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Non-linear effects of fiscal decentralization on efficiency: an application to the education and health sectors

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NON-LINEAR EFFECTS OF FISCAL DECENTRALIZATION ON EFFICIENCY: AN APPLICATION TO THE EDUCATION AND HEALTH SECTORS

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Resumo

A descentralização orçamental é um tema comum à esfera da economia pública e escolha pública e que, enquanto parte da organização económica, administrativa e política de um país, tem em vista a melhoria do bem-estar social dos indivíduos.

Uma das vias pelas quais, teoricamente, a descentralização orçamental contribui para esse objetivo normativo, é através do aumento da eficiência económica. No entanto, existem na literatura relevante, argumentos contrários a esta ideia. Os trabalhos empíricos mais importantes dentro do tema, apontam para uma relação não linear da descentralização orçamental dos países e a sua eficiência económica. Partindo deste pressuposto, este trabalho procura, empiricamente, contribuir para uma melhor compreensão da relação entre descentralização orçamental e eficiência económica.

Este estudo centra-se nos setores da educação e da saúde, nos 25 países da União Europeia que apresentam governos subnacionais, entre 2000 e 2021. Realizou-se uma análise bietápica, através do algoritmo II do modelo de Simar e Wilson (2007), adaptado para dados em painel.

Os resultados obtidos sugerem que os impactos da descentralização orçamental na eficiência dos setores da educação e na saúde são ambos não lineares, no entanto com formas diferentes. Na educação encontra-se uma relação de U invertido e na saúde uma relação em U.

Códigos JEL: C14; C24; H77; I10; I20

Palavras-Chave: Descentralização Orçamental; Eficiência; DEA; Educação; Saúde; União Europeia

Abstract

Fiscal decentralization is a theme common to the sphere of public economy and public choice and which, as part of the economic, administrative and political organization of a country, aims to improve the social well-being of individuals.

One of the ways in which, theoretically, fiscal decentralization contributes to this normative objective is through increasing economic efficiency. However, there are arguments against this idea in the relevant literature. The most relevant empirical works within the topic, suggest a non-linear relationship between fiscal decentralization and economic efficiency. Based on this hypothesis, this work seeks, empirically, to contribute to a better understanding of the relationship between fiscal decentralization and economic efficiency.

This study focuses on the education and health sectors, in the 25 countries of the European Union that have subnational governments, between 2000 and 2021. A two-stage analysis was carried out, using algorithm II of the Simar and Wilson (2007) model, adapted for panel data.

The results obtained suggest that the impacts of fiscal decentralization on the efficiency of the education and health sectors are both non-linear, although in different ways. In education there is an inverted-U relationship and in health a U-shaped relationship.

JEL Codes: C14; C24; H77; I10; I20

Keywords: Fiscal decentralization; Efficiency; DEA; Education; Health; European Union

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List of Acronyms

BN- Banker and Natarajan

CRS- Constant Returns to Scale

DEA- Data Envelopment Analysis

DMU- Decision-Making Units

ECSC- Economic, Social and Cultural Status Index

EU- European Union

FDH- Free Disposal Hull

GDP- Gross Domestic Product

GG- General Governments

IMR- Infant Mortality Rate

ISR- Infant Survival Rate

OECD- Organization for Economic Cooperation and Development

PEX- Public Expenditure

PISA- Programme for International Student Assessment

PSE- Public Sector Efficiency

PSP- Public Sector Performance

SFA- Stochastic Frontier Analysis

SG- Subnational Governments

SW- Simar and Wilson

VRS- Variable Returns to Scale

1 Introduction

The decentralization of state power can be defined as the division and sharing of power between governmental levels (the central and the subnational). The issues related to this topic have been a subject of the economic science for a few decades now, falling within the disciplines of public economics and public choice. Both focus on non-market decision-making, that is, the application of economic science to governmental/political decisions. Public Economics aims at analysing how and what governmental decisions should be made in order to achieve economic efficiency (normative vision) (Hindriks & Myles, 2013). Public Choice, on the other hand, seeks to understand and explain the reasons why policy decisions are made and to predict which ones will be followed in the future (positive view) (Musgrave, 1959). It is in this latter context that the problem of the distribution of decision-making power at the governmental level, usually referred to as federalism, arises.

There are three strands of federalism: political, administrative and fiscal. Fiscal federalism or fiscal decentralization focuses on the distribution of competences related to obtaining revenues and carrying out expenditures by the different levels of government and is the one this work is concerned with. Musgrave (1959) distinguishes three functions of fiscal policy, namely, the allocative, the stabilizing and the redistributive. The first can be assigned to the central government, subnational governments, or both. The other two functions are better allocated to the central government. Thus, it is the function of resource allocation by the government that can be decentralized (Musgrave & Musgrave, 1973).

The choice of fiscal decentralization should comply with the normative objective, that is, the form selected for the allocation of resources by the government should satisfy in the best possible way the needs of the citizens, maximizing their well-being, the ultimate end of any of the functions of the state. However, having in mind this general broad goal, the implementation of fiscal decentralization is meant to aim at several more concrete objectives. According to OECD (2019), fiscal decentralization can bring benefits in terms of allocative and technical efficiency, economic growth, reduction of regional inequalities, leverage of regional development, improvements in the quality of public services, fiscal responsibility, more innovation and greater efficiency of revenue collection by the state. Among these possible benefits of decentralization, our concern is the increase in technical and allocative efficiency together with the improvement of the quality of public services. OECD (2019) indicates that through better information on citizens' preferences and alignment with local demand, a local provision of public goods and services can be more efficient. But does this theoretical prediction hold true in practice? This is the question that this dissertation sets out to answer. Directing the focus to two of the most important goods provided by governments, health and education, this study seeks to understand the effects of fiscal decentralization on efficiency, for EU countries between 2000 and 2021.

Some literature on the topic studies the relationship between fiscal decentralization and efficiency from a linear point of view (Barankay & Lockwood, 2007; Letelier, 2010; Martínez et al., 2018). Nonetheless, we focus on testing the hypothesis of non-linearity argued in the works of Adam et al. (2014), Arends (2017) and Sow and Razafimahefa (2018), proposed on the grounds that fiscal decentralization may have opposing effects of efficiency.

To perform this study, we explore the methodological literature on the impact of contextual variables on efficiency scores and implement the algorithm II of Simar and Wilson (2007), adapted for panel data. Using this technique implies a two-step procedure: first calculating bootstrapped DEA efficiency scores, and then obtaining bootstrapped estimates of the effects of fiscal decentralization and some control variables, on those same scores, through a truncated maximum likelihood regression.

In what remains of this dissertation, section 2 addresses first, the definition of concepts within the theory of decentralization and efficiency issues, as well as their relationship and, second, it surveys some pertinent empirical work. Section 3 addresses methodological issues involving the data, the measurement of efficiency and the empirical model that are sought to be obtained and constructed. In Section 4 the results from our empirical research and its interpretation, both for the efficiency measurement and are presented the impacts of fiscal decentralization on it. Section 5 summarizes the main ideas that can be drawn from this work.

2 Literature review

This section seeks to define the key concepts of fiscal decentralization and efficiency and to present the historical context and evolution of both concepts in question. Additionally, a survey of the empirical treatment of both concepts is carried out, separately and together, with particular focus on the education and health sectors.

2.1 Fiscal federalism theory

Fiscal federalism can be viewed as an attempt to address a problem raised by Samuelson in its public expenditure theory. Samuelson (1954, 1955) states that the maximization of social welfare cannot be achieved since it relies on utility functions of individuals, which are based on their preferences that are never truly and completely revealed. As it is discussed in the following subsection, fiscal federalism main ideas and favourable arguments evolved around the aim of maximizing social well-being through better knowledge of people's preferences. Also known as fiscal decentralization, it focuses on the distribution of revenue collection and spending power over the different levels of government, and also on intergovernmental transfers. These tasks and roles can be assigned to the various levels of government, as part of the allocative function of public authorities. According to Musgrave (1959), fiscal policy also aims at carrying out adjustments in the redistribution of income and wealth, and at stabilizing the economy, but these should only be conducted by the central government (Musgrave & Musgrave, 1973). In the next sub-sections regarding fiscal federalism theory, it is intended to comprehend the positive and negative aspects, that the sharing of fiscal power between different levels of government may produce.

2.1.1 Arguments in favour

The concept of fiscal decentralization was developed in the second half of the twentieth century, within the theory of decentralization. Oates (1972, as cited in Oates, 1999) contributed to the development of this theory by enunciating it in the decentralization theorem:

> (…) in the absence of cost-savings from the centralized provision of a [local public] good and of interjurisdictional externalities, the level of welfare will always be at least as high (and typically higher) if Pareto-efficient levels of consumption are provided in each jurisdiction than if any single, uniform level of consumption is

maintained across all jurisdictions (p. 1122).

Dissecting this theorem, the first thing to point out is the normative goal of decentralization, indicated by Oates, which is the maximization of the well-being in the jurisdiction where the public authorities act. Second, the way that the goal is achieved is through an efficient provision of the public good. And third, the rationale behind the argument of Oates is that better efficiency will be achieved by local provision, since jurisdictions are diverse and heterogeneous. In other words, individuals in different areas or regions have different preferences, so a more local public provision, with better and more information about those same preferences, will produce a better match between the actions and decisions of public authorities and the needs and wants of the citizens (Musgrave & Musgrave, 1973).

However, in its theorem, Oates indicates two needed conditions for a decentralized provision of public goods and services, which are the absence of economies of scale and spillover effects. Regarding this idea, Musgrave and Musgrave (1973) argue that the benefits of social goods are limited in space, giving the example of public lighting. Stiglitz (2000), completes this space definition of public goods, dividing them in local, national and international and indicating that is the territorial extent of the benefit that assigns them into each category. This argument that some public goods have a limitation in terms of who benefits from them, has a strong and direct link with another seminal work within the theory of fiscal federalism. Olson (1969) coined the principle of budgetary equivalence which consists in the idea that there must be a direct correspondence between those who benefit from the provision of a public good and those who pay for it. Summarizing the idea, if a public good has a space limited benefit, it should be the authority responsible for that jurisdiction to bear the provision costs of that same public good. Of course, this is an argument in favour of, not only spending autonomy of subnational governments, but also taxing autonomy, in the sense that decision on public expenditure will be only to the extent of the needs of the citizens, and so will be the taxation that will finance that expenditure.

Another argument in favour of fiscal decentralization is the possibility of competition between regions. Tiebout (1956) coined the idea of "voting with-the-feet", which is the mechanism that makes competition between regions work, by revealing the preferences of the individuals. Each jurisdiction offers different baskets of local public goods, and individuals have the possibility to move to the jurisdiction that best corresponds to their preferences. With the chance of moving within a set of regions, social welfare benefits, in the sense that public provisioners will try to assemble a basket of social goods that matches with the preferences of most citizens as possible. There is some more literature in favour of this idea, such as Brennan and Buchanan (1980) who look at the question in different terms, arguing that the competition and the mobility of individuals among regions has a positive limiting role on the taxing power of the state. The authors understand tax competition in the "voting with the feet" context, as a substitute to fiscal rules/constrains. And, also, Oates and Schwab (1988) create a model to interact competition between jurisdictions and efficiency and find positive effects of the former on the latter.

To complete the list of favourable arguments, it is worth mentioning the idea that decentralization (not just its fiscal side) promotes social gains through innovation in politics. Local administrative units have the potential to function as experimental laboratories. Therefore, a higher number of local governments, which differ in terms of political parties and organizational cultures, results in contrasting policy approaches (Pierson, 1995). This argument suggests that successful policy innovations originating within a particular jurisdiction can ripple outward and diffuse across other localities, ultimately establishing themselves as nationally accepted norms (De Vries, 2000). Localities can serve as pioneering testing grounds, where innovative policies with demonstrated effectiveness gain momentum and spread. The distinct advantage lies in the fact that experimenting with policies at the local level entails less risk compared to undertaking innovation on a broader, central government scale. This is because any potential failure associated with the new policy would impact a smaller demographic, minimizing the social costs (Vanberg & Kerber, 1994).

2.1.2 Critical issues

Fiscal decentralization has not been a consensual topic in economic theory and many authors have presented arguments against it. Arends (2020), reviews these ideas and highlights three dimensions where fiscal decentralization may impact public service delivery negatively: efficiency, equality and accountability. Since this work is focused on efficiency issues, the other two dimensions are addressed more briefly.

Beginning with efficiency, and recalling Oates theorem of decentralization, the two necessary conditions stated by the author for the local provision of public goods to have better results than a centralized provision are the first two aspects that work against fiscal decentralization. The first aspect, the existence of significant scale economies or fixed costs. When this is the case, the provision of a public good will be more efficient at broader levels of government. Sectors where the production of public goods and services requires high fixed costs or high entry costs may call for the provision at larger jurisdictions or the central government (Arends, 2020; Prud'homme, 1995; Tullock, 1969). The second aspect is the existence of spillover effects. A public good or service produced and provided by a local authority may have a space limitation in terms of benefits but may also generate positive externalities for neighbouring jurisdictions. This infringes the principle of fiscal equivalence from Olson (1969), creating imbalances in terms of those who support the financing and those who reap the benefits of a public provision. Prud'homme (1995) indicates that the magnitude of geographical spillovers of different public goods and services is one main criterion to determine the possibility of decentralization of the provision of those goods and services.

Regarding competition between jurisdictions, some concerns arise about this argument favourable to decentralization, suggesting that it may generate a "race to the bottom" (Oates & Schwab, 1988). From the idea of Brennan and Buchanan (1980), of fiscal decentralization serving as a control for the taxing power of the state, arises the concern that sub-national governments may reduce tax rates to a point where public provision will be harmed (Arends, 2020; Brueckner, 2004; Keen, 1998). This discussion has been developed, mostly, in the field of environmental economics, regarding environmental taxes (Cumberland, 1980; Udeagha & Breitenbach, 2023).

However, fiscal concerns about subnational governments are much more directed towards overspending than underspending (Arends, 2020). Courant et al. (1979) argue that increases in intergovernmental transfers are more prone to raise public expenditure than increases in subnational governments income (flypaper effect). Hines and Thaler (1995) add that the preference of local administration to spend grants over own income is explained by the tendency to avoid raising tax rates since in theory it comes with a loss in the number of votes and the possibility of re-election. This creates voter's fiscal illusion, who do not perceive the true tax price of the public spending done by the government (Turnbull, 1998). To sum up this argument against fiscal decentralization, efficiency in public service delivery is harmed through the overspending, which, due to the fiscal illusion and the flypaper effect, is more likely in subnational authorities, since intergovernmental transfers play a big role in their financing.

In terms of accountability, fiscal decentralization faces a severe obstacle that may hinder efficiency of public service delivery, which is related with efficiency and with the argument presented in the last paragraph. The case is of soft budget constraints and the higher likelihood of subnational governments to become overindebted, if no-bailout policies from the central government are not credible (Arends, 2020; Hankla, 2008).

Corruption and lobbying are also a problem raised by fiscal decentralization critics. The relationship between local decision makers and interest groups is closer than in central administrations, not just because of spatial reasons, but also because central governments suffer from more scrutiny and monitoring (Prud'homme, 1995; Tanzi, 1995). Nonetheless, this argument is controversial, and the opposite view is also found in the literature, under the explanation that lower levels of government present lower rents, and so less interesting rent-seeking opportunities (Fisman & Gatti, 2002; OECD, 2019).

To end the exposition of the negative side of fiscal decentralization, it is important to briefly report the questions raised in the literature about the potential risks to inequality. The main idea revolves around the fact some jurisdictions within a territory may have bigger sizes, higher fiscal capacities, more resources, and with that develop and grow faster than the other regions (Prud'homme, 1995). Yet again, there is a set of the literature that offsets this idea. For example, Rodríguez-Pose and Ezcurra (2010) found positive effects of fiscal decentralization in the reduction of regional disparities, in countries with high income, limited internal disparities and strong welfare state.

2.1.3 Fiscal decentralization and efficiency

Having reviewed the arguments for and against fiscal decentralization, it is necessary to take a look at more empirical research on the impacts of fiscal decentralization. Again, the impacts of fiscal decentralization are studied on various economic themes: public service delivery, economic growth, stabilization, fiscal sustainability, inequality and regional disparities.

Nevertheless, Arends (2020) draws attention to a main issue of empirical studies on the impacts of fiscal decentralization and the efficiency of public service delivery. Most works relate fiscal decentralization with performance outcomes, and not with efficiency. This misconception of efficiency seems to have created a gap in the literature. Some exceptions are central studies that were the baseline for the present dissertation. These are studies that apply two-step approaches in their analysis: first estimating efficiency scores, with input and output variables, and only then assessing the impacts of fiscal decentralization on those scores.

Sow and Razafimahefa (2018) estimate efficiency through a Stochastic Frontier Analysis (SFA) model, for the education and health sectors. The results indicate positive impacts, through a direct channel, on advanced economies, but negative on emerging and developing ones. However, the most notorious result of their work is the non-linear relationship tested by the authors. An U-shaped relationship is found, which indicates "that a sufficient degree of expenditure decentralization is required to bring about positive impacts" (Sow & Razafimahefa 2018, p. 221).

The rest of the works differ from the one of Sow and Razafimahefa (2018) since efficiency scores are calculated through the non-parametric method of Data Envelopment Analysis (DEA). Martínez (2018) evaluates the contribution of fiscal decentralization to efficiency in the overall public sector, finding a negative correlation between both variables, that is, a higher level of decentralization is associated with lower efficiency. Arends (2017) focuses on the relationship of fiscal decentralization and public health efficiency, contending that while on the expenditure side it tends to decrease efficiency healthcare, on the revenue side it enhances it. Nonetheless, Arends also reports a similar U-shaped non-linear relationship as in Sow and Razafimahefa (2018). At last, Adam et al. (2014) reaches the opposite conclusion about the non-linear relationship between fiscal decentralization and efficiency, in education and health. An inverted U-shaped relationship is reported, indicating that, from a certain level, fiscal decentralization may start to harm efficiency.

2.2 Efficiency

2.2.1 Concept and measurement

The provision of public goods should be efficient. Thus, there is a need to better explain what the concept of economic efficiency means and its importance as a normative objective of the public sector.

A more generic definition of efficiency can be gathered from the more common definition of economics, that is, the science of decisions, where resources are scarce, and the needs of agents are unlimited. Therefore, the management of resources needs to be the best possible, which means the greatest possible use in production and least possible waste of resources, in order to satisfy the needs of economic agents. Derived from the analysis of production functions, a technically efficient production will be one that uses the smallest possible number of resources, to achieve a certain output, or where, having a given set of resources, production is maximized (Besanko et al., 2020; Coelli et al., 2005; Papanicolas & Smith, 2014). This is the concept of technical (or productive) efficiency.

However, Farrell (1957) defines overall efficiency not just as technical efficiency but also adding the concept of price efficiency. According to Coelli (2005), the terminology overall efficiency and price efficiency evolved to economic efficiency and allocative efficiency, respectively. The last one regards the optimal proportional use of a set of resources, taking into account the preferences of economic agents, prices and technology (Coelli et al., 2005; Mueller, 2012; Papanicolas e Smith, 2014). In this regard, it is also important to highlight the concept of Pareto efficiency, which is related to allocative efficiency, since it also depends on the allocation of resources in order to optimally satisfy the preferences of individuals. The Pareto criterion indicates that the best possible allocation of resources happens, when it is impossible to increase the utility of one economic agent without decreasing that of another (Besanko & Braeutigam, 2020; Hindricks and Myles 2013).

The study and measurement of efficiency were introduced to economic literature by seminal works from authors such as Debreu (1951), Farrell (1957) and Koopmans (1951) Since then, several ways to measure efficiency were developed. The broader division found in the literature is between parametric and non-parametric methods. Parametric estimation of efficiency depends upon an *a priori* specification of a particular functional form (eg. linear, Cobb-Douglas) to describe production's technology (eg. input-output relationship, cost functions) and allows for the distinction between efficiency and statistical noise. Non-parametric methods, on the other hand, have a flexibility advantage, as they do not require any assumptions on the functional form of technology of production, nonetheless their estimates do not account for statistical noise SFA is the most common parametric method of assessing efficiency, while DEA and Free Disposal Hull (FDH) are the most used non-parametric techniques (Coelli et al., 2005; De Borger & Kerstens, 1996; Kneip et al., 2015; Murillo-Zamorano & Vega-Cervera, 2001).

2.2.2 Efficiency Analysis in the Education Sector

Concerning the education sector, De Witte and López-Torres (2017) exhibit a list of input variables divided in four categories: student-related; family-related; education institution; and community-related. And the same goes for output variables, which are divided into:

student achievement; publications and research activity; educational results; and job market/success. Since they consider 223 papers, the full list of factors is extensive, therefore, it was decided to consider only the studies classified by the authors as analysis of the education system (country or multi-country), to make an initial filtering of possible variables. In terms of inputs, the following are considered: Expenditures; Lifestyle; Parental education; Resources available at home/internet use; Size variables; Teacher experience/education; Student/teacher ratio; Teaching methods/organization and management/quality /innovation; Faculty to student ratio/number of faculties/faculties with doctorates; Educational resources; Acceptance rate; Personnel and Percentage of population with post-primary education.

Regarding outputs, works analysing the education system used: Students' test scores/students' performance; Number of graduates; Citations; Publications; Employability; Starting salary of graduates; Student satisfaction; Enrolment. It is important to notice that some of these variables specifically relate to higher education, which does not invalidate their relevance, however the papers that used them should not have been classified by De Witte and López-Torres (2017) as studies at educational system level, but at university level. Thus, Faculty to student ratio/number of faculties/faculties with doctorates; Acceptance rate; Citations; and Publications are excluded from the list, for the purpose of our study.

2.2.3 Efficiency Analysis in the Health Sector

For the efficiency analysis of the health sector, Mbau et al. (2022), provide a literature review, that include 131 papers. In this work, inputs are divided into three main categories: health system building blocks, social determinants of health, and health risk factors. The former have the most widely used inputs: expenditures, human resources, and medical equipment. The only social determinant of health considered is education, and the health risk factors are tobacco and alcohol consumption, nevertheless, their effect showed little significance.

Outputs are also divided into three groups: single health outcomes, intermediate health service outputs, and composite indices of either the intermediate outputs or health outcomes. Mortality/survival rates and life expectancy, which belong to single measures of health outcomes, are the two most used variables. The most common intermediate health service outputs are variables of inpatient and outpatient workload, and maternal and childcare services. Composite measures are more rarely chosen since they are usually created by the authors of the paper.

This analysis allowed for a first selection of the possible factors that should be considered to affect education and health efficiency. Nonetheless, there is another type of literature that should be considered for this study, which addresses public sector efficiency.

2.2.4 Public sector efficiency

Afonso et al. (2005) present the seminal idea of a public sector efficiency (PSE) indicator calculated as the ratio between a public sector performance (PSP) indicator and the public expenditure (PEX), for any country i:

$$\mathrm{PSE}_i = \frac{\mathrm{PSP}_i}{\mathrm{PEX}_i} \tag{1}$$

The PSP indicator is composed of seven performing areas of the government. The first four are administrative, education, health, and public infrastructure, and their indicators are called "opportunity indicators". The last three represent the Musgravian tasks of the government, distribution, stabilization and allocation, and its indicators correspond to the "Musgravian indicators". The PEX is a more direct indicator that represents the public expenditure for each one of the 7 government performing areas. When computed in the DEA, the PEX is used as an input and the PSP as the output.

Nevertheless, our study is only focused on education and health, individually, so the indicators required are inputs and outputs for these two areas. In terms of inputs, the literature is more consensual, and most studies use only one, which is the expenditure of the government in percentage of GDP, either for education or health (Adam et al., 2014; Afonso et al., 2023; Afonso & Alves, 2022; Afonso & St. Aubyn, 2005, 2006; Sow & Razafimahefa, 2018). Only Dutu and Sicari (2020) use two inputs and modify the logic of using PEX as an input and PSP as the output. For education, the indicators used are the spending per student in secondary education, and the economic, social and cultural status (ECSC) index. For health, the total healthcare spending per capita and an index composed by GDP per capita, educational attainment of the adult population, nitrogen oxide emissions, fruit and vegetable consumption, tobacco and alcohol consumption (15-year lag). So, they use a "two input - one output" model that is justified in order to limit a small sample bias. Plus, the input indicators that do not represent the government expenditure are used to "control for factors that do influence the outcome variable but are not directly related to the health and education systems" (Dutu & Sicari, 2020, p. 257).

In terms of outputs, more variations can be reported. For education, most of the already mentioned studies present both quantitative and qualitative/performance indicators. Regarding the first one, the variables used are enrolment rates (Afonso et al., 2005, 2023; Afonso & Alves, 2022; Sow & Razafimahefa, 2018), or years of schooling (Adam et al., 2014; Sow & Razafimahefa, 2018; Martínez et al., 2018). Concerning the latter, the variables are quality of educational system (Afonso et al., 2023; Afonso & Alves, 2022) and PISA test scores in reading, science and math, (Afonso et al., 2005, 2023; Afonso & Alves, 2022; Afonso & St. Aubyn, 2006). In terms of health indicators, infant survival/mortality rate and life expectancy are always both employed by Afonso et al. (2005, 2006, 2020, 2022) and by Sow and Razafimahefa (2018). Adam et al. (2014) use only the infant mortality rate and Dutu and Sicari (2020) only life expectancy. Additionally, Afonso et al. (2023) and Afonso and Alves (2022) also use cardiovascular disease, cancer, diabetes or chronic respiratory disease survival rate. Still in matter of outputs, Adam et al. (2014) opt to multiply the health and education indicators by the ratio of public expenditure on total expenditure, respective to each area, to attenuate the impact of private spending in these outcomes.

3 Methodology

This chapter aims at explaining the method chosen to respond to the research question. With the goal of understanding the effects of fiscal decentralization to efficiency, it is necessary to, first, create a measure of efficiency and then, regress fiscal decentralization on it. To do this, we explore the DEA method and the literature regarding the analysis of contextual variables on efficiency scores. After the choice of the model, we proceed presenting our sample.

3.1 DEA framework

DEA is a quantitative method that uses mathematical programming techniques to assess and compare the efficiency of decision-making units (DMU). It constructs a convex frontier over the data, that represents the best achievable performance and calculates efficiency scores based on how closely each DMU approaches this frontier (Coelli et al. 2005; Cook et al., 2014; Kneip et al. 2015).

The works of Charnes et al. (1978) and Banker et al. (1984) develop two distinct DEA models, CCR and BCC, respectively. The difference between both lies on the fact that the former assumes constant returns to scale (CRS), and the latter variable returns to scale (VRS). This concerns to the relationship between input and output variations which the CRS model considers as being proportional and the VRS model does not.

Additionally, DEA models are also divided in input or output oriented relating to whether an input or output measure is used to calculate efficiency. Input measures of efficiency indicate by how much a unit could reduce its inputs without a decrease in the outputs. And output measures reflect by how much a unit could increase its outputs maintaining the same input quantities (Coelli et al., 2005).

In order to make a choice about both returns to scale and model orientation, we take into consideration the relevant literature, and the goals and framework of this dissertation. The use of VRS is consensual in the literature, due to the plausible hypothesis that the considered DMUs, which are the governments, are not operating in a optimal scale, condition necessary to use CRS (Adam et al., 2014; Afonso et al., 2023; Afonso & Alves, 2022). In what concerns input- or output-orientation, both orientations are commonly applied (Adam et al., 2014; Afonso et al., 2023; Afonso & Alves, 2022). Nonetheless Martínez (2018) chooses an output-oriented model, arguing that given the limited amount of its resources, every government tries to maximize the production of goods and services. This point of view is aligned with the aim of the present work, since we intent to examining the role of fiscal decentralization as welfare enhancer (output maximization) rather than a budgetary constraint (input minimization).

In order to specify the DEA output VRS model, first we consider the radial distance function of outputs as a function D_O: $\mathfrak{R}_+^N \times \mathfrak{R}_{++}^M \rightarrow \mathfrak{R}_+ \cup \{+\infty\}$ defined as follows:

$$D_O\ (x, y) = \min_{\mu} \{\mu : y / \mu \in P(x)\}, \forall x \in \mathfrak{R}_+^N \qquad (2)$$

y being an output vector, and P(x) being the set of all output vectors that it possible to produce with the input vector x. Then, the output distance function indicates the maximal radial expansion of vector y, given vector x.

Taking this into account, the technical efficiency measure of an output vector y, TE_O (x, y), is a function TE_O: $\mathfrak{R}_+^N \times \mathfrak{R}_{++}^M \rightarrow \mathfrak{R}_+$ defined as follows:

$$TE_O\ (x, y) = \max_{\theta} \{\theta : \theta\, y \in P(x)\}, y \in P(x) \qquad (3)$$

In consequence, the technical efficiency measure of outputs represents the inverse of the distance function of outputs:

$$TE_O\ (x, y) = \frac{1}{D_O\ (x, y)} \qquad (4)$$

Now, to define our DEA model we take into consideration:

$$S_{KT} = \{(y^{kt}, x^{kt}), k = 1, \dots , K; t = 1, \dots , T\} \qquad (5)$$

a sample with KT dimension, where K represents the number of DMUs and T the number of periods considered, and y^{kt} and x^{kt} represent the output vector and input vector, respectively, of DMU k, in period t.

$$T\hat{E}_O(x^j,y^j) = \frac{1}{D_O\ (x^j,y^j)} = \max_{\theta,\, z} \{\theta : \theta\, {}^j_y \in P(x^j)\}$$

$$\max_{\theta,\ z} \theta$$

$$\text{s.t.} \sum_{k=1}^{K} z^k .\ y_m^{kt} \geq \theta\, y_m^{jt}\ , m = 1, \dots, M;$$

$$\sum_{k=1}^{K} z^k .\ x_n^{kt} \leq x_n^{jt}\ , n = 1, \dots, N; \qquad (6)$$

$$\sum_{k=1}^{K} z^{kt} = 1$$

$$z^{kt} \geq 0\ ,\ \ k = 1, \dots K\ ,$$

$\sum_{k=1}^{K} z^{kt} = 1$ is the condition that imposes VRS and z^{kt} are intensity variables that indicate each variable weight regarding the determination of the efficiency frontier for each period t.

3.2 Second stage analysis

This subchapter delves into the second stage analysis of this study, with the objective of measuring the impact of fiscal decentralization on the efficiency values calculated in the previous step. The following discussion revolves around identifying the most suitable econometric solution for the approach here presented.

The literature about the impact of contextual/environmental variables on DEA efficiency scores has used several methods. Liu et al. (2016) identify some research fronts in DEA, with bootstrapping and two-stage approaches being the ones that matter for this work. The works of Simar and Wilson (SW), and Banker and Natarajan (BN) are the ones recognised as more important.

Banker and Natarajan (2008) argue in favour of two-stage DEA approaches over parametric ones. The methods they defend are DEA+OLS or DEA+Tobit, procedures that have been widely used. However, Simar and Wilson (2007) present a remark to the conventional two-step approach, indicating that the studies that employed an OLS or Tobit regression on the second stage do not have a well-defined data generating process, which creates uncertainty about the validity of those regressions. Additionally, Simar and Wilson (2007) state that the major problem not addressed is the serial correlation between DEA estimates. This means that the values generated by DEA are correlated with each other, since the efficiency frontier is established through the efficient DMUs. Bearing this in mind, SW suggest a bootstrapping method, along with a truncated maximum likelihood estimation, to perform an analysis of contextual variables on DEA efficiency estimates.

The authors criticize each other's works in similar ways. Banker and Natarajan (2008) indicate that SW assumptions are too restrictive, and Simar and Wilson (2011) advocate that BN also made restrictive assumptions in their model, although not explicitly. Banker et al. (2019), the latest paper addressing this discussion, present some Monte Carlo simulations to argue that the DEA+OLS and DEA+Tobit methods provide consistent estimators. This work concludes that both SW and BN methods are valid under certain DGP assumptions, and that the choice between them must depend on the context of each study.

Summarizing this discussion, both methods are criticized for being too restrictive and Liu et al. (2016) indicate that the discussion is confusing, and it is not clear how and when each method should be chosen.

Since methodological literature does not provide a clear argument to choose over the two methods analysed, it is important to look at the empirical literature on the effects of contextual variables on DEA efficiency estimates, for the education and health sectors, and understand what choices have been made. Regarding education it is possible to find some articles that apply the SW method (Agasisti et al., 2023; Agasisti & Zoido, 2019; Aparicio et al., 2019; Martínez-Campillo & Fernández-Santos, 2020) and others that choose the BN's (Agasisti, 2014; Aparicio et al., 2018; Duh et al., 2014). In health, the situation is analogous, Cordero-Ferrera et al. (2011), Lupu and Tiganasu, (2022) and Samut and Cafrı, (2016) are examples of studies that choose the BN method, while Ahmed et al. (2019), Chowdhury and Zelenyuk (2016) and Zhang et al. (2020) choose SW's. Afonso and St. Aubyn, (2006, 2011) carry out a two-stage DEA analysis in education and health (respectively), using both DEA+Tobit and DEA+Bootstrap analysis, reporting no significant difference on the results from both methods.

Adam et al. (2014) and Martínez et al. (2018) are also two relevant works to look for at this stage since they also regress fiscal decentralization on DEA efficiency estimates. Both these studies indicate that it is not possible to apply the SW method to panel data, or at least it had not been applied to their knowledge. Considering this, they opt for a similar Tobit regression in the second stage of their analysis, although Adam et al. (2014) also consider an adaptation of the SW approach, using bootstrapping but with a Tobit regression instead of a truncated maximum likelihood one. This point is fundamental to the present work since it uses panel data. It is true that the SW model was designed for cross sectional data (Badunenko & Tauchmann, 2019). Nevertheless, Du et al. (2018), which investigate the influence of earning asset diversification on Chinese bank efficiency from 2006 to 2011, present an extension of the SW method to panel data. This extension solves the problem of the non-applicability of the SW approach to studies similar to ours, and therefore we choose to apply it.

3.2.1 Simar and Wilson method: panel data application

We consider the following statistical model based on Du et al. (2018):

$$\hat{\theta}_i^t = z_i^t\beta + d^t\gamma + \epsilon_i^t, \qquad i = 1, \dots, n_t \text{ and } t = 1, \dots, T \tag{7}$$

where z_i^t represents the contextual variables of the model, d^t the dummy variables and γ the annual effects that will be estimated.

As in Du et al. (2018), a truncated regression with double-bootstrap approach is employed to efficiency analysis, where the error term, ϵ_i^t, has a truncated nature. Also, it is assumed that $\epsilon_i^t \sim N(0, \sigma_\epsilon^2)$ with left-tail truncation at $1 - z_i^t\beta - d\gamma$. This model is based on Simar and Wilson (2007) but Du et al. (2018) make this extension for panel data. The authors state that the aim of this specification is to account for the possibility of different frontiers in different periods, using dummy variables. Nevertheless, this method also allows a common regression relationship (common slopes), with the dummy variables taking into account only the annual effects. Doing this, it is possible to use the SW method to measure the impact of fiscal decentralization, something that distinguishes this work from the ones of Adam et al. (2014) and Martínez et al. (2018), who address the same topic.

Du et al. (2018) indicate the following steps to perform this extension[1]:

Step 1. For each period t (t = 1, …, T), use the original data, denoted as $S_{n_t}^t = \left\{ \left(x_i^t, y_i^t\right) : i = 1, \dots, n_t \right\}$, to compute $\hat{\theta}_i^t$ using separately for each year t.

Step 2. Organize the DEA efficiency estimates and their factors into the panel data set $SN = \{ \{ \left(\hat{\theta}_I^1, z_i^1, d^1\right) \}_{i=1}^{n_t}, \{ \left(\hat{\theta}_I^2, z_i^2, d^2\right) \}_{i=1}^{n_t}, \dots, \left\{\left(\hat{\theta}_I^T, z_i^T, d^T\right) \}_{i=1}^{n_t}\right\}$, with sample size $N = \sum_{t=1}^{T} n_t$. Exclude the observations on the boundary (i.e., remove the "spuriously efficient" observations and use only $m_t < n_t$ observations for which $\hat{E}_i^t > 1$at this stage) and use the method of maximum likelihood estimation to obtain the estimated β, γ and σ_ϵ in the

[1] See also Simar and Wilson (2007) and Badunenko and Tauchmann (2019) for the original cross-sectional formulation.

truncated regression of $\hat{\theta}_I^t$ on z_i^t and d^t denoting them as $\hat{\beta}, \hat{\gamma}$ and $\hat{\sigma}_\epsilon$.

Step 3. Loop over the next four steps L_1 times to obtain a set of bias-corrected estimates $\mathcal{B}_i^t = \{\theta_{i,b}^{t^*}\}_{b=1}^{L_1}$ as following:

Step 3.1 For each DMU i = 1, ..., n_t and t = 1, ..., T, draw $\hat{\epsilon}_{ib}^t$ from $N(0, \hat{\sigma}_\epsilon^2)$ distribution with truncation on the left at $\left(1 - z_i^t\hat{\beta} - d^t\hat{\gamma}\right)$

Step 3.2. For each i = 1, ..., n_t and t = 1, ..., T, compute the bootstrap artificial efficiency scores as $\theta_{i,b}^{t^*} = z_i^t\hat{\beta} + d^t\hat{\gamma} + \hat{\epsilon}_{i,b}^t$.

Step 3.3. Define $x_{i,b}^{t^*} = x_i^t, y_{i,b}^{t^*} = \left(\hat{\theta}_I^t / \theta_{i,b}^{t^*}\right) \times y_i^t, z_{i,b}^{t^*} = z_i^t$ for all i = 1, . . ., n_t and t = 1, . . ., T.

Step 3.4. Separately for each year (t = 1, ..., T), compute $\theta_{i,b}^{t^*}$ using formulation (3) but after replacing y_j^t and $x_j^t$with their bootstrapping analogues $y_{j,b}^{t^*}$ and $x_{j,b}^{t^*}$for all j = 1, . . ., n_t.

Step 4. For each DMU i = 1, ..., n_t and t = 1, ..., T, compute the bias-corrected estimates $\hat{\hat{\theta}}_i^t$ defined by $\hat{\hat{\theta}}_i^t = \hat{\theta}_i^t - B\left(\hat{\theta}_i^t\right)$, where $B\left(\hat{\theta}_i^t\right)$ is the bootstrap-based estimate of the bias of $\hat{\theta}_i^t$ using the bootstrapping estimates in $\mathcal{B}_i^t$ obtained in Step 3.

Step 5. Organize the bias corrected efficiency estimates and their factors into the panel data set $SN = \{\{\left(\hat{\hat{\theta}}_I^1, z_i^1, d^1\right)\}_{i=1}^{n_t}, \{\left(\hat{\hat{\theta}}_I^2, z_i^2, d^2\right)\}_{i=1}^{n_t}, \ldots, \left\{\left(\hat{\hat{\theta}}_I^T, z_i^T, d^T\right)\}_{i=1}^{n_t}\right\}$, and use the method of maximum likelihood estimation on the full sample (of size $N = \sum_{t=1}^{T} n_t$) to estimate the truncated regression of $\hat{\hat{\theta}}_I^t$ on z_i^t and d^t yielding new (redefined) estimates of the regression, denoting them as ($\hat{\hat{\beta}}, \hat{\hat{\gamma}}$ and $\hat{\hat{\sigma}}_\epsilon$)

Step 6. Loop over the next three steps L_2 times to obtain a set of bootstrap analogues of parameters of the regression $\left\{\hat{\beta}^*, \hat{\gamma}^*, \hat{\sigma}_\epsilon^*\right\}_{b=1}^{L_2}$ as following:

Step 6.1. For each observation (i = 1, ..., n_t and t = 1, ..., T), draw $\hat{\hat{\epsilon}}_{i,b}^t$ from $N\left(0, \hat{\hat{\sigma}}_\epsilon\right)$ with left-truncation at $\left(1 - z_i^t\hat{\hat{\beta}} - d^t\hat{\hat{\gamma}}\right)$.

Step 6.2. Obtain the double-bootstrap analogues of efficiency scores as following: $\theta_{i,b}^{t^{**}} = z_i^t\hat{\hat{\beta}} + d^t\hat{\hat{\gamma}} + \hat{\hat{\epsilon}}_{I,b}^t$ for each i = 1, . . ., n_t and t = 1, . . ., T.

Step 6.3. Use the maximum likelihood method to estimate the truncated regression of $\theta_{i,b}^{t^{**}}$

on fd_i^t and d^t, yielding estimates $\hat{\hat{\beta}}^*, \hat{\gamma}^*$ and $\hat{\hat{\sigma}}_\epsilon^*$.

Step 7. Use the bootstrapping values in $\left\{\left(\hat{\beta}^*, \hat{\gamma}^*, \hat{\sigma}_\epsilon^*\right)_b\right\}_{b=1}^{L_2}$ and the refined estimates $\hat{\hat{\beta}}, \hat{\gamma}$ and $\hat{\hat{\sigma}}_\epsilon$ to construct bootstrap-based confidence intervals for each element of β, γ and σ_ϵ. In terms of bootstrap replications, we consider $L_1 = 500$ and $L_2 = 2000$.

As in any method, two-stage DEA is not without its limitations. In this case, Du et al. (2018) state that one is the assumption of 'separability', which requires that the explanatory or environmental variables used in the second stage to explain inefficiency cannot influence the technology frontier. In order to proceed with the following regression analysis, this assumption should be granted. Intuitively, this means that fiscal decentralization does not directly affect the production of public health and education services or its resource allocation. That is a plausible assumption, however, since the (theoretical) advantage and goal of fiscal decentralization is that services are produced and provided and, therefore, expenditures are made by public bodies that have better information about citizen preferences.

3.3 Data and Variables

Next, let us describe the data and variables used in this work for both the educational and health sectors, and for both stages of the analysis.

3.3.1 DEA variables

According to Golany and Roll, (1989) two steps must be taken before the application of the DEA model to an efficiency study. First, the definition and selection of decision-making units (DMUs) and then the choice of the relevant inputs and outputs. For step one, the aim is to select homogeneous DMUs. The units chosen must perform the same tasks, with similar goals and under the same market conditions. In this case, the DMUs selected are countries' governments. Confining the analysis to their specific role in financing education or the health system meets the first condition. The intention of any government in intervening in these two areas of analysis is to improve the educational and health levels of the population, so the second point also checks. Using only EU countries is a way of homogenizing the group of DMU's, in respect of the "performing under the same market conditions" requirement. EU countries have common rules and regulations, aligned policies and goals, either in terms of education and health, or in fiscal terms. Furthermore, the socio-economic conditions are more comparable, and the availability of data is higher, more specifically, this decision allows the use of Eurostat database. Then, this study constructed and employed a panel database that covered the 25 EU countries with subnational governments[2], for a period 22 years (2000-2021).

The second step of choosing the relevant inputs and outputs is the most important, but also difficult part of the process. Golany and Roll (1989) stated that, initially, it is important to consider a wide list of possible variables, something that was done in the literature review. Having that into account, the inputs and outputs chosen for the DEA models to the education and health sectors are indicated in Table 1 and Table 2 respectively.

In both sectors, the respective public expenditure was considered an input, as in most of the literature that focuses on education and health system's efficiency. Although the public sector is the decision maker being studied, this work distances itself from PSE literature, because the point of view here presented is sectorial and not holistic in terms of the public sector. This being said, other inputs are considered in the DEA models. For both sectors, inputs regarding human resources are considered: in education, the teacher-student ratio, and in health the number of medical doctors per thousand habitants. The teacher-student ratio is the inverse of the student teacher ratio, which is an easier indicator to interpret. However, the DEA variables need follow a logic of "the more, the better". Since it is considered that a lower number of students per teacher is better, the inverse of it is used. Aiming to account for the influence of private expenditure on the outcomes of education and health, household consumption in both areas was considered as a non-discretionary input since it is not in control of the government.

In terms of outputs for education, the model includes the PISA test results, enrolment rates and the employment rates of young people after completing tertiary education. Enrolment rates deserve a special not since the gross rates are used, which means that values above 100% are presented. This occurs because, in this case, enrolment rates are calculated dividing the number of enrolments by the population of the corresponding age group of secondary education. However, some enrolments are from students not in the corresponding age group. This disparity leads to more enrolments than people in the

[2] Cyprus and Malta were excluded from the sample since Eurostat indicates that the subnational governments dimension, on government data, is not applicable to them.

Table 1: Variables for education sector's DEA model

Variables	Description	Unit	Source
Inputs			
Public expenditure on education (PEeduc)	General government expenditure in Education (COFOG 09)	% GDP	Eurostat - GOV_10A_EXP
Teacher-student ratio (TS_ratio)	Inverse of the student-teacher ratio for ISCED levels 1 to 3	Ratio	Own calculation based on: Eurostat - EDUC_ISTE and Eurostat - EDUC_UOE_PERP04
Household consumption on education (HC_educ)	Final consumption expenditure of households on Education (COICOP 10)	% of total household consumption expenditure	Eurostat -TEC00134
Outputs			
PISA test results (PISA)	Simple average of Pisa Test results (Math, Reading and Science)	Scores	Own calculations based on OECD iLibrary - Books Book series - PISA
Enrolment rates (Enrol_rate)	Gross Enrolment rate, secondary education (ISCED 2-3)	% of population in the corresponding age group	World bank - SE.SEC.ENRR
Employment rates, after tertiary education (Emp_rate)	Employment rates of 15 to 34 years old, not in education and training, 1 to 3 years after completing tertiary education (ISCED 5-8)	% of total population	Eurostat - EDAT_LFSE_34

Source: Own elaboration

corresponding age group. Net enrolment rates have into account this disparity, but the availability of data for them is much lower, with that being the main reason why this study proceeded with the use of gross enrolment rates.

The outputs chosen for the DEA model of the health sector were the two most found in the literature: life expectancy and the infant survival rate (ISR). The latter follows the same logic described for the teacher-student ratio, being described in the literature as the inverse

Table 2: Variables for health sector's DEA model

Variable	Description	Unit	Source
Inputs			
Public expenditure on health (PEhlth)	General government expenditure in health (COFOG 07)	%GDP	Eurostat - GOV_10A_EXP
Doctors per habitant (Docs_ph)	Number of medical doctors per thousand habitants	Ratio	Eurostat - HLTH_RS_PRSRG
Household consumption on health (HC_hlth)	Final consumption expenditure of households on health (COICOP 06)	% of total household consumption expenditure	Eurostat - TEC00134
Outputs			
Infant survival rate (ISR)	Ratio of children that survived the first year to the number of children that died	Ratio	Own calculation based on: Eurostat - DEMO_MINFIND
Life expectancy (Life_exp)	Mean number of years a new-born child is expected to live	Years	Eurostat - SDG_03_10

Source: Own elaboration

of the infant mortality rate (IMR). It is calculated using the following formula:

$$ISR=\frac{1000\text{-}IMR}{IMR} \tag{8}$$

Some descriptive statistics of the input and output variables, for both models are presented in Table 3. Nevertheless, observing table 3 it is possible to see the imbalances in the magnitude of each indicator, a fact that may create some scale problems in the performance of the DEA model, as described by Sarkis (2007). Taking as an example the mean values of the public expenditure and household expenditure on education, 0.0509 and 542.07, respectively, the differences become explicit. To solve this problem, a mean normalization of the data, proposed by Sarkis (2007) is performed, by year. For each value of each input and output, of both sectors, the following formula was applied, by year:

$$Vnorm_{it}=\frac{V_{it}}{\overline{V}_t} \tag{9}$$

$Vnorm_{it}$ representing the normalized value, for a country, in a certain year, V_{it} the original value, and $\overline{V}_t$ the mean value of a given input or output, in a year. The descriptive statistics for these variables is exhibited in the Annex, in table 8.

Table 3: Inputs and outputs descriptive statistics

Sector	Variable	Obs	Mean	Std. dev.	Min	Max
Education	PEeduc	550	.0509309	.0096763	.028	.071
	TS_ratio	550	.0831855	.0152066	.0564972	.125
	HC_educ	550	542.0691	373.1712	15.30779	1832.461
	PISA	550	489.1529	24.98174	409.7047	552.8498
	Enrol_rate	550	1.081842	.1651775	.7977613	1.639347
	Emp_rate	550	.8362269	.0877335	.454	.966
Health	PEhlth	550	.0622927	.0133925	.032	.101
	Docs_ph	550	346.7313	79.53596	192.65	629.3878
	HC_hlth	550	486.5066	278.2023	20	1420
	ISR	550	269.5769	105.5696	52.76344	713.2857
	Life_exp	550	78.30465	3.371728	69.90785	84

Source: own elaboration

3.3.2 Fiscal Decentralization measure and controls

Similarly to the previous subsection, the present one aims at providing a description of the environmental variables chosen to enter the truncated maximum likelihood regression of the second stage of the SW model, as described in section 3.2. These are variables that are not assumed to have a direct influence on the outcomes of the education and health sectors, but rather on their efficiency. In other words, it is assumed that its impact is verified in the input-output relationship, and not just in its individual parts. Table 4 presents the main information on each variable.

Fiscal decentralization is the main independent variable of the model and the focus of this work. The first thing to notice is that fiscal decentralization can be observed in various perspectives, but the main division may be done in terms of revenue and expenditure. Here, the focus is just on the expenditure side since the analysis is sectorial and government revenue or tax data is not reported sector wise. Another reason is the fact that, in this work, the impact of the government finances on the outcomes of each sector, is given by the input public expenditure. In fact, the goal of this work is to understand how

Table 4: Environmental variables for the second stage of SW model

Variable	Abbreviation	Description	Unit	Source
Fiscal decentralization	FD_spent	Subnational governments expenditure on education/health (COFOG 09/COFOG07)	% of general government expenditure	Own calculations based on Eurostat-GOV_10A_EXP
GDP per capita	GDPpc_PPS	Gross Domestic Product, per capita	Power Purchasing Standard units	Eurostat - NAMA_10_PC
Good Governance	good_gov	Average of government effectiveness, rule of law, regulatory quality, and control of corruption dimensions	Index ranging 0-1	Own calculations based on World Bank - Worldwide Governance Indicators
Population density	Pop_Den	Annual average population by land area	Population per km^2	Eurostat - DEMO_R_D3DENS
Urban population	Urb_pop	People living in urban areas	% of total population	World Bank - SP.URB.TOTL.IN.ZS
Old-age dependency ratio	OA_dep	Ratio between inactive population (65+ years old) and active population (20-64 years old)	Ratio	Eurostat - DEMO_PJANIND
Youth unemployment rate	unemp_youth	Unemployed population (15-24 years old)	% of active population	Eurostat - UNE_RT_A_H and UNE_RT_A
Total unemployment rate	unemp_tot	Unemployed population (15-74 years old)	% of active population	Eurostat - UNE_RT_A_H and UNE_RT_A

Source: Own elaboration

the share of this public expenditure affects the whole input-output relationship, in each sector. Having this into account, the fiscal decentralization measure calculated here is the subnational governments (SG) share of the consolidated general government (GG) expenditure, for the education and health sectors. This indicator was constructed based on Dougherty and Montes (2023) "spent by" methodology, that indicate that "this approach show which is the level of government that actually executes spending in each policy area" (p. 17).

The formula used for each sector is the following:

$$FD_{spent} = \frac{\text{SG expenditure - Intergovernmental transfers paid by SG}}{\text{GG expenditure}} \quad (10)$$

It is important to notice that the majority of the EU countries only have one level of subnational government, the local one. Nonetheless, Austria, Belgium, Germany and Spain, are the exceptions, and present state governments, an intermediate level. This difference, and the impacts it may have due to the distinct dimensions of government levels are acknowledged. However, the analysis proceeds gathering both local and state expenditure shares for these countries, since it represents better the true value of expenditure decentralization in these countries than just the local expenditure, and a separate look would care for a different analysis. Stegarescu (2005) is critical of this fiscal decentralization measure, indicating that it is not clear at what extent it reflects the allocation of functions and resources to different levels of government or just the relative size of sub-central government activities. Stegarescu (2005) also adds that public finance data is not a good indicator to measure the provision of public goods by the subnational governments. Nonetheless, no upgraded measure of expenditure decentralization is constructed by Stagarescu (2005), and none of the studies of interest to ours (Adam et al., 2014; Arends, 2017; Sow and Razafimahefa, 2018) report different measures, than the one used here[3]. The criticisms of Stagarescu (2005) and the limitations of the measure are acknowledged, but they do not interfere with the main goal of the indicator, which is to quantify the amount of spending executed by subnational governments, in education and health.

[3] In the cited works is not even clear if intergovernmental transfers are considered when calculating the share of subnational government expenditure, which would mean an upgrade of this work in relation to the closest literature.

Changing the focus now to the control variables, Gross Domestic Product per capita (GDPpc) controls for the size of the economy taking into account the population size of the country. The good governance measure is a compound index that aggregates data from four World Bank governance indicators, control of corruption, government effectiveness, political stability and absence of violence/terrorism, and rule of law. This measure is constructed based on (Miranda-Lescano et al., 2022, 2023), averaging the four indicators, but transforming its scale from between -2.5 and 2.5, to between 0 and 1, in order to avoid negative values. The good governance measure permits the control of political and institutional factors that may affect efficiency in the studied sector. Population density controls for the populational dimension of the country, taking into account its land size. The old-age dependency ratio controls for the financial issues Europe's population structure problem may cause on efficiency. The unemployment rate is the only control variable that differs in the analysis of both sectors. For health, the total unemployment is used and for education the choice falls upon youth unemployment rates. The reason behind this choice relies on human capital theory, that states that the decision of an individual between another year of schooling and joining the job market is affected by the expected wage and employment probability (Becker, 1993). Youth unemployment rates are correlated with both concepts and so are considered a better control for efficiency in education. The descriptive statistics for these variables is exhibited in the Annex, in table 9.

Our final sample presents 550 observations (25 countries x 22 years) for each variable. Nonetheless, not all values are available, and those that are not, had to be estimated. For missing data not preceded by any value or without subsequent values, we calculate and apply the annual average rate of change, backwards or forward, respectively, for the available period. In the other cases missing data (preceded and proceeded by values), we calculate a compound annual change rate, to avoid big discrepancies between consecutive values. For a better explanation both formulas are presented in the Annex in equations (12) and (13). Regarding the fiscal decentralization variable, Croatia, Germany and Poland no data is available for the education and health sectors' intergovernmental transfers. For these countries we take the assumption that the fiscal decentralization level for education and health is equal to that of the overall government. The same problem happens for France, from 2000 to 2008. In this case, we assume the annual variations of the fiscal decentralization level of the two analysed sectors are the same as for the ones of the overall government. We calculate the annual rate of change of the fiscal decentralization levels of the overall government prior to 2009 and apply this rate to the education and health sectors.

4 Results and discussion

In this section, a descriptive analysis of the fiscal decentralization variable and the DEA efficiency scores is conducted, followed by the presentation of the results of the second stage analysis, which basically follows Simar and Wilson (2007) method.

4.1 Descriptive analysis

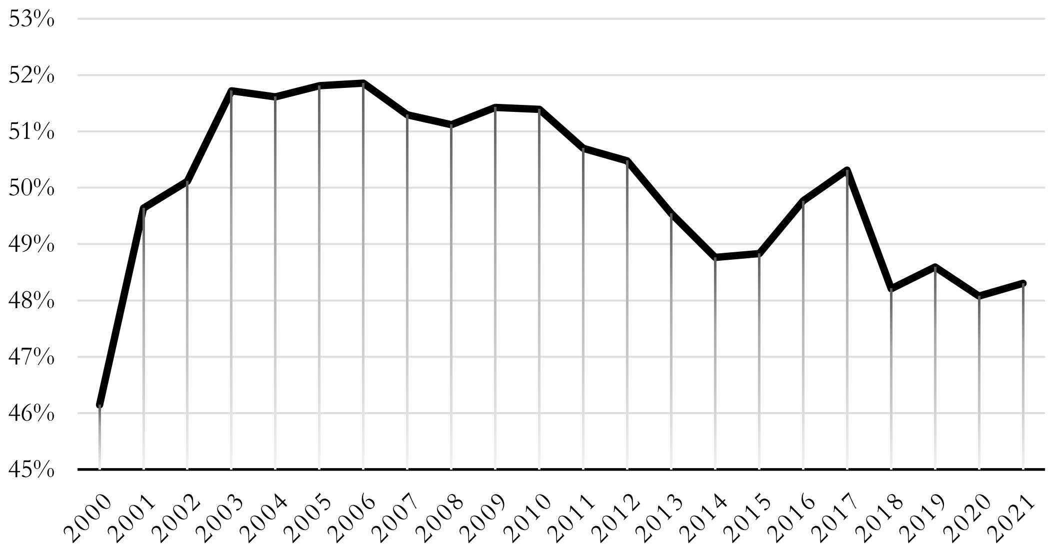
The following descriptive analyses, of both fiscal decentralization and efficiency are done by country and by year.

4.1.1 Fiscal decentralization

(i) Education

In Figure 1 it is possible to see the evolution of fiscal decentralization of education

Figure 1: Average annual fiscal decentralization level of education sector, in EU, from 2000 to 2021



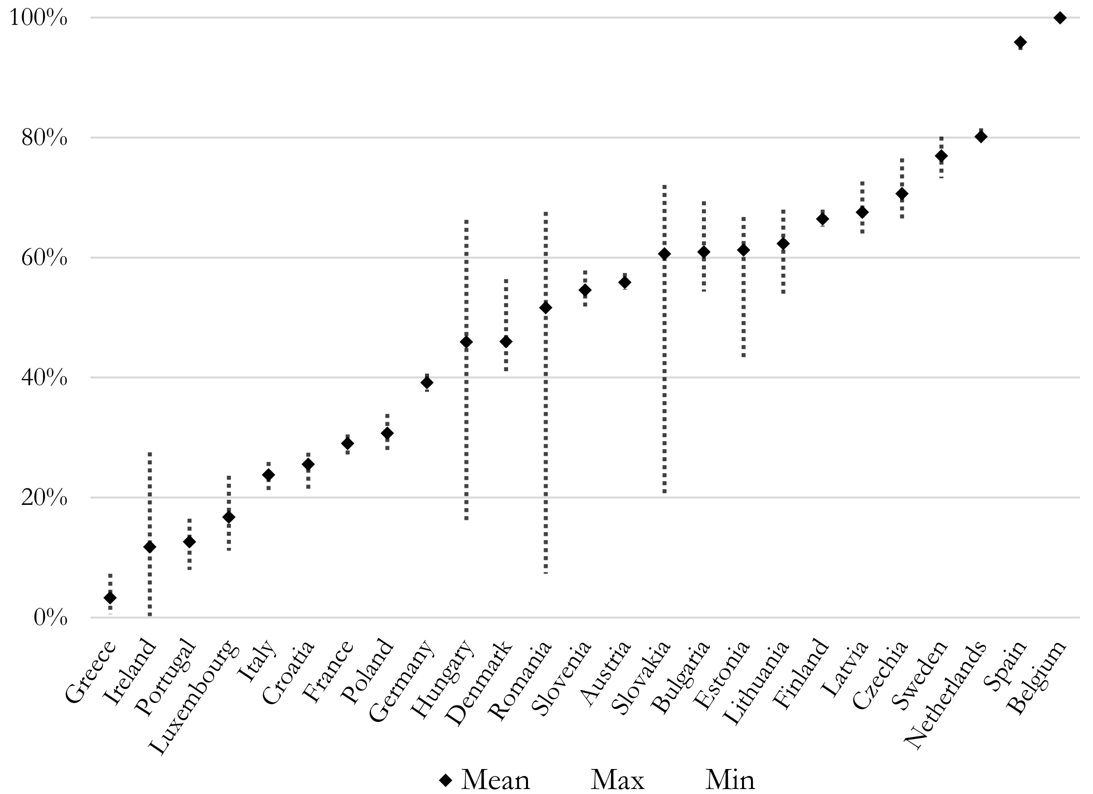
Source: Own elaboration

expenditure in the EU from 2000 to 2021, on average. It is possible to observe that the values have been bounded between 46% and 52%, which shows relative stability. Nonetheless, the biggest change of this indicator takes place between 2000 to 2003, fiscal decentralization registered the lowest value of the studied period in 2000 (46.14%) and three years later the third biggest one (51.72%). Although a small drop happened in 2004 this upward trend continued until 2006 when the highest value of the period was registered

(51.85%). Between 2006 and 2014, (with the exception of 2009) fiscal decentralization decreased continuously, reaching the value of 48.76% in 2014. Since then, the evolution has been less regular, growing until 2017, dropping in 2018, recovering in 2019, registering the lowest value since 2000, in 2020 (48.07%) and recovering again in 2021.

Looking now at the numbers of fiscal decentralization in the education sector, by country, on average, in Figure 2 we see a very heterogeneous pattern.

Figure 2: Average fiscal decentralization level of education sector, by EU countries with subnational governments, from 2000 to 2021



Source: Own elaboration

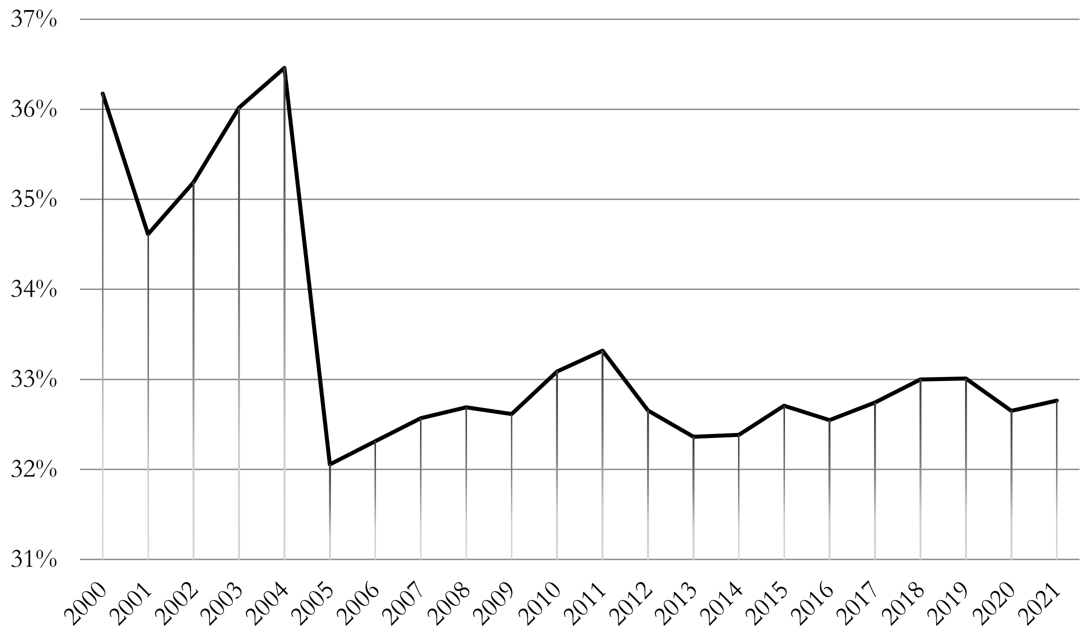
It is possible to observe that there is at least one country with its mean value of fiscal decentralization in education for every decile of this variable. Spain and Belgium stand out as the most fiscally decentralized countries in this sector, always recording values above 90%. These are two countries that have two layers of subnational government, and it is the regional one that carries out most expenditures. On the other hand, Greece, Ireland and Portugal are the most fiscally centralized for the education sector; these 3 countries show mean values under 15%, nonetheless Greece stands out never registering a value bigger that 10%. Our data shows that Ireland went through a centralization reform in this sector:

from 2000 to 2006 between 20% and 30% of the government expenditures were carried out by the local government, and from then onwards, this number decreased, reaching values lower than 1% from 2014 to 2021. In terms of major changes in the spending power of subnational governments in the EU, Hungary, Romania and Slovakia are also worth mentioning. Hungary shows a level of fiscal decentralization above 50% until 2012; this value dropped to 26,08% in 2013 and reached its lowest point in 2021 (15.85%). In Romania, a decentralisation reform took place in 2000-2001. The lowest value registered in the country was in 2000 (7.31%), and between 2001 and 2017 the level of expenditure decentralization was always higher than 55%, recording its highest level in 2017 (67.63%). However, in 2018, Romania moved towards centralization, as the share of subnational expenditures decreased to 14.26% and remained under 20% until the end of the period. Finally, Slovakia is the country where the shift towards decentralization in the education sector was stronger. In 2000, local governments only amounted to 20.08% of the expenditure, number that grew to 28.56% in 2002. The major change occurred in 2003, registering a level of fiscal decentralization of 67.57%. Since then, this value was always bigger than 60%, exceeding 70% from 2017 to 2021, and reaching the highest value of 72.10%, in 2019.

(ii) Health

Figure 3 shows the fiscal decentralization levels for the health sector, by year. The first thing to notice is the fact that the average value, by year, in the EU, is lower than the ones observed in the education sector. In health, values are bounded from 32% to 37%. Higher values of fiscal decentralization were registered in the first five years of the period, and the peak was reached in 2004 (36.46%). In 2005 a 4.4 p.p. drop took place, reaching an average value of 32.06%, the lowest in the period. This sharp drop was mainly due to Ireland's policy shift: being one of the most decentralized EU countries from 2000 to 2004, with a 91.10% level of fiscal decentralization in 2004, completely centralized its expenditures in 2005. Keeping a 0% level of fiscal decentralization in the health sector until 2021. After the major change in 2005, the average fiscal decentralization level in the EU became more constant. First, a growing trend, only interrupted in 2009, was registered until 2011, when the value of 33.32% was reached. In the following years, this number decreased to 32.36% in 2013 and, from 2013 to 2021, fiscal decentralization showed signs of a small upward trend.

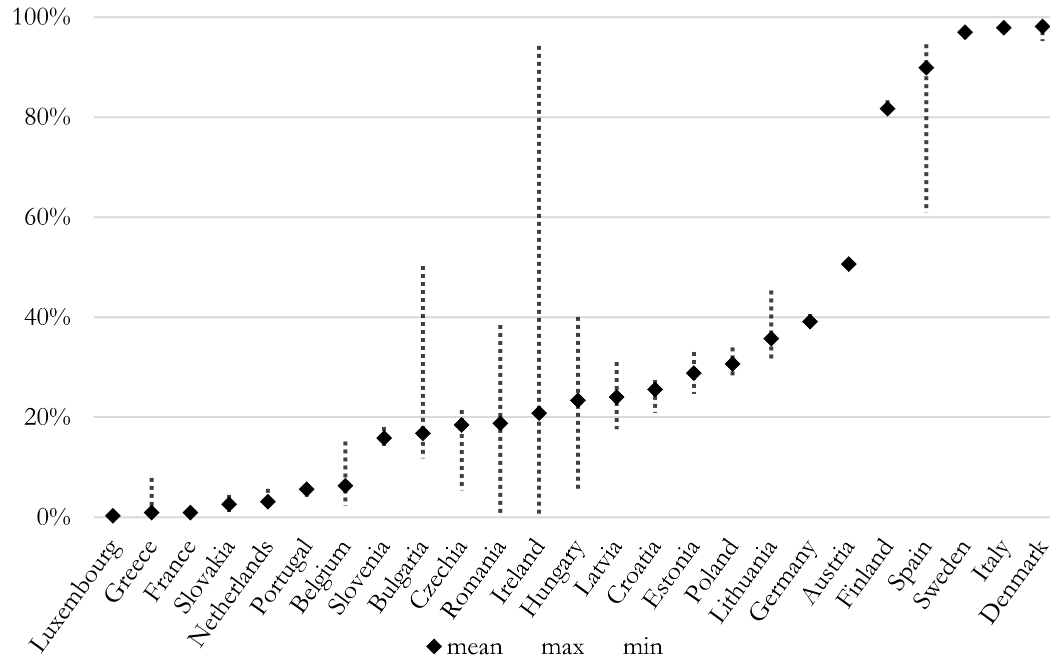
Figure 3: Average annual fiscal decentralization level of health sector, in EU, from 2000 to 2021



Source: Own elaboration

The analysis fiscal decentralization by country, in the health sector (Figure 4), reveals a more homogeneous pattern in comparison to the education sector. Nineteen of the twenty-five countries recorded an average fiscal decentralization level under 40%. The five most centralized countries showed an average fiscal decentralization level lower than 5%, namely Luxemburg, Greece, France, Slovenia and the Netherlands. It is worth mentioning the case of Belgium as a low decentralized country where there are regional governments, which may indicate a strong willingness to decentralize. Yet, Belgium only presents an average value of 6.36% expenses done by the subnational governments in the health sector. On the side of the most decentralized countries, there is also five that stand out, namely Finland, Spain, Sweden, Italy and Denmark. All these countries recorded mean values higher than 80%, and the last three higher than 90%. Looking now at big modifications in the spending power of subnational governments, the most relevant one is Ireland, as already mentioned, but Bulgaria, Romania, Hungary and Spain are also worth mentioning. Bulgaria had a 50.27% level of decentralized spending in the health sector, in 2000. This value fell to 20.22% the year after and fluctuates until the end of the period between 11% and 23%, reaching its lowest value of 11.78%, in 2020. Hungary is another country that saw its local governments lose spending power in this area. The level of decentralization during the 2000 and 2011 period varied between 35% and 40%. In 2012, this value dropped to 14.55% and kept diminishing in 2013, and thereafter the fiscal decentralization magnitude in the country was always lower than 10%. The opposite movement was found in Romania and Spain. The former registered a fiscal decentralization level lower than 2% from 2000 to 2008. The shift towards more decentralization took place in 2009, 2010 and 2011, reaching the values of 4.91%, 19.07% and 30.32%, respectively. Since 2011, the spending power of local governments in Romania presented an upward trend, reaching its highest level in 2020 (38.45%). In Spain, departing from a level of around 61% in the beginning of the period, fiscal decentralization in the health sector reached 91.71% in 2002, and since then has stabilized between 92% and 95%.

Figure 4: Average fiscal decentralization level of health sector, by EU countries with subnational governments, from 2000 to 2021



Source: Own elaboration

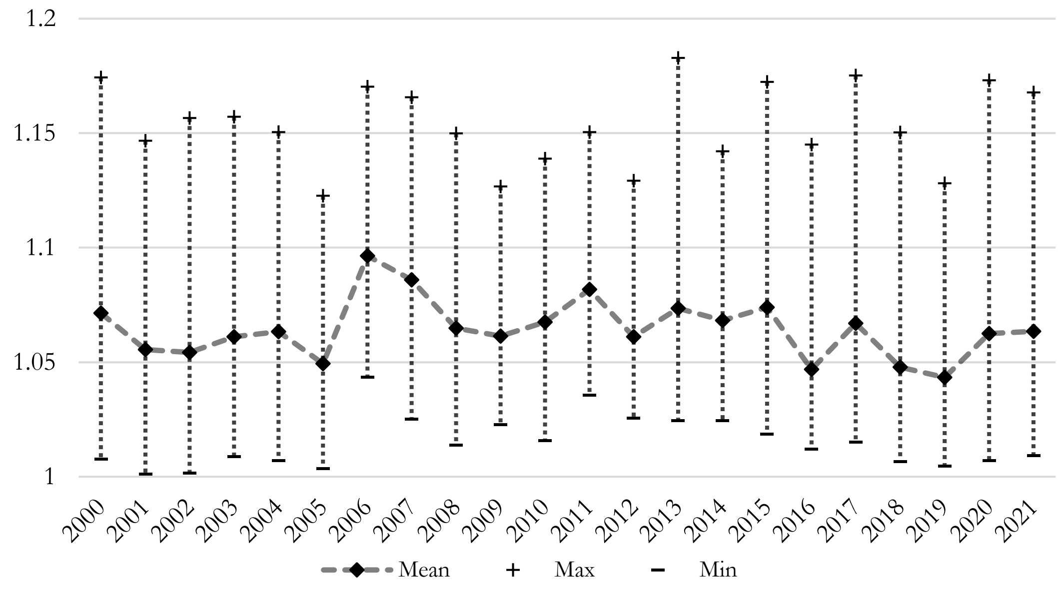
4.1.2 Efficiency Analysis

As described in the methodology, the first part of the SW method implies the construction of bias corrected DEA efficiency scores. In this section, these scores are analysed for each sector, by year and by country, taking into account the mean, maximum and minimum values, similar to what was done for the fiscal decentralization indicator. Nevertheless, it is necessary to mention two important aspects about the efficiency estimates. The first is the fact that, since an output oriented measured was calculated, the values are bounded from 1 to infinity (not 0 to 1). This means that a score equal to 1 represents a fully efficient DMU, and the bigger the scores, the bigger the inefficiency. What these scores represent is how much output production could increase, regarding the considered input level, in percentage. In practical terms, subtracting 1 from the DEA score leaves us with the inefficiency value (for example, 1.1234 - 1 = 0.1234, means output could increase 12.34%). The second aspect is that efficiency scores are different each time the SW method is applied, with different control variables. This happens due to the truncation in step 3.1 (see section 3.1), where the environmental variables impact the bias estimation. This being said, only one set of efficiency scores, for each sector, is analysed here (multiple applications of the method are done, as the subsequent section dissects). Nonetheless, the results are similar and the analysis of only one set of scores gives us a relevant picture of the behaviour of the dependent variable. The descriptive statistics for all efficiency scores are presented in the Annex, in Tables 10, 11 and 12.

(i) Education Sector

In Figure 5, it is possible to see the evolution of inefficiency in the education sector since, 2000 to 2021, in the 25 EU countries here analysed.

Figure 5: Annual mean, maximum and minimum bootstrapped DEA efficiency scores, for the education sector, in the EU, between 2000 and 2021

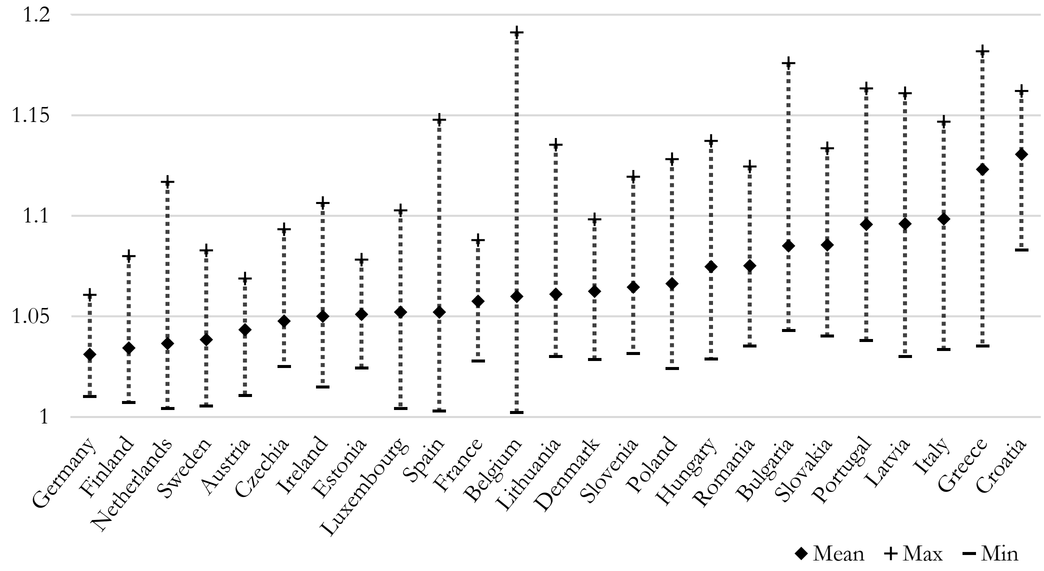


Source: Own elaboration

These results denote an irregular pattern on the yearly mean value of DEA efficiency scores in this sector: the value oscillates up and down every one, two or three years. Overall, in mean terms, the education sector reported 6.46% inefficiency, which, in the output-oriented perspective means that output production could be increased by 6.46%, with the same input allocation. The lowest mean value was registered in 2019 (4.33%), and the highest in 2006 (9.64%). Between 2006 and 2015, above average inefficiency values are found in 8 of those 10 years, with 2009 and 2012 being the exceptions. This is interesting to report since it appears to indicate that the negative effects of the financial and debt crisis were felt by the input-output relationship of the education sector in EU countries. The dispersion of results, seems to provide some more information on this topic. The smallest differences between maximum and minimum values are registered between 2006 and 2012. The lower gap takes place in 2012, with the most efficient country reporting 2.56% inefficiency and the less one 12.92%. In parallel to this, the minimum values of inefficiency by year are higher between 2006 and 2017. From 2000 to 2005 and from 2018 to 2021, there is always at least one country, which presents lower than 1% inefficiency. Since the same does not happen between 2006 and 2017, it is possible to conjecture that, just like in average terms, the most efficient education sectors in EU operated further from the efficiency frontier, around the time of the financial and debt crisis.

In Figure 6, mean, maximum and minimum efficiency scores, by country, are displayed for the education sector. The countries that present, on average, the most efficient education sectors are Finland, the Netherlands and Czechia, denoting the possibility of growing their output production in 3.12%, 3.38% and 3.86%, respectively, for the observed input level. In contrast, Croatia (12.80%), Greece (11.81%) and Italy (9.61%) were the countries where, on average, the education system performed worse. It is relevant to refer the case of Belgium, since this country reported, the highest (1.1828 in 2013) and lowest (1.0010 in 2001) efficiency scores of the period, followed by Spain and Greece. On the other hand, the education systems of Estonia, Finland and Czechia are the ones that show more regularity in terms of efficiency.

Figure 6: Mean, maximum and minimum bootstrapped DEA efficiency scores, for the education sector, by country, between 2000 and 2021

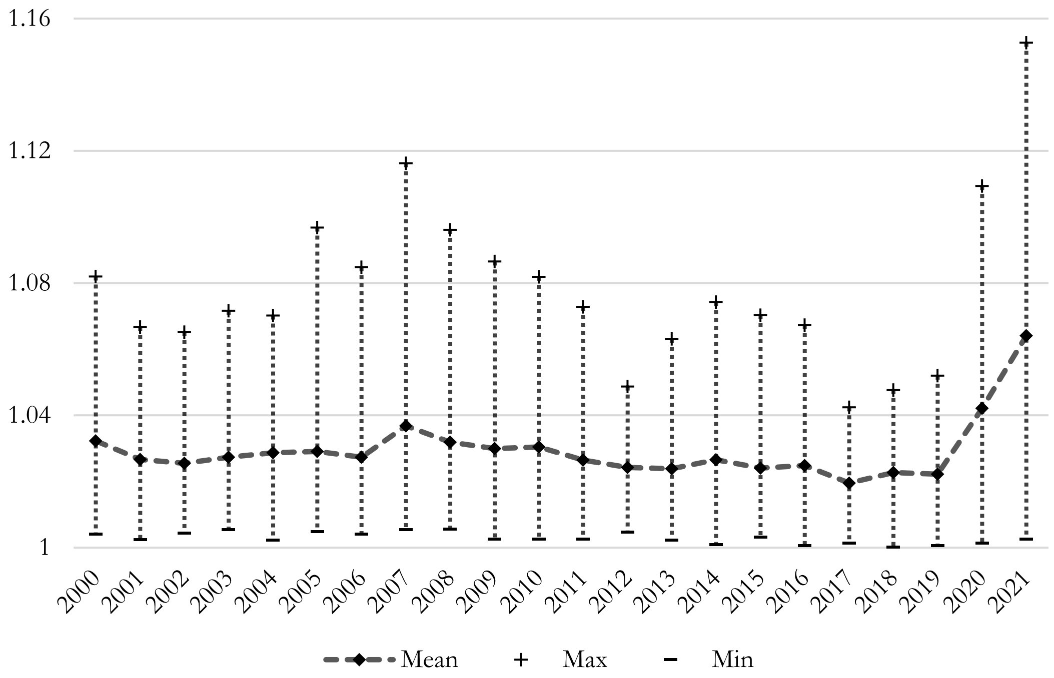


Source: Own elaboration

(ii) Health Sector

Now the same analysis is done for the health sector efficient scores. Observing Figure 7, the first thing to notice is that inefficiency is lower in comparison to education, on average (2.94% in comparison with 6.46%). Although there is some stability in this time series, there are some movements worth reporting. Before 2007, only 2000 registers an above average value of inefficiency (3.23%), but between 2007 and 2010 values are always higher than 2.94%. This higher mean inefficiency is found around the time of the financial crisis, indicating the possibility of efficiency in the health sector suffering some impacts of the economic conjuncture. Nevertheless, after 2007, when it reached a peak (3.69%) the health sector showed a decreasing trend in inefficiency terms, until 2017, when the lowest average value is registered (1.95%). Within this period only 2010, 2014 and 2016, deviate from the prevailing trend. The last two years of the studied period show an unprecedented inefficiency increase and, consequently, the highest mean values reported. In 2021, the output production of EU's health sector could have been 6.41% higher having into account the input level registered. This has a recognizable impact from the Covid-19 pandemic, that caused increase spending on health and life expectancy not growing or even falling in some countries. In term of the dispersion of results, it is interesting to see that

Figure 7: Annual mean, maximum and minimum bootstrapped DEA efficiency scores, for the health sector, in the EU, between 2000 and 2021

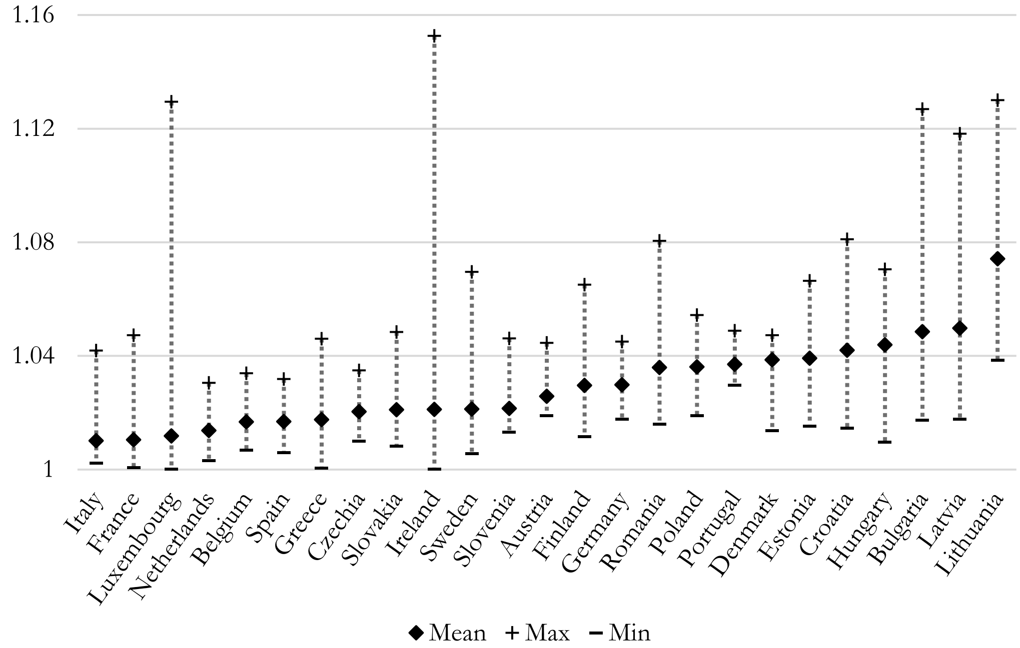


Source: Own elaboration

minimum values were always lower than 1%. The maximum values, however, show some signs of being affected by the economic situation since higher than 8% values are found between 2005 and 2010 and then again in 2020 and 2021. In relation to the last two years of our data, the significant differences between the highest and lowest inefficient health systems in EU indicate contrasting impacts from the pandemic.

In Figure 8 it is possible to observe the efficiency scores of the health sector by country. Italy (1.02%), France (1.05%) and Luxembourg (1.12%) report the most efficient health systems, on average. On the other hand, Bulgaria (4.86%), Latvia (4.98%) and Lithuania (7.43%) report the worst results. In terms of disparities between maximum and minimum values, Portugal, Austria and Czechia show more consistency in its efficiency scores. Oppositely, Ireland and Luxemburg show the most significant differences between maximum and minimum values, and just like Belgium in the education sector, these countries present the higher and lower efficiency scores of the period. It is interesting to note that the maximum scores of both these countries are outliers, when we compare them to their mean score, and both were registered in 2021. In fact, 18 out of the 25 EU

Figure 8: Mean, maximum and minimum bootstrapped DEA efficiency scores, for the education sector, by country, between 2000 and 2021



Source: Own elaboration

countries that were selected for this work registered their maximum value of inefficiency in 2021, which again, appears to indicate significant impacts from the Covid-19 pandemic.

4.2 Econometric Analysis

As described in the methodology, the second part of the SW method involves the regression of the efficiency scores on a set of environmental variables. The baseline model applied goes as follows:

$$\text{Inefficiency} = B_0 + \text{FD\_spent} + \text{FD\_spent}^2 + \text{Controls} + \text{Time dummies} + \epsilon_i^t \qquad (11)$$

The main variable of interest, FD_spent, represents the fiscal decentralization measure and displays both its linear and quadratic terms. The set of controls and annual time dummies are also added to the model.

4.2.1 Education Sector

The first analysis focuses on the education sector. The results of the estimations are presented in Table 5. A negative sign for the linear term of fiscal decentralization, and a positive one for the quadratic term are found in every specification. These results are

Table 5: Second-stage regressions of education sector's SW model

Dep Var.: Inefficiency	(1)	(2)	(3)	(4)
FD_spent	-0.145***	-0.117***	-0.145***	-0.086**
	(0.022)	(0.021)	(0.023)	(0.027)
FD_spent2	0.102***	0.080***	0.097***	0.035
	(0.021)	(0.020)	(0.022)	(0.028)
log_GDPpc	-0.023**	-0.020**	-0.026***	-0.023**
	(0.008)	(0.007)	(0.007)	(0.008)
good_gov	-0.105***	-0.120***	-0.081**	-0.070*
	(0.028)	(0.025)	(0.026)	(0.029)
log_Pop_Den	0.001			
	(0.002)			
Urb_pop		0.032**		
		(0.004)		
OA_dep			0.140***	
			(0.038)	
unemp_youth				0.077***
				(0.022)
cons	0.394***	0.351***	0.380***	0.353***
	(0.059)	(0.056)	(0.060)	(0.067)
sigma	0.030***	0.029***	0.030***	0.032***
	(0.001)	(0.001)	(0.001)	(0.001)
Time dummies	Yes	Yes	Yes	Yes
Statistics				
N	550	550	550	550
ll	1227.89	1243.99	1232.13	1221.68
chi2	358.49	378.28	336.97	274.52
aic	-2399.79	-2431.97	-2408.26	-2387.36
bic	-2279.11	-2311.29	-2287.58	-2266.68

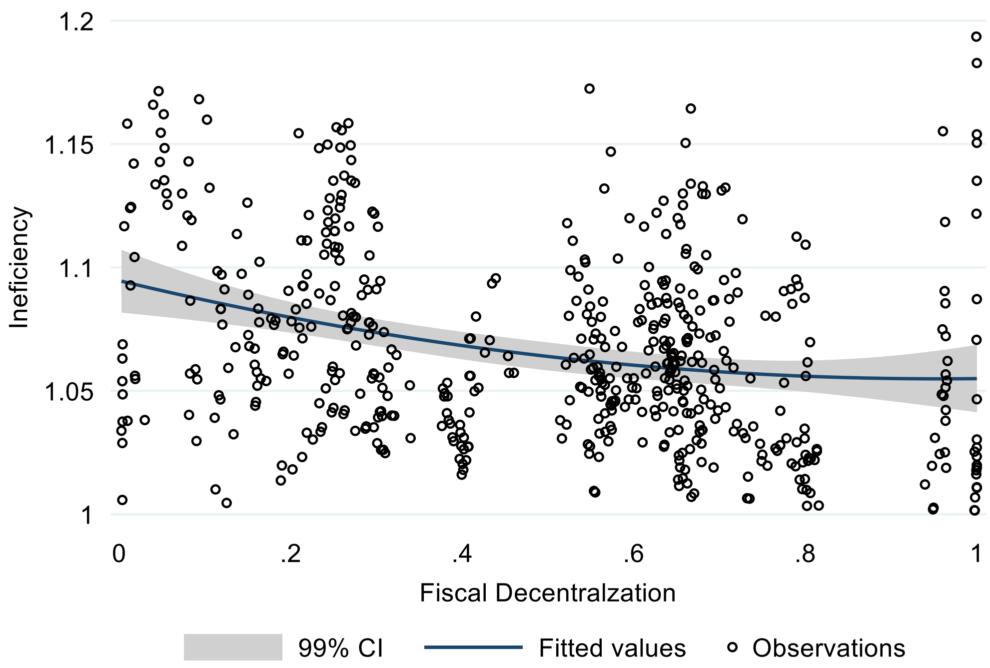
Significance levels 10% (*), 5% (**) and 1%(***)

Source: Own elaboration

statistically significant for every specification, except for column (4). This represents a non-linear effect of fiscal decentralization on efficiency, indicating that, up until a certain level, for the least decentralized countries, more spending power on the subnational governments, appears to reduce inefficiency.

On the other hand, after a certain level, decentralization may start to hinder efficiency. The results here presented are in line with the non-linear impacts described by Adam et al. (2014), and in disagreement with the ones analysed by Sow and Razafimahefa (2018). For a better perception of the non-linearity here described, a scatter plot between FD_Spent and Inefficiency is shown in Figure 9, along with a curve representing the fitted values and 99%

Figure 9: Inefficiency and fiscal decentralization scatter plot and fitted values with 99% confidence intervals – Education sector

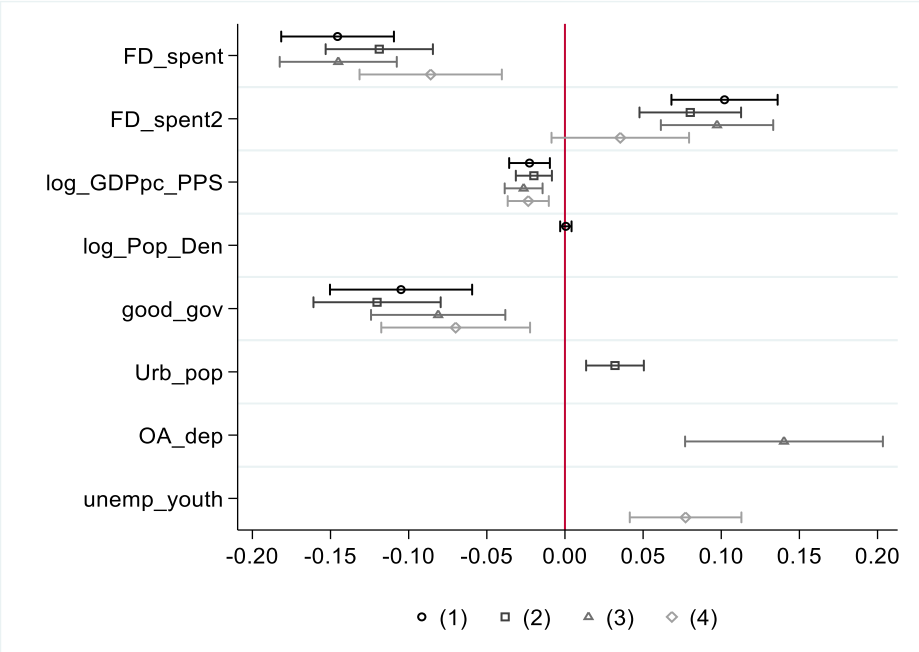


Source: Own elaboration

confidence intervals. The specification of column (2) was chosen for this representation because of its better results in terms of log-likelihood (ll), Akaike Information Criteria (aic) and Bayesian Information Criteria (bic) metrics used to evaluate the fitting of the model. Observing the chart then, it is possible to see some dispersion of results, nonetheless, lower inefficiency scores are more concentrated between the 50% and 85% levels of fiscal decentralization. Another conclusion possible to draw from Figure 9 is that the initial decrease in inefficiency is bigger than the increase revealed in the higher levels of decentralization, showing an almost linear pattern. This is also visible in Table 5, when the coefficient values are analysed. In specification (2), the linear term of fiscal decentralization presents a value of -0.117 and the quadratic term a value of 0.080. That being said, although low, the non-linear impacts of fiscal decentralization are verified in the education sector, presenting an inverted U-shaped relationship with efficiency.

As argued by Simar and Wilson (2007), one of the advantages of the Algorithm II of the SW method is the bias corrected confidence intervals that it calculates, since their coverage is very good. In Figure 10 it is possible to see the 90% (lower level of significance

Figure 10: Bootstrapped confidence intervals for table 5 regressions



Source: Own elaboration

considered) confidence intervals for the coefficient of every variable in each specification of the education model. FD_spent and FD_spent2 show similar intervals, with specification (2) having the narrowest and (4) the widest. Focusing on the main controls of the model, it is possible to observe that both GDPpc and the good governance measure show statistically significant impacts on the reduction of inefficiency. This is consistent for each specification and has the expected sign. Nonetheless, it is important to note that the estimation of the coefficient of GDPpc is the one that shows better precision. For the remaining controls, the following can be concluded: population density, in equation (1), does not display any statistically significant contribution to efficiency, while the percentage of urban population (2), the old age dependency ratio (3) and the youth unemployment rate (4) seem to deteriorate it. On these three additional controls that show statistical significance, precision is higher in the estimate of urban population and lower for the old age dependency ratio.

4.2.2 Health Sector

Now, a similar analysis is conducted for the results of the health sector, which are presented in Table 6. The first thing to notice is that the impact of fiscal decentralization

Table 6: Second-stage regressions of health sector's SW model

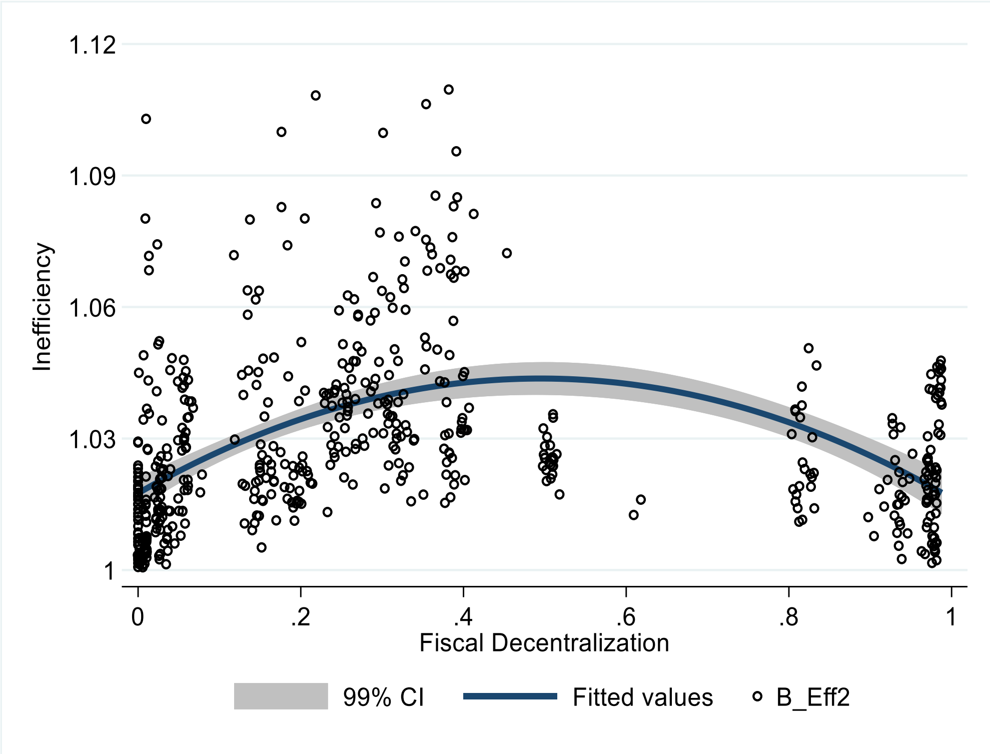
Dep. Var.: Inefficiency	**(1)**	**(2)**	**(3)**	**(4)**
FD_spent	0.092*** (0.013)	0.076*** (0.010)	0.086*** (0.010)	0.081*** (0.009)
FD_spent2	-0.091*** (0.012)	-0.067*** (0.010)	-0.081*** (0.010)	-0.072*** (0.009)
log_GDPpc	-0.043** (0.006)	-0.058*** (0.005)	-0.049*** (0.004)	-0.056*** (0.004)
good_gov	0.079*** (0.000)	0.105*** (0.000)	0.087*** (0.000)	0.079*** (0.000)
log_Pop_Den	-0.003* (0.002)			
Urb_pop		-0.004 (0.007)		
OA_dep			0.038 (0.024)	
unemp_tot				-0.190*** (0.023)
cons	0.387*** (0.045)	0.504*** (0.039)	0.411*** (0.035)	0.517*** (0.035)
sigma	0.019*** (0.000)	0.016*** (0.001)	0.015*** (0.001)	0.014*** (0.001)
Time dummies	Yes	Yes	Yes	Yes
Statistics				
N	550	550	550	550
ll	1605.62	1659.21	1659.64	1719.30
chi2	310.17	362.87	335.42	430.32
aic	-3155.24	-3262.43	-3263.28	-3382.61
bic	-3034.56	-3141.75	-3142.60	-3261.93

Source: Own elaboration

on efficiency is the opposite of the one found in the education sector. The linear term of fiscal decentralization, in this case, presents a coefficient with positive signal, while the quadratic term presents a coefficient with negative signal. Therefore, the results indicate an inverted U-shaped relationship of the subnational governments' spending power with inefficiency. This is verified in every specification presented, with both terms always showing statistical significance at the highest level. Another thing that differs when comparing the results of both sectors is the magnitude of the differences between the coefficients of FD_Spent and FD_Spent2. While in education the latter was smaller and suggested a smoother impact of fiscal decentralization at its highest levels, in health it shows a more symmetric effect. For instance, specification (2) exhibits the lowest absolute difference between the coefficients of the linear term and the quadratic term (0.37) for the education sector, and the highest (0.09) for the health sector. These ideas become clearer in Figure 11, where it is possible to see a scatter plot of inefficiency and fiscal decentralization, and the fitted values for regression (4) with 99% confidence intervals. The quadratic and non-linear form is more evident than the one in Figure 9. Also, the dispersion of the observations is lower.

Interesting to point out is the concentration of the less inefficient observations in the extreme values of fiscal decentralization. The countries that present lower inefficiency scores in the health sector are the ones who have (almost) completely centralized or (almost) completely decentralized government health expenditure. Regarding this, it is important to notice the difference in the dispersion of observations between the lowest and the highest levels of decentralization. For countries with more than 80% of health expenditures made by the subnational governments, inefficiency scores are always between 1 and 1.06. It is in countries with lower than 50% level of fiscal decentralization that the highest inefficiency is registered, with the values varying from 1 to 1.12. So, although both extremes present the best efficiency results, only the most centralized countries present outliers. Overall, this result is contrary to the one found by Adam et al. (2014), but in line with the findings reported by Arends (2017) and Sow and Razafimahefa (2018). As Sow and Razafimahefa (2018) indicate, efficiency in the health sector seems to only benefit from expenditure decentralization after a certain degree.

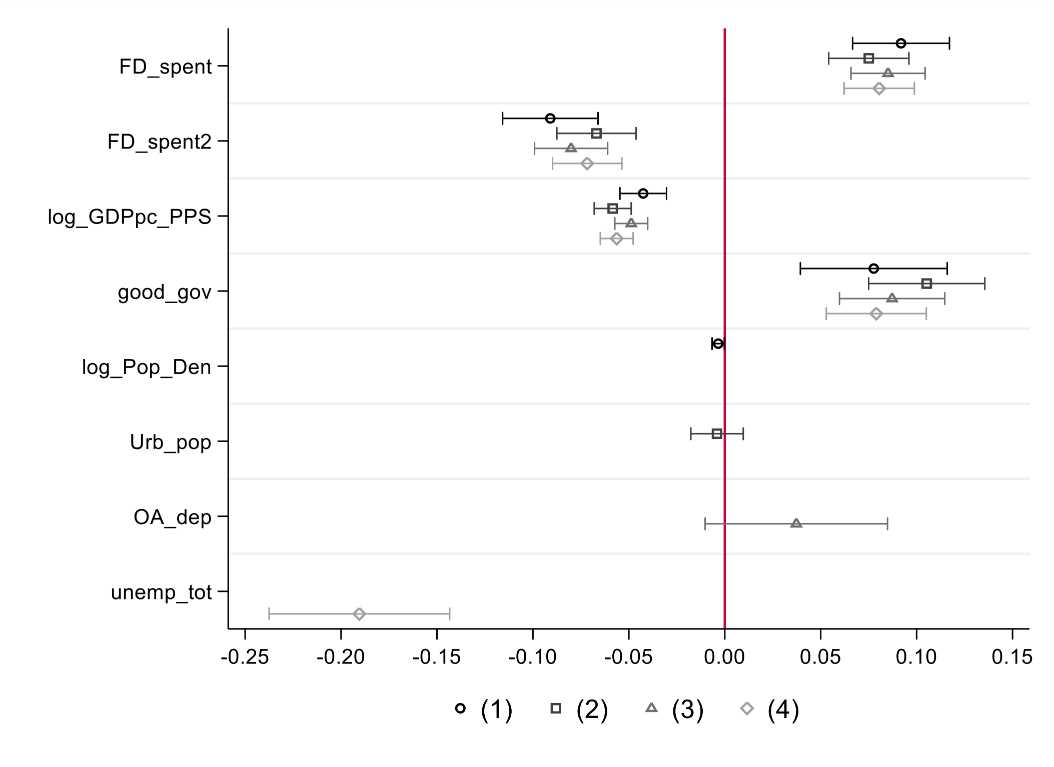
Figure 11: Inefficiency and fiscal decentralization scatter plot and fitted values with 99% confidence intervals – Health sector



Source: Own elaboration

In Figure 12, the bootstrapped confidence intervals for the regressions presented in Table 6 are exhibited. Specification (4) shows better precision for fiscal decentralization terms and for the main controls. The symmetry reported in the coefficients of fiscal decentralization is also visible in their confidence intervals, which are similar in terms of width. Looking at the controls, it is possible to observe, once again, that GDPpc presents a statistically significant negative relationship with inefficiency, for all four specifications. The good governance measure, however, does not present the same expected negative relationship in any regression. Its coefficients are always positive and significant at the 1% level. Nonetheless, GDPpc presents narrower confidence intervals, indicating more precise estimates. For the other controls, only the unemployment rate, in column (4), displays statistical significance at the highest level; despite being the least precise estimated coefficient (with significance), it reports a positive effect towards inefficiency. Although only for a 90% confidence level, population density (1) exhibits a low, but precise positive contribute to inefficiency. The percentage of urban population (2) and the old age dependency ratio do not present estimated coefficients with statistical significance.

Figure 12: Bootstrapped confidence intervals for table 6 regressions



Source: Own elaboration

Having into account all that was analysed on this subsection and on the previous one, two inferences can be made. First, the inverted U-shaped relationship between fiscal decentralization and inefficiency, found in the education sector, produces an optimal point of expenditure power of subnational governments. In the health sector, however, the maximum point in the U-shaped form that is found between fiscal decentralization and inefficiency, appears to represent a threshold from where countries above it should fully decentralize their expenditures to the subnational governments, and countries behind it should fully centralize them. The rationale behind it may be that, once the initial high fixed costs of providing health services are incurred (such as the construction of an hospital), the benefits of expenditure decentralization excel to a point where any central expenditure is less efficiently done at a subnational level, as it is similarly discussed by Sow and Razafimahefa (2018). This idea raises some questions about its reliability since it seems to ignore the heterogeneity regarding health expenditures. So, a question arises to what extent do fiscal decentralization returns on efficiency increase after the observed threshold. In order to test the hypothesis of whether a too high fiscal decentralization harms efficiency, a cubic term of the main independent variable of the model is added to the equation, and the same four specifications are performed. The results of these estimations are presented in Table 7 and a second inflexion point is observed in all specifications.

Table 7: Second-stage regressions of health sector's SW model, adding a cubic term of fiscal decentralization

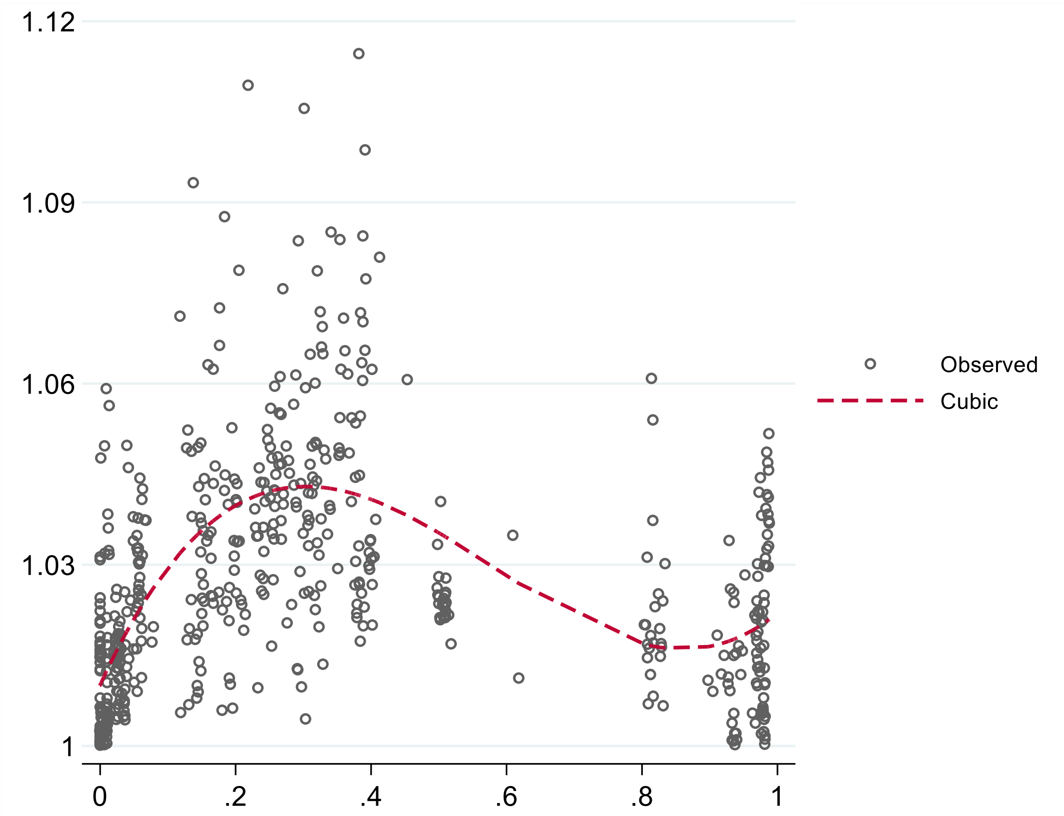
Dep Var.: Inefficiency	(1)	(2)	(3)	(4)
FD_spent	0.207*** (0.030)	0.210*** (0.027)	0.235*** (0.029)	0.212*** (0.024)
FD_spent2	-0.459*** (0.091)	-0.467*** (0.079)	-0.508*** (0.084)	-0.466*** (0.070)
FD_spent3	0.260*** (0.066)	0.277*** (0.057)	0.290*** (0.060)	0.272*** (0.050)
log_GDPpc	-0.036*** (0.006)	-0.063*** (0.006)	-0.051*** (0.006)	-0.056*** (0.005)
good_gov	0.090*** (0.000)	0.143*** (0.000)	0.122*** (0.000)	0.108*** (0.000)
log_Pop_Den	-0.006*** (0.002)			
Urb_pop		-0.009 (0.008)		
OA_dep			0.025 (0.029)	
unemp_tot				-0.183*** (0.025)
cons	0.325*** (0.047)	0.514*** (0.044)	0.401*** (0.043)	0.491*** (0.039)
sigma	0.019*** (0.001)	0.017*** (0.001)	0.018*** (0.001)	0.015*** (0.001)
Time dummies	Yes	Yes	Yes	Yes
Statistics				
N	550	550	550	550
ll	1607.85	1673.35	1634.56	1732.74
chi2	315.54	368.26	295.73	419.26
aic	-3157.69	-3288.70	-3211.12	-3407.49
bic	-3032.70	-3163.71	-3086.13	-3282.50

Source: Own elaboration

Table 7 reports the same positive and negative signs for the linear and quadratic terms of fiscal decentralization, respectively, as Table 6. The cubic term shows a positive sign, which represents an increased inefficiency at the higher levels of spending power assigned to subnational governments. One thing to notice is the increase in the magnitude of the coefficients of the fiscal decentralization terms, in relation to the estimates of Table 6, indicating that its marginal impacts on efficiency may be higher. This increase in magnitude was higher in the quadratic term, as indicated by the most negative coefficient in column (3) -0.508 and the least negative in column (1) -0.459. The highest and lowest coefficients in the linear term are, respectively, 0.235 (column (3)) and 0.207 (column (1)), and for the cubic term 0.290 (column (3)) and 0.260 (column (1)). These results seem to indicate stronger effects of decentralizing expenditures after the threshold is surpassed, for the health sector. This appears to be an argument in favour of decentralization since it indicates that when the initial high costs of decentralization are surpassed, the efficiency improvement is stronger. Nevertheless, after a certain point, this inefficiency decrease does not hold anymore, which seems to point out the need of the central government to keep some control on health expenditures. For a better visualization of the cubic relationship described between fiscal decentralization and inefficiency, in Figure 13, a scatter plot between inefficiency and fiscal decentralization is presented. In relation to Figure 11, the observed results in terms of dispersion and concentration of most efficient units in the extremes are the same. What changes is the curve representing the estimation results, that captures the idea of stronger impacts with bigger slopes; it suggests that the threshold from where decentralization starts to diminish inefficiency is lower than in Figure 7 and that inefficiency starts to increase at high levels of subnational health expenditure.

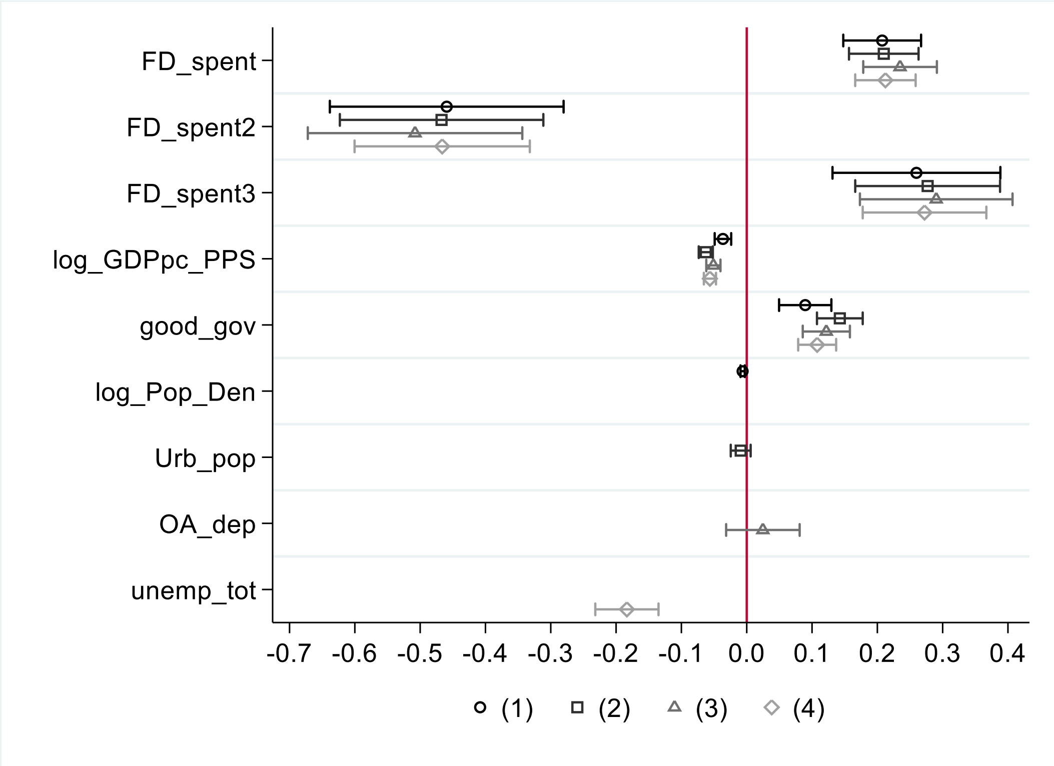
To finish this analysis, it is important to look at the bootstrapped confidence intervals, in order to examine the precision of the reported estimations. Figure 14 shows different widths for the confidence intervals for the fiscal decentralization terms, with the quadratic term having the wider one, a fact that weakens the idea of benefits of expenditure decentralization working at a higher pace, since precision seems to be lower. Nonetheless, precision is lower for all terms of fiscal decentralization in every specification of Table 7, in relation to Table 6. Scrutinising the controls, there is no major change to register in terms of significance, sign of the effect and confidence intervals widths. The only aspects to point out are, first, that population density is now significant at the highest level and, second, that the unemployment rate and the old-age dependency ratio, although keeping similar confidence intervals, are not the widest ones. The estimations of the quadratic and cubic fiscal decentralization terms show the largest intervals which, again, leaves some concerns over their precision.

Figure 13: Inefficiency and fiscal decentralization scatter plot and cubic curve fit



Source: Own elaboration

Figure 14: Bootstrapped confidence intervals for table 7 regressions



Source: Own elaboration

5 Conclusion

This dissertation aimed at empirically analysing the relationship between fiscal decentralization and efficiency. Following the works of Adam et al. (2014), Arends (2017) and Sow and Razafimahefa (2018), we tested the hypothesis of non-linear effects from fiscal decentralization on efficiency. This is done through the application of a two-stage analysis, based on the algorithm II of Simar and Wilson (2007), adapted for panel data, centred on the education and health sectors of the 25 EU countries that have subnational governments, between 2000 and 2021.

In the context of our sample, fiscal decentralization in the EU presents higher values and more heterogeneity in education than in health. Countries show less willingness to decentralize health expenditures to the subnational governments, but the ones that do, almost fully decentralize them. In average terms, the DEA analysis on inefficiency reported higher possibility of improving the output levels on education than in health, considering the same input level. The efficiency results also show little influence from the economic situation in both sectors, except for the Covid-19 pandemic, from which the impacts are clear on the health sector.

The association of fiscal decentralization levels and efficiency scores reported a higher concentration of efficient units within the 50% and 85% levels of fiscal decentralization in the education sector. On the other hand, the health sector shows two distinct groups with higher concentration of efficient observations, the countries with almost fully centralized health expenditures, and the ones where expenditure is almost completely done by the subnational governments.

The results from the truncated maximum likelihood regression show statistically significant non-linear effects from fiscal decentralization on efficiency, in both sectors. Nonetheless, the shape of this non-linearity differs between sectors. In the education sector, the results indicate an inverted U-shaped relationship between fiscal decentralization and efficiency, which suggests an optimal point of decentralized expenditure where efficiency is maximized. These results align with Adam et al. (2014) findings but contradict the ones from Sow and Razafimahefa (2018). In the health sector, however, the opposite relationship was found, as the results denote an U-shaped relationship between fiscal decentralization and efficiency. In this case, the inflexion point of the relationship seems to represent a threshold from where countries below it potentially gain from almost fully centralize their health expenditures, and countries above it seem to benefit from almost fully decentralize them. This is in line with the results from Sow and Razafimahefa (2018) and Arends (2017), but contrary to the ones from Adam et al. (2014).

As in any study, this analysis has some limitations, especially in terms of measurement of the main variables. Fiscal decentralization can be explored in various perspectives as Stagarescu (2005) discusses, and the share of expenditure made by subnational governments does not reflect the concept of fiscal decentralization holistically, nevertheless, was the best measure found, regarding the sectoral analysis we conducted. Measuring efficiency also has its difficulties, and the advantages and disadvantages of using DEA were discussed already. Despite this, it is important to understand that choosing other inputs and outputs for the DEA model would impact the results. The choice relied on the relevant literature, however, in the health sector outputs, life expectancy seems to be too similar between EU countries. Healthy life years is an indicator that could differentiate better the countries, but its data availability is lower.

For future research, it would be interesting to compare the health and the education sectors, to comprehend more precisely which are the characteristics of each, that make their performance be affected so differently by fiscal decentralization. It would provide better information to policymakers on what factors should be accounted for, in order that fiscal decentralization might generate efficiency returns.

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Annex

Table 8: Inputs and outputs descriptive statistics – normalized values

Sector	Variable	Obs	Mean	Std. dev.	Min	Max
Education	PEeduc	550	1	.186723	.5481597	1.431535
	TS_ratio	550	1	.1783883	.6737963	1.494077
	HC_educ	550	1	.6582693	.0449109	3.400447
	PISA	550	1	.0509159	.8372308	1.129748
	Enrol_rate	550	1	.1475033	.7659832	1.542245
	Emp_rate	550	1	.1022306	.570983	1.183469
Health	PEhlth	550	1	.2023752	.5434783	1.372283
	docs_ph	550	1	.2089218	.5941758	1.719117
	HC_hlth	550	1	.5429942	.0647997	2.360273
	ISR	550	1	.3390876	.279102	2.174079
	life_exp	550	1	.0392018	.903889	1.055438

Source: Own calculation

Table 9: Contextual variables descriptive statistics

Variable	Obs	Mean	Std. dev.	Min	Max
FD_spent (education)	550	.4998833	.2652764	.0024158	.9999901
FD_spent (health)	550	.3336002	.3379586	-.0004849	.9879646
GDPpc_PPC	550	25248.95	12644.32	4855.005	87056.4
good_gov	550	.6974452	.116248	.4333173	.9106398
Pop_Den	550	125.4644	104.8512	17	510.2
Urb_pop	550	.7138181	.1230515	.50754	.98117
unemp_youth	550	.2017436	.0969658	.046	.583
unemp_tot	550	.0873418	.0438166	.02	.275
OA_dep	550	.2827637	.047725	.173	.403

Source: Own elaboration

$$\text{Annual average rate of change} = \frac{r_1 + r_2 + ... + r_N}{N}, \tag{12}$$

r_i are the annual rates of change and N is the number of years.

$$\text{Compound annual rate of change} = \left(\frac{V_{t+n}}{V_t}\right)^{\frac{1}{n}}, \tag{13}$$

V_t represent the initial value, V_{t+n} the final value and n the number of years with missing data.

Table 10: Descriptive statistics for the efficiency scores of the education sector model

Variable	Obs	Mean	Std. dev.	Min	Max
Eff1	550	1.027303	.0350487	1	1.148716
Bias1	550	-.039622	.0272315	-.1911888	-.0022963
B_Eff1	550	1.066925	.0391361	1.002296	1.191189
Eff2	550	1.027303	.0350487	1	1.148716
Bias2	550	-.0396959	.0274384	-.1935592	-.0015444
B_Eff2	550	1.066999	.038523	1.001544	1.193559
Eff3	550	1.027303	.0350487	1	1.148716
Bias3	550	-.0372743	.0274357	-.1828386	-.0010398
B_Eff3	550	1.064578	.0392902	1.00104	1.182839
Eff4	550	1.027303	.0350487	1	1.148716
Bias4	550	-.0352585	.0296982	-.1889435	-.0005157
B_Eff4	550	1.062562	.0398834	1.000516	1.188944

Legend: Eff – DEA scores; Bias – bootstrap-based estimate of the bias of the DEA scores; B_Eff – Bias corrected DEA scores.

Note: Each variable is followed by the number of the corresponding second stage regression

Source: Own calculation

Table 11: Descriptive statistics for the efficiency scores of the health sector model

Variable	Obs	Mean	Std. dev.	Min	Max
Eff1	550	1.011132	.0156166	1	1.076627
Bias1	550	-.0182661	.0163276	-.1526818	-.000143
B_Eff1	550	1.029398	.021779	1.000143	1.152682
Eff2	550	1.011132	.0156166	1	1.076627
Bias2	550	-.0175947	.014229	-.1029241	-.0006388
B_Eff2	550	1.028727	.0201442	1.000639	1.109613
Eff3	550	1.011132	.0156166	1	1.076627
Bias3	550	-.0178164	.0135432	-.0786981	-.0014837
B_Eff3	550	1.028949	.0194455	1.001484	1.115678
Eff4	550	1.011132	.0156166	1	1.076627
Bias4	550	-.016383	.0132433	-.0646502	-.0005904
B_Eff4	550	1.027515	.0192946	1.000773	1.11425

Legend: Eff – DEA scores; Bias – bootstrap-based estimate of the bias of the DEA scores; B_Eff – Bias corrected DEA scores.

Note: Each variable is followed by the number of the corresponding second stage regression

Source: Own calculation

Table 12: Descriptive statistics for the efficiency scores of the health sector model, with the cubic term

Variable	Obs	Mean	Std. dev.	Min	Max
Eff1	550	1.011132	.0156166	1	1.076627
Bias1	550	-.0182399	.0171359	-.1488816	-.0001428
B_Eff1	550	1.029372	.0221218	1.000143	1.148882
Eff2	550	1.011132	.0156166	1	1.076627
Bias2	550	-.0167335	.0154291	-.0810664	-.0005058
B_Eff2	550	1.027866	.0208783	1.000506	1.109092
Eff3	550	1.011132	.0156166	1	1.076627
Bias3	550	-.0176077	.0161953	-.1108467	-.0008415
B_Eff3	550	1.02874	.0210472	1.000841	1.115319
Eff4	550	1.011132	.0156166	1	1.076627
Bias4	550	-.0160826	.0143168	-.0631264	-.0001274
B_Eff4	550	1.027215	.0198506	1.000127	1.114636

Legend: Eff – DEA scores; Bias – bootstrap-based estimate of the bias of the DEA scores; B_Eff – Bias corrected DEA scores.

Note: Each variable is followed by the number of the corresponding second stage regression

Source: Own calculation

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