find that countries with larger population and larger voice and accountability are associated with lower government performance. On the other hand, countries characterized by governments with higher effectiveness index exhibit better performance. In addition, no statistically significant result is available for the age dependency ratio, and government indebtedness.

Table 4. Regression on input efficiency scores conditioning for additional controls

Dependent Variable	PSE_0			PSE_1			PSE_2		
Specification	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Tax dec.	-0.643***			-0.812***			-0.827***		
	(0.153)			(0.200)			(0.184)		
Spend dec.	0.369***			0.334**			0.322***		
	(0.133)			(0.150)			(0.118)		
Regional authority index		0.022***			0.019***			0.021***	
		(0.006)			(0.006)			(0.006)	
Self-rule			0.023***			0.020***			0.022***
			(0.006)			(0.006)			(0.006)
Shared rule			-0.035			-0.038***			-0.020*
			(0.025)			(0.013)			(0.011)
L(Population) (t-1)	-0.229	-0.333**	-0.364**	-0.073	-0.263	-0.294*	-0.210	-0.296*	-0.318*
	(0.198)	(0.168)	(0.171)	(0.189)	(0.169)	(0.172)	(0.182)	(0.164)	(0.166)
Age dependency ratio (t-1)	-0.148	-0.075	-0.104	-0.169	-0.042	-0.071	-0.247	-0.057	-0.079
	(0.248)	(0.182)	(0.183)	(0.242)	(0.182)	(0.182)	(0.239)	(0.195)	(0.194)
Debt-to-GDP ratio (t-1)	-0.047	-0.040	-0.047*	-0.014	0.018	0.012	-0.044	-0.032	-0.036
	(0.033)	(0.027)	(0.027)	(0.036)	(0.029)	(0.029)	(0.032)	(0.028)	(0.028)
Majority (t-1)	0.050**	0.012	0.011	0.061***	0.010	0.009	0.036**	0.002	0.001
	(0.020)	(0.014)	(0.014)	(0.019)	(0.014)	(0.014)	(0.018)	(0.013)	(0.013)
Government effectiveness (t-1)	0.009	0.052**	0.047**	0.029	0.076***	0.071***	0.032	0.077***	0.073***
	(0.029)	(0.023)	(0.023)	(0.030)	(0.024)	(0.024)	(0.025)	(0.023)	(0.023)
Voice and accountability (t-1)	-0.026	-0.086***	-0.081**	0.036	-0.088**	-0.083**	-0.046	-0.100***	-0.096***
	(0.036)	(0.032)	(0.032)	(0.042)	(0.037)	(0.037)	(0.031)	(0.032)	(0.032)
Country effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	295	432	432	295	432	432	295	432	432
R-squared	0.884	0.876	0.877	0.856	0.834	0.836	0.909	0.880	0.881

Note: The models include country and year fixed effects. Constant term included but omitted. Standard errors in parenthesis. The symbols *, **, and *** denote significance levels at 10%, 5%, and 1%, respectively.

4.2.2.2. The effect of natural disasters

To evaluate how natural disasters affect the relationship between tax and spending decentralization and public sector efficiency, we estimate equation (5) using as dependent variable PSE_0 (our baseline model). The estimates are reported in Table 5. The control variables are included and not reported.

We continue to find a negative effect for tax revenue decentralization and a positive effect for spending decentralization and regional authority index on input efficiency scores. The coefficient associated with the interaction variable between tax decentralization and natural disasters, spending decentralization and natural disasters and regional authority index and natural disasters are negative. The interaction effect between tax centralization and natural disasters loses statistical significance in column (3), when we are considering together both the effects of tax and spending decentralization together. Notice that the number of observations reduces significantly from column (1) to (3). To sum up, these results suggest that in cases of extreme natural disasters, tax and spending decentralization reduce government efficiency.

Table 5. Regression on input efficiency scores adding interaction with natural disasters

Dependent Variable	PSE_0			
Specification	(1)	(2)	(3)	(4)
Tax decentralization	-0.481***		-0.586***	
	(0.184)		(0.205)	
Spend dec.		0.433***	0.428**	
		(0.162)	(0.177)	
Natural disasters	0.025	0.063***	0.058***	0.018
	(0.016)	(0.021)	(0.021)	(0.011)
Tax dec. x Nat. disasters	-0.162**		-0.070	
	(0.072)		(0.084)	
Spend dec. x Nat disasters		-0.222***	-0.164*	
		(0.070)	(0.088)	
Regional authority index				0.022***
				(0.006)
Regional authority index x Nat. disasters				-0.001**
				(0.001)
Country effects	Yes	Yes	Yes	Yes
Time effects	Yes	Yes	Yes	Yes
Control variables	Yes	Yes	Yes	Yes
Observations	433	284	284	407
R-squared	0.866	0.892	0.895	0.879

Note: The models include country and year fixed effects. Constant term and control variables included but omitted. Standard errors in parenthesis. The symbols *, **, and *** denote significance levels at 10%, 5%, and 1%, respectively.

Next, we disaggregate the natural disaster indicator into six dummy variables, more specifically drought, extreme temperature, flood, landslides, storm, and wildfire. The results are presented in Tables 6 and 7, separately for tax decentralization and spending decentralization. We continue to find a negative effect of tax decentralization and a positive effect for spending decentralization on input efficiency scores. Additionally, we find that the negative effect of tax decentralization and natural disasters is mainly driven by storms events and the negative effect of spending decentralization and natural disasters is mainly driven by extreme temperature. In case of landslides, tax and spending decentralization improve public sector efficiency.

Table 6. Regression on input efficiency scores adding interaction of tax decentralization and natural disasters by category

	PSE_0					
	(1)	(2)	(3)	(4)	(5)	(6)
Tax dec.	-0.618***	-0.599***	-0.615***	-0.613***	-0.581***	-0.593***
	(0.175)	(0.177)	(0.170)	(0.173)	(0.185)	(0.175)
Drought	-0.035					
	(0.043)					
Tax dec. x Drought	0.073					
	(0.118)					
Extreme temperature		0.000				
		(0.010)				
Tax dec. x Extreme temperature		-0.007				
		(0.040)				
Flood			-0.003			
			(0.015)			
Tax dec. x Flood			0.046			
			(0.055)			
Landslides				-0.043***		
				(0.015)		
Tax dec. x Landslides				0.181*		
				(0.095)		
Storm					0.019	
					(0.016)	
Tax dec. x Storm					-0.107*	
					(0.057)	
Wildfire						0.016
						(0.017)
Tax dec. x Wildfire						-0.061
						(0.044)
Country effects	Yes	Yes	Yes	Yes	Yes	Yes
Time effects	Yes	Yes	Yes	Yes	Yes	Yes
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Observations	433	433	433	433	433	433
R-squared	0.864	0.864	0.864	0.865	0.866	0.864

Note: The models include country and year fixed effects. Constant term and control variables included but omitted. Standard errors in parenthesis. The symbols *, **, and *** denote significance levels at 10%, 5%, and 1%, respectively.

Table 7. Regression on input efficiency scores adding interaction of spending decentralization and natural disasters by category

	PSE_0					
	(1)	(2)	(3)	(4)	(5)	(6)
Spend dec.	0.314**	0.322**	0.316**	0.285**	0.290**	0.303**
	(0.127)	(0.131)	(0.124)	(0.126)	(0.136)	(0.128)
Drought	-0.105*					
	(0.053)					
Spend dec. x Drought	0.210					
	(0.171)					
Extreme temperature		0.032				
		(0.021)				
Spend dec. x Extreme Temperature		-0.109*				
		(0.065)				
Flood			0.021			
			(0.024)			
Spend dec. x Flood			-0.011			
			(0.072)			
Landslides				-0.055***		
				(0.021)		
Spend dec. x Landslides				0.159*		
				(0.089)		
Storm					0.018	
					(0.026)	
Spend dec. x Storm					-0.085	
					(0.075)	
Wildfire						0.015
						(0.016)
Spend dec. x Wildfire						-0.026
						(0.055)
Country effects	Yes	Yes	Yes	Yes	Yes	Yes
Time effects	Yes	Yes	Yes	Yes	Yes	Yes
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Observations	284	284	284	284	284	284
R-squared	0.889	0.889	0.889	0.889	0.890	0.888

Note: The models include country and year fixed effects. Constant term and control variables included but omitted. Standard errors in parenthesis. The symbols *, **, and *** denote significance levels at 10%, 5%, and 1%, respectively.

4.2.3. Robustness Checks

We have carried out a several robustness checks for both the local projection and panel data analysis.

Starting with the former, a possible bias from estimating equation (3) using country-fixed effects is that the error term may have a non-zero expected value, due to the interaction of fixed effects and country-specific developments (Tuelings and Zubanov, 2014). This would lead to a bias of the estimates that is a function of the horizon k. To address this issue, equation (3) was re-estimated by excluding country fixed effects from the analysis. Results suggest that this bias is negligible (See Figure C.1 panel (a) of Appendix C).

To try and estimate the causal impact of tax and spending decentralization shocks on public sector efficiency outcomes, it is important to control for previous trends in dynamics of such variables. Our baseline specification attempts to do this by controlling for up to two lags in the dependent variable.[16] To further mitigate this concern, we re-estimate equation (3) by including country-specific time trends as additional control variables. Our results in Figure C.1 panel (b) of Appendix C keep the main thrust of our previous findings.

Another possible concern regarding the analysis is that the results may suffer from omitted variable bias. To address this issue, we control for the same list of covariates entering the panel analysis, namely population, debt, age dependency ratio, government effectiveness and voice and accountability. Figure C.1 panel (c) of Appendix C shows that the results are in line with those presented in Figure 1 but in general both the magnitude and the statistical significance are smaller.

Finally, to mitigate cross-sectional dependency concerns, we re-estimated equation (3) with a Driscoll-Kraay (1998) robust standard errors. This non-parametric technique assumes the error structure to be heteroskedastic, autocorrelated up to some lag and possibly correlated between the groups. Results displayed in Figure C.1 panel (d) of Appendix C, are qualitatively similar suggesting cross-sectional dependence is not a major issue in our setting.

Our robustness exercises concerning the panel analysis consists in running equation (5) considering alternative variables for public sector performance and using an alternative estimation approach. We use alternative dependent variables, namely output efficiency scores (cf. section 3.1

[16] Similar results are obtained when using alternative lag parametrizations. Results for zero, one and three lags (available at request) confirm that previous findings are not sensitive to the choice of the number of lags.

for the efficiency scores). As the output efficiency scores are higher or equal to 1 and to easily interpret the results, we applied the following transformation $PSE_{i,t} = \frac{1}{\theta_{i,t}}$. The conditional results are reported in Table C.2 and support our baseline results in Table 4. We continue to find a negative effect of tax decentralization and a positive effect of spending decentralization (except for Model 2, where the coefficients lose statistical significance) and regional authority index (for all models) on efficiency. Again, the positive effect of regional authority on public sector efficiency is driven by the self-rule domain. Although we find a negative effect of share rule in the output regressions, the coefficients are not statistically significant. Including the interaction effects between decentralization and natural disasters does not change our main results. In fact, we continue to find that in cases of extreme natural disasters, tax and spending decentralization and regional authority index reduce government efficiency (see Table C.3 of Appendix C). Our results are similar when we consider alternative models (results available by request).

Another possible concern regarding the two-stage estimation procedure used in our panel data analysis is the lack of theory underlying data-generating process and that the model ignores that estimated DEA efficiency scores are calculated from a common sample of data. Because of these problems related to invalid inference due to serial correlation, we use an alternative Simar Wilson (2007) estimation approach. The results are shown in Tables C.4 and C.5 and remain similar to the baseline estimations.

5. Conclusion and Policy Implications

In this paper we have empirically linked the efficiency of the public sector, proxied by efficiency scores, to government tax revenue and expenditure decentralization, for sample covering 36 OECD countries between 2006 and 2019.

First, we have computed government spending efficiency scores via data envelopment analysis (DEA). Second, relying on panel data and impulse response approaches, we estimate the effect of tax and spending decentralization on public sector efficiency. Our results show that tax revenue decentralization is negatively related to public sector efficiency, while spending decentralization and regional authority index are positively related to higher public sector efficiency. For instance, efficiency rises by 10 percent in the first year, following a spending decentralization shock (reaching over 20 percent 4 years after the shock). These results hold true for both input-oriented and output-oriented efficiency scores and considering different models. Nonetheless, in cases of natural disasters spending decentralization reduces public sector efficiency and tax decentralization deteriorates even further public sector efficiency. These results suggest that sub-national discretionary spending and tax revenues responses might be less fruitful when these extreme events occur. Importantly, the exact category of natural disasters matters. For instance, the negative effect of tax decentralization and natural disasters on public sector efficiency is mainly driven by storms events and the negative effect of spending decentralization and natural disasters is mainly driven by extreme temperature.

Therefore, it seems relevant to highlight one main key message with clear policy implications: measures to decentralize government spending for the sub-national government levels promote public sector efficiency, notably due to better proximity to economic agents and the population, implying better preference matching and stronger accountability. The opposite holds for the running of the tax system, where efficiency gains are more likely centralized due to technical issues and scale economies, and also some possible obstructions to the Musgravian redistribution function of the government.

Nevertheless, in cases of natural disasters, a more centralized response is needed to improve public sector performance and efficiency. Indeed, in the presence of most extreme natural disasters, the improvement in public sector efficiency after a spending decentralization shock is smaller than in their absence.

References

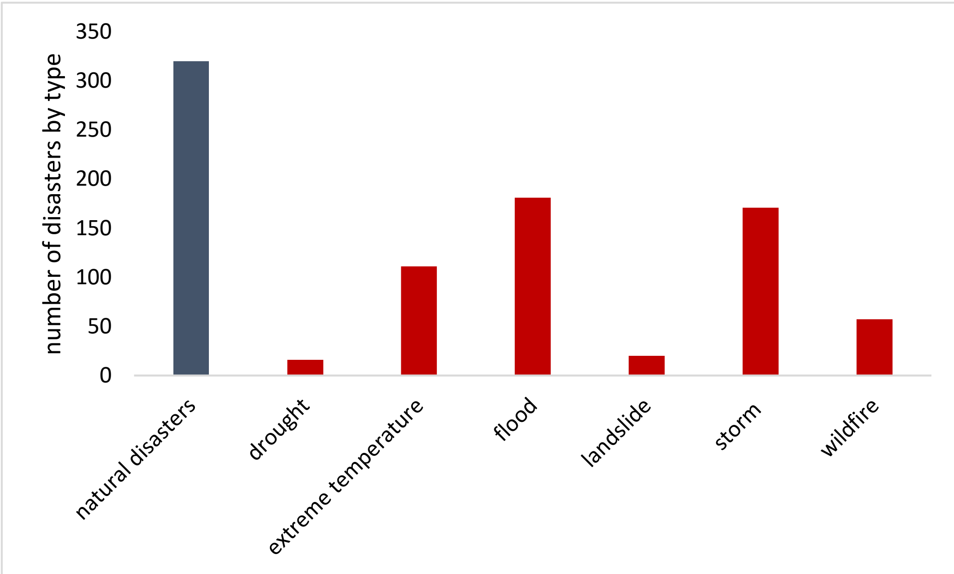
1. Adam, A., Delis, M., Kammas, P. (2011). “Public sector efficiency: levelling the playing field between OECD countries”, **Public Choice**, 146 (1-2), 163–183.
2. Afonso, A., Jalles, J., Venâncio, A. (2021b). “Structural tax reforms and public spending efficiency”, **Open Economies Review**, 32, 1017–1061.
3. Afonso, A., Jalles, J., Venâncio, A. (2021a). “Taxation and Public Spending Efficiency: An International Comparison”, **Comparative Economic Studies**, 63 (3), 356-383.
4. Afonso, A., Jalles, J., Venâncio, A. (2022). “Do Financial Markets Reward Government Spending Efficiency?”, **Journal of International Financial Markets, Institutions and& Money**, 77, 101505.
5. Afonso, A., Jalles., Venâncio, A. (2023b). “Government Spending Efficiency, Measurement and Applications: a Cross-country Efficiency Dataset”, in Afonso, A., Jalles, J. and Venâncio. A. (eds.), ***Handbook on Public Sector Efficiency,*** Edward Elgar Publishing.
6. Afonso, A., Kazemi, M. (2017). “Assessing Public Spending Efficiency in 20 OECD Countries”, in *Inequality and Finance in Macrodynamics (Dynamic Modeling and Econometrics in Economics and Finance)*, Bökemeier, B., Greiner, A. (Eds). Springer.
7. Afonso, A., Romero, A., Monsalve, E. (2013). “Public Sector Efficiency: Evidence for Latin America”. IADB Discussion Paper IDB-DP-279.
8. Afonso, A., Schuknecht, L., Tanzi, V. (2005). “Public Sector Efficiency: An International Comparison”, **Public Choice**, 123 (3-4), 321-347.
9. Afonso, A., Schuknecht, L., Tanzi, V. (2010). “Public Sector Efficiency: Evidence for New EU Member States and Emerging Markets”, **Applied Economics**, 42 (17), 2147-2164.
10. Afonso, A., Schuknecht, L., Tanzi, V. (2023a). “The size of government”, in Afonso, A., Jalles, J., Venâncio, A. (eds), *Handbook on Public Sector Efficiency*, Edward Elgar Publishing.
11. Afonso, A., St. Aubyn, M. (2006). “Cross-country Efficiency of Secondary Education Provision: a Semi-parametric Analysis with Non-discretionary Inputs”, **Economic Modelling**, 2006, 22 (3), 476-491.
12. Afonso, A., St. Aubyn, M. (2011). “Assessing health efficiency across countries with a two-step and bootstrap analysis”, **Applied Economics Letters**, 18 (15), 1427-1430.
13. Antonelli, M., de Bonis, V. (2019). “The efficiency of social public expenditure in European countries: a two-stage analysis”, **Applied Economics**, forthcoming.
14. Auerbach, A., and Gorodnichenko. Y. (2013). “Fiscal Multipliers in Recession and Expansion” in Fiscal Policy after the Financial Crisis, Alberto Alesina and Francesco Giavazzi, eds., University of Chicago Press.
15. Bachmann, R., and E.R. Sims (2012). “Confidence and the Transmission of Government Spending Shocks”, **Journal of Monetary Economics**, 59(3), 235–49
16. Balaguer-Coll, M.T., Prior, D., & Tortosa-Ausina, E. (2010). “Decentralization and efficiency of local government. **The Annals of Regional Science**, 45, 571–601.
17. Charnes, A., Cooper, W., Rhodes, E. (1978). “Measuring the efficiency of decision makingdecision-making units”, **European Journal of Operational Research**, 2, 429–444.
18. Choi, S., Furceri, D., Loungani, P., Mishra, S., Poplawski-Ribeiro, M. (2018), “Oil prices and inflation dynamics: evidence from advanced and developing economies”, **Journal of International Money and Finance**, 82, 71-96.

19. Coelli T., Rao, D., Battese, G. (2002). "An Introduction to Efficiency and Productivity Analysis", 6th edition, Massachusetts, Kluwer Academic Publishers.
20. Cruz C, Keefer P, Scartascini C (2021), "Database of Political Institutions 2021 (DPI2021)". Inter- American Development Bank.
21. Cruz, Cesi, Keefer, Philip, and Carlos Scartascini (2021). "The Database of Political Institutions 2020". Inter-American Development Bank.
22. Driscoll, J. and Kraay, A. (1998). "Consistent Covariance Matrix Estimation with Spatially Dependent Panel Data." **Review of Economics and Statistics**, 80(4), 549-560.
23. Dutu, R., Sicari, P. (2016). "Public Spending Efficiency in the OECD: Benchmarking Health Care, Education and General Administration", OECD Economics Department Working Papers 1278.
24. Farrell, M. (1957). "The Measurement of Productive Efficiency", **Journal of the Royal Statistical Society Series A** (General), 120, 253-281.
25. Giordano, R., S. Momigliano, S. Neri, and R. Perotti. (2007). 'The Effects of Fiscal Policy in Italy: Evidence from a VAR Model'. **European Journal of Political Economy**, 23(3), 707–33
26. Gupta, S., Verhoeven, M. (2001). "The efficiency of government expenditure—experiences from Africa." **Journal of Policy Modelling** 23, 433-467.
27. Gonzalez-Alegre, J. (2010) "*Decentralization and the Composition of Public Expenditure in Spain*", *Regional Studies*, 44 (8), 1067-1083.
28. Gutiérrez-Arango, L., Giménez, V., Osorio-Barreto, D., Prior, D. (2023). "Efficiency and economic growth: A panel analysis of Colombian regions", in Afonso, A., Jalles, J., Venâncio, A. (eds), *Handbook on Public Sector Efficiency*, Edward Elgar Publishing.
29. Hauner, D., Kyobe, A. (2008). "Determinants of Government Efficiency", IMF WP/08/228.
30. Herrera, S., Ouedraogo, A. (2018). Efficiency of Public Spending in Education, Health, and Infrastructure: An International Benchmarking Exercise, World Bank Policy Research Working Paper 8586.
31. Hooghe, Liesbet, Gary Marks, Arjan H. Schakel, Sandra Chapman Osterkatz, Sara Niedzwiecki, Sarah Shair-Rosenfield (2016). Measuring Regional Authority. Oxford: Oxford University Press, xiv+ 687pp.
32. Jordà, O. (2005). "Estimation and inference of impulse responses by local projections." **American Economic Review**, 95, 161–182.
33. Lledó, Victor, William Gbohoui, Clement Ncuti (2022). The IMF Fiscal Decentralization Dataset.
34. Miyamoto, W., Nguyen, T., Rey, H. (2018), "US monetary policy and the Global Financial Cycle" NBER WP No. 21722, Cambridge MA, USA
35. Mohanty, R., Bhanumurthy, N., Sahoo, B. (2023). "Analysing public sector efficiency of the Indian States", in Afonso, A., Jalles, J., Venâncio, A. (eds), *Handbook on Public Sector Efficiency*, Edward Elgar Publishing.
36. Musgrave, R. (1969) "*Theories of Fiscal Federalism*", *Public Finance*, 24(4), 521–32.
37. Oates, W. (1999). "An essay on fiscal federalism", **Journal of Economic Literature**, 37, 1120-1149.
38. OECD (2003). "Fiscal relations across levels of government", OECD Economic Outlook 74, December, 143-160.

39. Olanubi, S., Olanubi, O. (2023), “Political short termism and government spending efficiency in Sub-Saharan Africa“, in Afonso, A., Jalles, J., Venâncio, A. (eds), *Handbook on Public Sector Efficiency*, Edward Elgar Publishing.
40. Plagborg-Møller, M. Wolf, C. (2021). “Local Projections and VARs Estimate the Same Impulse Responses”. **Econometrica**. 89. 955-980.
41. Romer, C. D., and D.H. Romer (2010). ‘The Macroeconomic Effects of Tax Changes: Estimates Based on a New Measure of Fiscal Shocks’. **American Economic Review**, 100(3), 763–801.
42. Shah, A. (2006). “Fiscal Decentralization and Macroeconomic Management”, *International Tax and Public and Public Finance*, 13, 437-462.
43. Shair-Rosenfield, Sarah, Arjan H. Schakel, Sara Niedzwiecki, Gary Marks, Liesbet Hooghe, Sandra Chapman-Osterkatz (2021). Language difference and regional authority. **Regional and Federal Studies**, 31(1): 73-97.
44. Simar, L., Wilson, P., (2007). “Estimation and Inference in Two-Stage, Semi-Parametric Models of Production Processes”. **Journal of Econometrics**, 136 (1), 31-64.
45. Sims, C. A., and T. Zha. (1999). “Error Bands for Impulse Responses,” **Econometrica**, 67 (5), 1113–1156.
46. Song, Y., Ren, X., Yang, G. Guan, Z.-C. (2023), “Estimating returns to scale for the science and technology activities of Project 985 universities in China”, in Afonso, A., Jalles, J., Venâncio, A. (eds), *Handbook on Public Sector Efficiency*, Edward Elgar Publishing.
47. Sow, M., Razafimahefa, I, (20015). “Fiscal Decentralization and the Efficiency of Public Service Delivery”, IMF Working Paper No. 2015/059.
48. Stegarescu, D. (2005). “Public Sector Decentralisation: Measurement Concepts and Recent International Trends”. **Fiscal Studies**, 26 (3), 301–333.
49. Sutherland, D., Price, R., Gonand, F., (2009). “Improving Public Spending Efficiency in Primary and Secondary Education”. **OECD Journal: Economic Studies**, 2009, 1–30.
50. Tiebout, C. (1956). “A pure theory of local expenditures”. **Journal of Political Economy**, 64, 416-424.
51. von Hagen, J. and Eichengreen, B. (1996). “Federalism, Fiscal Restraints, and European Monetary Union”, **American Economic Review**, 86 (2), 134-138.
52. Zhang, T. and Zou, H. (1998) "*Fiscal Decentralization, Public Spending, and Economic Growth in China*", *Journal of Public Economics*, 67 (2), 221-240.

Appendix A

Figure A.1. Natural Disaster Counts by type, 36 OECD countries, 2006-2019



Source: Emergency Events Database (EM-DAT). Droughts are defined as as "an extended period of unusually low precipitation that produces a shortage of water for people, animals and plants"; extreme temperatures as "a general term for temperature variations above (extreme heat) or below (extreme cold) normal conditions"; wildfires as any uncontrolled and non-prescribed combustion or burning of plants in a natural setting such as a forest, grassland, brush land or tundra, which consumes the natural fuels and spreads based on environmental conditions (e.g., wind, topography); landslides as any kind of moderate to rapid soil movement including lahar, mudslide, debris flow; and storms as meteorological events including extra-tropical, tropical and convective storms

Appendix B

Table B.1. DEA Output Components

Sub Index	Variable	Source	Series
Opportunity Indicators			
Administration	Corruption	Transparency International's Corruption Perceptions Index (CPI) (2006- 2019)	Corruption on a scale from 10 (Perceived to have low levels of corruption) to 0 (highly corrupt), 2006-2011; Corruption on a scale from 100 (Perceived to have low levels of corruption) to 0 (highly corrupt), 2012-2019.
	Red Tape	World Economic Forum: The Global Competitiveness Report (2006-2017) World Economic Forum: Global Competitiveness Index 4.0 (2018-2019)	Burden of government regulation on a scale from 7 (not burdensome at all) to 1 (extremely burdensome).
	Judicial Independence	World Economic Forum: The Global Competitiveness Report (2006-2017) World Economic Forum: Global Competitiveness Index 4.0 (2018-2019)	Judicial independence on a scale from 7 (entirely independent) to 1 (heavily influenced).
	Property Rights	World Economic Forum: The Global Competitiveness Report (2006-2017) World Economic Forum: Global Competitiveness Index 4.0 (2018-2019)	Property rights on a scale from 7 (very strong) to 1 (very weak). Property rights on a scale from 100 (very strong) to 0 (very weak).
	Shadow Economy	Medina and Schneider (2019) (2006-2017)	Shadow economy measured as percentage of official GDP. Reciprocal value 1/x. For the missing years, we assumed that the scores were the same as in the previous years.
Education	Secondary School Enrolment	World Bank, World Development Indicators (2006-2019)	Ratio of total enrolment in secondary education.
	Quality of Educational System	World Economic Forum: The Global competitiveness Report (2006-2017)	Quality of educational system on a scale from 7 (very well) to 1 (not well at all). For the missing years, we assumed that the scores were the same as in the previous years.
	PISA scores	PISA Report (2006, 2009, 2012, 2015, 2018)[17]	Simple average of mathematics, reading and science scores for the years 2018, 2015, 2012, 2009. For the missing years, we assumed that the scores were the same as in the previous years.
Health	Infant Survival Rate	World Bank, World Development Indicators (2006-2019)	Infant survival rate = (1000-IMR)/1000. IMR is the infant mortality rate measured per 1000 lives birth in a given year.
	Life Expectancy	World Bank, World Development Indicators (2006-2019)	Life expectancy at birth, measured in years.
	CVD, cancer, diabetes or CRD Survival Rate	World Health Organization, Global Health Observatory Data Repository (2000,-2019)	CVD, cancer and diabetes survival rate =100-M. M is the mortality rate between the ages 30 and 70. For the missing years, we assumed that the scores were the same as in the previous years.
Public Infrastructure	Infrastructure Quality	World Economic Forum: The Global competitiveness Report (2006-2017) World Economic Forum: Global Competitiveness Index 4.0 (2018-2019)	Infrastructure quality on a scale from 7 (extensive and efficient) to 1 (extremely underdeveloped) Quality of road infrastructure from 7 (extensive and efficient) to 1 (extremely underdeveloped) Efficiency of train services from 7 (extensive and efficient) to 1 (extremely underdeveloped) Efficiency of air transport services from 7 (extensive and efficient) to 1 (extremely underdeveloped) Efficiency of seaport services from 7 (extensive and efficient) to 1 (extremely underdeveloped) Reliability of water supply from 7 (extensive and efficient) to 1 (extremely underdeveloped)

[17] For Costa Rica, we were only able to collect data for the years 2018, 2015 and 2012.

Standard Musgravian Indicators

Distribution	Gini Index	Eurostat (2006-2019) OECD (2006-2019) World Bank, World Bank, Development Research Group (2006-2019)[18]	Gini index on a scale from 1(perfect inequality) to 0 (perfect equality). Transformed to 1-Gini. For the missing years, we assumed that the scores were the same as in the previous years.
Stabilization	**Coefficient of Variation of Growth**	IMF World Economic Outlook (WEO database) (2006-2019)	Coefficient of variation=standard deviation/mean of GDP growth based on 5 year data. GDP constant prices (percent change). Reciprocal value 1/x.
	Standard Deviation of Inflation	IMF World Economic Outlook (WEO database) (2006-2019)	Standard deviation of inflation based on 5-year consumer prices (percent change) data. Reciprocal value 1/x.
Economic Performance	GDP per Capita	IMF World Economic Outlook (WEO database) (2006-2019)	GDP per capita based on PPP, current international dollar.
	GDP Growth	IMF World Economic Outlook (WEO database) (2006-2019)	GDP constant prices (percent change).
	Unemployment	IMF World Economic Outlook (WEO database) (2006-2019)	Unemployment rate, as a percentage of total labor force. Reciprocal value 1/x.

[18] For Colombia we were collected data from World Bank.

Table B.2. Input Components

Sub Index	Variable	Source	Series
Opportunity Indicators			
Administration	Government Consumption	IMF World Economic Outlook (WEO database) (2005-2018)	General government final consumption expenditure (% of GDP) at current prices
Education	Education Expenditure	UNESCO Institute for Statistics (2005-2018)[19]	Expenditure on education (% of GDP)
Health	Health Expenditure	OECD database (2005-2018)[20]	Expenditure on health compulsory (% of GDP)
Public Infrastructure	Public Investment	European Commission, AMECO (2005-2018)[21]	General government gross fixed capital formation (% of GDP) at current prices
Standard Musgravian Indicators			
Distribution	Social Protection Expenditure	OECD database (2005-2018)[22]	Aggregation of the social transfers (% of GDP)
Stabilization/ Economic Performance	Government Total Expenditure	OECD database (2005-2018)[23]	Total expenditure (% of GDP)

[19] From IMF World Economic Outlook (WEO database), we retrieved data for Belgium for the period between 2001 to 2007, France for the period between 2000 and 2014, Greece for the period between 2006 and 2015, South Korea for the period between 2001 and 2009 and 2012 and 2015, for Turkey for the period between 2012 and 2014, and for the USA for the period 2010 and 2012. For the missing years, we assumed that the scores were the same as in the previous years.

[20] We were not able to collect data on the following countries: Canada, Mexico, New Zealand, and Turkey. For the missing years, we assumed that the scores were the same as in the previous years.

[21] We were not able to collect data on the following countries: Australia, Canada, Chile, Colombia, Costa Rica, Mexico, New Zealand, Israel and South Korea. For the missing years, we assumed that the scores were the same as in the previous years.

[22] From IMF World Economic Outlook (WEO database), we retrieved data for New Zealand for the period 2005 and 2012. For Turkey, we retrieve data from European Commission, AMECO database. For Turkey, we were only able to get data for the period between 2009 and 2015. We were not able to collect data for Canada. For the missing years, we assumed that the scores were the same as in the previous years.

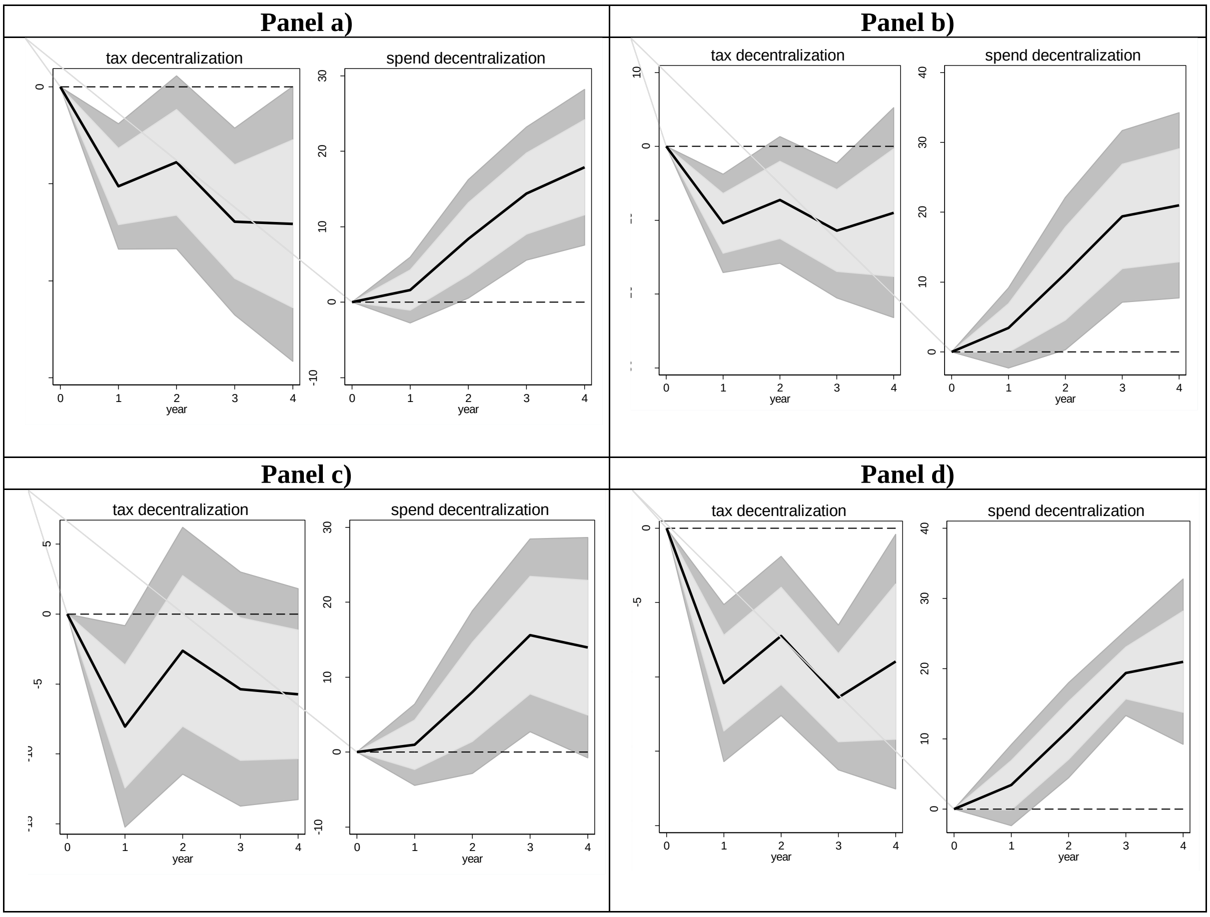
[23] From IMF World Economic Outlook (WEO database), we retrieved data for Canada for the period between 2000 and 2017, for New Zealand for the period 2009 and 2017 and for Turkey for the period 2004 and 2017. We were not able to collect data for Mexico. For the missing years, we assumed that the scores were the same as in the previous years.

Appendix C

Table C.1. – Summary statistics

Variable	Obs	Mean	Std. dev.
PSE_0	468	0.62	0.15
PSE_1	468	0.68	0.14
PSE_2	468	0.65	0.15
Tax revenue decentralization	464	0.20	0.15
Expenditure decentralization	295	0.34	0.15
Regional authority index	432	14.04	10.52
Self-rule	432	11.48	7.27
Shared-rule	432	2.55	4.17
Natural disasters	437	0.68	0.47
L(Population) (t-1)	468	16.33	1.50
Age dependency ratio (t-1)	468	0.50	0.05
Debt-to-GDP ratio (t-1)	468	0.64	0.43
Majority (t-1)	468	0.13	0.34
Government effectiveness (t-1)	468	1.28	0.55
Voice and accountability (t-1)	468	1.12	0.43

Figure C.1. Robustness Effects of Fiscal Decentralization on Public Sector Efficiency



Note: Impulse response functions are estimated using a sample of 36 OECD member countries between the period of 2006 and 2019. The graph shows the response on PSE_0 input score and both the 90 and 68 percent confidence bands. The x-axis shows years (k) after fiscal decentralization shocks; t = 0 is the year of the fiscal decentralization shock. Estimates based on equation 3. Standard errors in parentheses are clustered at the country level.

Table C.2. Conditional regression on output efficiency scores

Dependent Variable	OPSE_0			OPSE_1			OPSE_2		
Specification	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Tax dec.	-0.744**			-0.817***			-0.147		
	(0.300)			(0.290)			(0.175)		
Spend dec.	0.524*			0.629**			0.146		
	(0.277)			(0.272)			(0.091)		
Regional authority index		0.020***			0.027***			0.007**	
		(0.006)			(0.006)			(0.003)	
Self-rule			0.020***			0.028***			0.007**
			(0.006)			(0.006)			(0.003)
Shared rule			0.004			0.004			0.001
			(0.020)			(0.023)			(0.009)
L(Population) (t-1)	-0.385*	-0.204	-0.213	-0.407*	-0.202	-0.215	0.054	0.087	0.084
	(0.226)	(0.178)	(0.182)	(0.232)	(0.189)	(0.194)	(0.101)	(0.089)	(0.091)
Age dependency ratio (t-1)	0.925**	0.389	0.381	0.654*	0.167	0.155	0.337*	0.174	0.171
	(0.368)	(0.366)	(0.370)	(0.364)	(0.334)	(0.337)	(0.179)	(0.165)	(0.167)
Debt-to-GDP ratio (t-1)	-0.274***	-0.219***	-0.221***	-0.248***	-0.214***	-0.216***	-0.061***	-0.043**	-0.043**
	(0.046)	(0.044)	(0.044)	(0.043)	(0.043)	(0.043)	(0.022)	(0.019)	(0.019)
Majority (t-1)	-0.009	-0.021	-0.021	-0.008	-0.023	-0.023	-0.004	-0.017**	-0.017**
	(0.021)	(0.017)	(0.017)	(0.021)	(0.017)	(0.017)	(0.010)	(0.008)	(0.008)
Government effectiveness (t-1)	0.126***	0.116***	0.114***	0.090*	0.093***	0.091***	0.065***	0.067***	0.067***
	(0.048)	(0.036)	(0.036)	(0.049)	(0.033)	(0.033)	(0.021)	(0.016)	(0.016)
Voice and accountability (t-1)	-0.102	-0.086	-0.084	-0.094	-0.094	-0.092	-0.085***	-0.066**	-0.066**
	(0.077)	(0.065)	(0.065)	(0.088)	(0.072)	(0.072)	(0.029)	(0.027)	(0.027)
Country effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	295	431	431	295	431	431	295	432	432
R-squared	0.776	0.768	0.768	0.792	0.790	0.790	0.893	0.872	0.872

Note: The models include country and year fixed effects. Constant term included but omitted. Standard errors in parenthesis. The symbols *, **, and *** denote significance levels at 10%, 5%, and 1%, respectively.

Table C.3. Regression on output efficiency scores adding interaction with natural disasters

Dependent Variable	OPSE_0			
Specification	(1)	(2)	(3)	(4)
Tax dec.	-0.888***		-0.650*	
	(0.318)		(0.389)	
Spend dec.	0.052***	0.055	0.049	0.042**
	(0.020)	(0.033)	(0.037)	(0.020)
Natural disasters	-0.214***		-0.081	
	(0.070)		(0.117)	
Tax dec. x Nat. disasters		0.583*	0.576*	
		(0.314)	(0.332)	
Spend dec. x Nat disasters		-0.183**	-0.117	
		(0.090)	(0.152)	
Regional authority index				0.019***
				(0.006)
Regional authority index x Nat. disasters				-0.002*
				(0.001)
Country effects	Yes	Yes	Yes	Yes
Time effects	Yes	Yes	Yes	Yes
Control variables	Yes	Yes	Yes	Yes
Observations	433	284	284	407
R-squared	0.866	0.892	0.895	0.879

Note: The models include country and year fixed effects. Constant term and control variables included but omitted. Standard errors in parenthesis. The symbols *, **, and *** denote significance levels at 10%, 5%, and 1%, respectively.

Table C.4. Robustness regression: Simar-Wilson

Dependent Variable	PSE_0					
Specification	(1)	(2)	(3)	(4)	(5)	(6)
Tax dec.	-0.570***	-0.553***				
	(0.131)	(0.138)				
Spend dec.	0.240**	0.377***				
	(0.119)	(0.137)				
Regional authority index			0.019***	0.021***		
			(0.002)	(0.002)		
Self-rule					0.019***	0.022***
					(0.002)	(0.002)
Shared rule					-0.006	-0.017
					(0.023)	(0.022)
L(Population) (t-1)		-0.247***		-0.314***		-0.338***
		(0.091)		(0.083)		(0.082)
Age dependency ratio (t-1)		-0.183		-0.246*		-0.275**
		(0.158)		(0.142)		(0.137)
Debt-to-GDP ratio (t-1)		-0.029		-0.045**		-0.048***
		(0.022)		(0.019)		(0.018)
Majority (t-1)		0.010		-0.013*		-0.014*
		(0.010)		(0.008)		(0.008)
Government effectiveness (t-1)		-0.020		0.022		0.019
		(0.023)		(0.018)		(0.019)
Voice and accountability (t-1)		-0.057**		-0.096***		-0.093***
		(0.029)		(0.027)		(0.027)
Country effects	Yes	Yes	Yes	Yes	Yes	Yes
Time effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	260	260	398	398	398	398

Note: The models include country and year fixed effects. Constant term included but omitted. Standard errors in parenthesis. The symbols *, **, and *** denote significance levels at 10%, 5%, and 1%, respectively.

Table C.5. Robustness regression: Simar-Wilson

Dependent Variable	PSE_0			
Specification	(1)	(2)	(3)	(4)
Tax decentralization	-0.543***		-0.679***	
	(0.167)		(0.163)	
Spend dec.	0.009	0.029	0.032*	0.003
	(0.009)	(0.018)	(0.017)	(0.009)
Natural disasters	-0.025		0.084	
	(0.054)		(0.067)	
Tax dec. x Nat. disasters		0.377**	0.472***	
		(0.151)	(0.152)	
Spend dec. x Nat disasters		-0.077	-0.133*	
		(0.060)	(0.071)	
Regional authority index				0.021***
				(0.002)
Regional authority index x Nat. disasters				-0.000
				(0.001)
Country effects	Yes	Yes	Yes	Yes
Time effects	Yes	Yes	Yes	Yes
Control variables	Yes	Yes	Yes	Yes
Observations	396	249	249	373

Note: The models include country and year fixed effects. Constant term and control variables included but omitted. Standard errors in parenthesis. The symbols *, **, and *** denote significance levels at 10%, 5%, and 1%, respectively.

Appendix D

Table D.1. Input-oriented DEA VRS Efficiency Scores Model 0

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
AUS	0.74	0.66	0.66	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	0.79	0.69	0.69	0.68	0.71	**1.00**
AUT	0.56	0.50	0.47	0.49	0.47	0.46	0.46	0.46	0.50	0.50	0.52	0.51	0.54	0.53
BEL	0.47	0.49	0.48	0.49	0.48	0.47	0.46	0.45	0.48	0.49	0.52	0.52	0.54	0.53
CAN	0.71	0.60	0.71	0.61	0.58	0.56	0.56	0.57	0.75	0.64	0.64	0.63	0.65	0.64
CHE	**1.00**	**1.00**	**1.00**	**1.00**	0.79	0.82	0.75	0.78	**1.00**	**1.00**	**1.00**	0.78	0.81	0.81
CHL	0.98	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	0.98	0.99	**1.00**
COL	0.77	0.76	0.77	0.82	0.81	0.79	0.80	0.83	0.83	0.81	0.85	0.86	0.88	0.75
CZE	0.52	0.53	0.55	0.57	0.54	0.54	0.54	0.54	0.57	0.61	0.60	0.64	0.69	0.65
DEU	0.50	0.50	0.52	0.55	0.51	0.52	0.53	0.52	0.60	0.59	0.60	0.58	0.60	0.58
DNK	0.48	0.43	0.41	0.44	0.41	0.40	0.39	0.39	0.44	0.44	0.47	0.46	0.49	0.64
ESP	0.76	0.65	0.55	0.54	0.52	0.51	0.51	0.53	0.56	0.59	0.63	0.65	0.67	0.65
EST	0.66	0.63	0.59	0.55	0.53	0.58	0.59	0.56	0.61	0.63	0.64	0.64	0.64	0.64
FIN	0.49	0.48	0.46	0.49	0.44	0.44	0.43	0.40	0.42	0.42	0.46	0.45	0.48	0.47
FRA	0.53	0.43	0.41	0.44	0.42	0.42	0.41	0.41	0.44	0.45	0.47	0.46	0.48	0.47
GBR	0.65	0.59	0.54	0.57	0.53	0.52	0.52	0.52	0.63	0.60	0.62	0.62	0.64	0.63
GRC	0.50	0.48	0.48	0.47	0.47	0.48	0.47	0.46	0.51	0.52	0.55	0.55	0.56	0.57
HUN	0.52	0.44	0.47	0.51	0.53	0.53	0.53	0.52	0.53	0.54	0.56	0.63	0.63	0.60
IRL	0.67	0.60	0.53	0.50	0.45	0.47	0.53	0.55	0.68	**1.00**	0.91	0.91	1.00	**1.00**
ISL	0.57	0.58	0.48	0.51	0.52	0.54	0.52	0.55	0.59	0.62	0.65	0.59	0.63	0.60
ISR	0.54	0.55	0.58	0.62	0.64	0.65	0.67	0.71	0.70	0.68	0.71	0.70	0.69	0.68
ITA	0.48	0.48	0.49	0.50	0.49	0.50	0.50	0.49	0.50	0.53	0.55	0.56	0.58	0.57
JPN	0.61	0.76	0.60	0.63	0.60	0.57	0.56	0.55	0.59	0.61	0.64	0.64	0.66	0.65
KOR	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	0.99	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	0.96
LTU	0.63	0.61	0.58	0.56	0.53	0.53	0.57	0.62	0.67	0.70	0.74	0.76	0.79	0.75
LUX	0.64	0.68	0.57	0.60	0.55	0.55	0.54	0.53	0.66	0.61	0.63	0.61	0.62	0.62
LVA	0.64	0.63	0.62	0.60	0.56	0.57	0.60	0.58	0.61	0.66	0.69	0.72	0.72	0.68
NLD	0.51	0.56	0.65	0.74	0.52	0.51	0.49	0.49	0.54	0.55	0.58	0.58	0.61	0.61
NOR	0.51	0.52	0.50	0.55	0.49	0.50	0.50	0.48	0.58	0.51	0.48	0.45	0.48	0.47
NZL	0.59	0.55	0.55	0.62	0.58	0.53	0.50	0.55	0.69	0.66	0.68	0.68	1.00	0.70
POL	0.50	0.50	0.52	0.55	0.55	0.63	0.59	0.54	0.56	0.58	0.62	0.63	0.64	0.61
PRT	0.47	0.49	0.51	0.51	0.48	0.47	0.49	0.50	0.51	0.55	0.59	0.62	0.64	0.63
SVK	0.55	0.57	0.62	0.61	0.56	0.56	0.57	0.57	0.57	0.57	0.56	0.62	0.65	0.62
SVN	0.46	0.47	0.50	0.51	0.48	0.46	0.47	0.44	0.46	0.50	0.54	0.58	0.61	0.60
SWE	0.44	0.43	0.43	0.47	0.47	0.47	0.45	0.43	0.48	0.50	0.51	0.49	0.50	0.50
TUR	0.66	0.68	0.70	0.71	0.68	0.71	0.74	0.69	0.72	0.75	0.76	0.74	0.76	0.72
USA	0.67	0.63	0.60	0.61	0.59	0.58	0.59	0.61	0.81	0.72	0.72	0.70	0.73	0.72
Count	2	3	3	4	3	3	2	3	3	4	3	1	2	3
Average	0.61	0.60	0.59	0.61	0.58	0.58	0.58	0.58	0.63	0.63	0.65	0.65	0.68	0.66
Median	0.57	0.56	0.55	0.56	0.53	0.53	0.53	0.54	0.59	0.60	0.62	0.63	0.64	0.64
Min	0.44	0.43	0.41	0.44	0.41	0.40	0.39	0.39	0.42	0.42	0.46	0.45	0.48	0.47
Max	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Stdev	0.15	0.15	0.15	0.16	0.16	0.16	0.16	0.16	0.15	0.16	0.15	0.14	0.15	0.14

Table D.2. Input-oriented DEA VRS Efficiency Scores Model 1

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
AUS	0.83	0.70	0.69	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	0.89	0.70	0.69	0.71	0.74	**1.00**
AUT	0.60	0.57	0.56	0.59	0.58	0.57	0.58	0.58	0.61	0.62	0.62	0.58	0.59	0.60
BEL	0.54	0.58	0.56	0.60	0.60	0.59	0.56	0.55	0.58	0.59	0.61	0.59	0.59	0.60
CAN	0.74	0.62	0.77	0.67	0.66	0.62	0.62	0.63	0.79	0.71	0.69	0.65	0.65	0.65
CHE	**1.00**	**1.00**	**1.00**	**1.00**	0.95	0.98	0.90	0.90	**1.00**	**1.00**	**1.00**	0.88	0.88	0.91
CHL	0.98	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
COL	0.79	0.77	0.77	0.86	0.85	0.80	0.82	0.85	0.83	0.85	0.88	0.87	0.88	0.77
CZE	0.53	0.54	0.56	0.60	0.57	0.58	0.58	0.58	0.64	0.66	0.60	0.64	0.69	0.66
DEU	0.63	0.64	0.66	0.71	0.68	0.66	0.67	0.67	0.72	0.73	0.73	0.69	0.69	0.69
DNK	0.52	0.50	0.47	0.53	0.51	0.49	0.48	0.48	0.50	0.52	0.53	0.50	0.52	0.72
ESP	0.82	0.65	0.57	0.61	0.59	0.59	0.61	0.66	0.73	0.77	0.76	0.77	0.78	0.78
EST	0.71	0.67	0.62	0.56	0.57	0.62	0.63	0.56	0.62	0.66	0.66	0.64	0.64	0.64
FIN	0.53	0.55	0.54	0.59	0.56	0.55	0.53	0.49	0.51	0.53	0.56	0.52	0.54	0.55
FRA	0.55	0.51	0.49	0.55	0.54	0.53	0.52	0.52	0.54	0.57	0.58	0.55	0.56	0.57
GBR	0.66	0.65	0.62	0.66	0.64	0.61	0.61	0.61	0.68	0.68	0.69	0.66	0.66	0.67
GRC	0.54	0.53	0.55	0.56	0.57	0.62	0.64	0.65	0.66	0.70	0.70	0.66	0.63	0.70
HUN	0.56	0.48	0.55	0.66	0.68	0.67	0.66	0.65	0.64	0.62	0.59	0.70	0.64	0.61
IRL	0.68	0.63	0.56	0.55	0.58	0.53	0.61	0.64	0.73	**1.00**	**1.00**	0.92	**1.00**	**1.00**
ISL	0.69	0.70	0.49	0.57	0.53	0.56	0.52	0.56	0.61	0.65	0.65	0.59	0.66	0.67
ISR	0.54	0.56	0.58	0.64	0.69	0.68	0.69	0.73	0.70	0.72	0.73	0.70	0.69	0.68
ITA	0.56	0.54	0.58	0.62	0.62	0.63	0.64	0.64	0.67	0.72	0.72	0.70	0.71	0.73
JPN	0.64	0.78	0.67	0.74	0.71	0.69	0.66	0.64	0.67	0.69	0.71	0.69	0.70	0.71
KOR	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	0.96
LTU	0.64	0.63	0.59	0.60	0.61	0.58	0.58	0.65	0.71	0.77	0.77	0.77	0.79	0.79
LUX	0.64	0.73	0.67	0.73	0.69	0.66	0.68	0.64	0.73	0.74	0.75	0.70	0.71	0.73
LVA	0.65	0.67	0.67	0.62	0.64	0.65	0.63	0.59	0.63	0.71	0.72	0.75	0.72	0.68
NLD	0.57	0.58	0.67	0.74	0.59	0.57	0.55	0.55	0.59	0.62	0.63	0.60	0.62	0.64
NOR	0.52	0.55	0.52	0.60	0.54	0.55	0.55	0.53	0.59	0.54	0.52	0.46	0.48	0.48
NZL	0.65	0.55	0.57	0.62	0.60	0.54	0.53	0.56	0.77	0.68	0.72	0.72	**1.00**	0.77
POL	0.59	0.56	0.58	0.62	0.64	0.70	0.63	0.61	0.66	0.67	0.70	0.72	0.70	0.67
PRT	0.50	0.53	0.55	0.59	0.57	0.52	0.59	0.64	0.67	0.72	0.73	0.76	0.73	0.75
SVK	0.60	0.58	0.68	0.70	0.66	0.65	0.64	0.66	0.67	0.66	0.57	0.65	0.67	0.67
SVN	0.51	0.51	0.55	0.58	0.56	0.55	0.55	0.55	0.54	0.58	0.60	0.65	0.67	0.65
SWE	0.50	0.51	0.50	0.55	0.55	0.55	0.54	0.50	0.53	0.55	0.57	0.52	0.52	0.52
TUR	0.69	0.69	0.73	0.80	0.82	0.83	0.86	0.73	0.75	0.81	0.81	0.74	0.76	0.72
USA	0.82	0.72	0.70	0.66	0.60	0.60	0.63	0.65	**1.00**	0.80	0.78	0.77	0.78	0.81
Count	2	3	3	4	3	3	3	3	4	4	4	2	4	3
Average	0.65	0.64	0.63	0.67	0.66	0.65	0.65	0.65	0.70	0.71	0.71	0.69	0.71	0.71
Median	0.63	0.60	0.58	0.62	0.60	0.61	0.62	0.64	0.67	0.70	0.70	0.69	0.69	0.69
Min	0.50	0.48	0.47	0.53	0.51	0.49	0.48	0.48	0.50	0.52	0.52	0.46	0.48	0.48
Max	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Stdev	0.14	0.14	0.13	0.14	0.14	0.14	0.14	0.14	0.14	0.13	0.13	0.13	0.14	0.13

Table D.3. Input-oriented DEA VRS Efficiency Scores Model 2

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
AUS	0.79	0.74	0.72	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	0.81	0.76	0.74	0.74	0.71	**1.00**
AUT	0.59	0.57	0.57	0.56	0.55	0.54	0.55	0.56	0.57	0.57	0.57	0.58	0.54	0.53
BEL	0.56	0.53	0.54	0.53	0.51	0.51	0.50	0.50	0.52	0.54	0.57	0.56	0.54	0.53
CAN	0.71	0.67	0.73	0.68	0.66	0.65	0.66	0.68	0.76	0.72	0.70	0.70	0.65	0.64
CHE	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
CHL	0.98	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	0.98	0.99	**1.00**
COL	0.77	0.76	0.77	0.83	0.82	0.81	0.83	0.89	0.90	0.82	0.85	0.86	0.88	0.75
CZE	0.52	0.53	0.56	0.57	0.54	0.54	0.54	0.54	0.58	0.61	0.60	0.64	0.69	0.65
DEU	0.63	0.61	0.62	0.61	0.59	0.59	0.62	0.64	0.65	0.67	0.66	0.66	0.60	0.58
DNK	0.56	0.53	0.52	0.51	0.48	0.48	0.46	0.46	0.49	0.51	0.52	0.53	0.49	**1.00**
ESP	**1.00**	0.77	0.56	0.54	0.52	0.51	0.52	0.56	0.58	0.62	0.65	0.66	0.67	0.65
EST	0.71	0.63	0.61	0.56	0.54	0.59	0.61	0.59	0.64	0.67	0.67	0.68	0.64	0.64
FIN	0.62	0.60	0.60	0.58	0.54	0.55	0.55	0.54	0.53	0.52	0.55	0.55	0.56	0.57
FRA	0.55	0.48	0.48	0.49	0.48	0.47	0.47	0.47	0.48	0.50	0.51	0.50	0.48	0.48
GBR	0.66	0.62	0.59	0.60	0.57	0.57	0.59	0.61	0.64	0.67	0.68	0.69	0.64	0.63
GRC	0.50	0.49	0.48	0.48	0.47	0.48	0.47	0.46	0.51	0.52	0.55	0.55	0.56	0.57
HUN	0.70	0.44	0.47	0.52	0.53	0.53	0.53	0.52	0.53	0.54	0.56	0.63	0.63	0.60
IRL	0.68	0.60	0.56	0.52	0.47	0.50	0.60	0.65	0.70	**1.00**	**1.00**	0.99	**1.00**	**1.00**
ISL	0.71	0.64	0.57	0.59	0.63	0.64	0.62	0.66	0.67	0.70	0.72	0.67	0.64	0.60
ISR	0.57	0.56	0.58	0.62	0.64	0.65	0.67	0.72	0.72	0.69	0.73	0.72	0.69	0.68
ITA	0.48	0.48	0.49	0.50	0.49	0.50	0.50	0.49	0.50	0.53	0.55	0.56	0.58	0.57
JPN	0.75	0.83	0.70	0.70	0.67	0.66	0.64	0.65	0.68	0.70	0.71	0.72	0.67	0.67
KOR	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	1.00	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	0.96
LTU	0.63	0.62	0.58	0.57	0.53	0.53	0.57	0.62	0.68	0.70	0.74	0.76	0.79	0.75
LUX	0.67	0.73	0.66	0.66	0.62	0.62	0.64	0.64	0.67	0.69	0.69	0.69	0.63	0.62
LVA	0.64	0.64	0.62	0.61	0.56	0.57	0.60	0.58	0.61	0.66	0.69	0.72	0.72	0.68
NLD	0.68	0.62	0.69	0.74	0.60	0.60	0.61	0.63	0.65	0.68	0.68	0.70	0.70	0.69
NOR	0.60	0.57	0.56	0.59	0.53	0.54	0.56	0.56	0.58	0.56	0.52	0.51	0.48	0.48
NZL	0.65	0.58	0.60	0.67	0.64	0.59	0.59	0.66	0.72	0.74	0.75	0.77	**1.00**	0.70
POL	0.50	0.50	0.53	0.56	0.56	0.79	0.62	0.54	0.56	0.58	0.62	0.63	0.64	0.62
PRT	0.48	0.50	0.52	0.52	0.48	0.47	0.50	0.53	0.56	0.59	0.62	0.65	0.64	0.64
SVK	0.55	0.57	0.68	0.62	0.57	0.56	0.57	0.57	0.57	0.57	0.56	0.62	0.65	0.63
SVN	0.46	0.47	0.51	0.51	0.48	0.46	0.47	0.44	0.46	0.50	0.54	0.58	0.61	0.60
SWE	0.51	0.51	0.52	0.54	0.55	0.55	0.54	0.52	0.52	0.55	0.57	0.56	0.53	0.51
TUR	0.66	0.68	0.70	0.71	0.68	0.72	0.74	0.71	0.74	0.76	0.76	0.74	0.76	0.72
USA	0.80	0.72	0.71	0.68	0.65	0.65	0.67	0.71	0.83	0.80	0.81	0.82	0.81	0.76
Count	3	3	3	4	4	4	3	4	3	4	4	2	4	5
Average	0.66	0.63	0.63	0.64	0.61	0.62	0.63	0.64	0.66	0.67	0.68	0.69	0.69	0.69
Median	0.64	0.60	0.59	0.59	0.56	0.57	0.59	0.60	0.64	0.67	0.68	0.67	0.65	0.64
Min	0.46	0.44	0.47	0.48	0.47	0.46	0.46	0.44	0.46	0.50	0.51	0.50	0.48	0.48
Max	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Stdev	0.15	0.15	0.14	0.15	0.16	0.16	0.15	0.16	0.15	0.15	0.14	0.14	0.15	0.16