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Jin Hui

Zhejiang Sci-Tech University, Ecological Civilization Research Center of Zhejiang Province,
jinhui2017@zjut.edu.cn

Jorge Martinez-Vazquez

Georgia State University

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Hui, Jin and Martinez-Vazquez, Jorge, "Sustainable Development and the Optimal Level of Fiscal Expenditure Decentralization" (2021). *ICEPP Working Papers*. 116.
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**International Center for Public Policy
Working Paper 21-03
February 2021**

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International Center for Public Policy
Andrew Young School of Policy Studies
Georgia State University
Atlanta, Georgia 30303
United States of America

Phone: (404) 413-0235
Fax: (404) 651-4449
Email: paulbenson@gsu.edu
Website: <http://icepp.gsu.edu/>

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Sustainable Development and the Optimal Level of Fiscal Expenditure Decentralization

Jin Hui^{1,2} and Jorge Martinez-Vazquez³

February 2021

Abstract

Both excessive and insufficient levels of expenditure decentralization reduce efficiency of government and service provision, thereby exerting an adverse impact on national sustainable development. The main goal of this paper is to explore this proposition theoretically and empirically, seeking to determine the optimal level of expenditure decentralization. From a theoretical perspective, we introduce the expenditures of central and sub-national governments into Barro's (1990) model and find a hump-shaped relationship between expenditure decentralization and sustainable development as well as striking upon the optimal expenditure decentralization on the theoretical level. To further test this finding empirically, we adopt the NSDI (National Sustainable Development Index) to measure sustainable development and use panel data for 52 countries covering the period 1991-2016 to validate the theorized hump-shaped relationship between expenditure decentralization and sustainable development both in the short and long run. These results remain significant even in two-stage least squares (2SLS) estimations with the Geographic Fragmentation Index (GFI) as the instrumental variable and are robust to alternative specifications. Finally, we also utilize the Lind-Mehlum method to determine the optimal level of expenditure decentralization and find results consistent with the other methods.

Keywords: sustainable development; fiscal decentralization; NSDI; Lind-Mehlum method; optimal expenditure decentralization

* This paper is supported by the Major program project of the National Social Science Fund of China (No: 19ZDA055). Please address all correspondence to Jin Hui, School of Economics and Management, Zhejiang Sci-Tech University, Hangzhou, Zhejiang Province, 310018 China (E-mail: jinhui2017@zjut.edu.cn; Phone +86 18767121770).

¹ School of Economics and Management, Zhejiang Sci-Tech University

² Ecological Civilization Research Center of Zhejiang Province

³ International Center for Public Policy, Andrew Young School, Georgia State University

1. Introduction

This paper focuses on the impact of fiscal expenditure decentralization on sustainable development. In recent decades, the excessive consumption of natural resources, the deterioration of the environment and the imbalance of social economic development, have become increasingly serious problems, leading to many countries and international organizations to put forward plans or goals for sustainable development, such as the United Nations 2030 Agenda. And while the literature on fiscal decentralization has paid considerable attention to the impact of fiscal decentralization on economic growth (Martinez-Vazquez et al., 2017), it has ignored the broader and increasingly urgent issue of its impact on sustainable development.

Decentralized subnational governments may play important roles in the economic, social and environmental dimensions of national sustainable development. Fiscal decentralization helps give full play to local governments' information advantages and initiative, leading to overall increased economic efficiency. However, excessive fiscal decentralization can also lead to lost economic efficiency and other negative effects such as intensified predatory intergovernmental competition, distorting the composition of public expenditures with an adverse impact on sustainable development. This means that there is likely to be an appropriate level of fiscal decentralization that is the optimal choice for national sustainable development.

However, to the best of our knowledge, until now no one has studied the impact of fiscal decentralization on sustainable development. As reviewed in the next section, a growing list of economic studies have analyzed the factors impacting sustainable development and some of them have pointed out the important effect of fiscal *policy*, but fiscal *decentralization* has been ignored as a potential important factor.

This paper fills that vacuum in the literature by studying the hump-shaped impact of

fiscal expenditure decentralization on sustainable development and in doing so analyzes what the optimal level of expenditure decentralization may be. To achieve this goal, we use a panel data set of 52 countries, including 20 developed countries and 32 developing countries, over two periods, 2010-2016 for short-run effect estimates and 1991-2015 for long-run effect estimates, and apply the Geographic Fragmentation Index (GFI) as an instrumental variable to solve the endogeneity problem with the two-stage least squared (2SLS) approach. We find a strong, statistically significant non-linear (hump-shaped) relationship between expenditure decentralization and sustainable development, implying an average optimal level of expenditure decentralization ranging between 0.31 and 0.40, although the specific optimal expenditure decentralization level for national sustainable development depends, of course, on the actual conditions and development level of a country. The empirical results are robust to alternative measurements of sustainable development and fiscal decentralization.

The rest of the paper is organized as follows. Section 2 is literature review. Section 3 develops a theoretical framework. Section 4 describes the National Sustainable Development Index, methodology, and data. Section 5 presents the empirical results, robustness check, and estimation of optimal expenditure decentralization. Section 6 concludes.

2. Review of the Literature

The concept of sustainable development originated from ecology, and more recently, it has also become a main theme in economics, and environmental science and sociology (Ramos & Caeiro, 2009; Bolcárová & KološTa, 2015). Environmentalists and ecologists study sustainable development from the perspectives of environment pollution, biodiversity, and ecosystem optimization, focusing on the long-term and healthy survival of human beings as well as the sustainability of the ecosystem and regional environments (Adrián & Américo, 2002; Ebert & Welsch, 2004; Kondyli, 2010). Economists continue to explore how economic theories

and methods can contribute to promote sustainable development (Ranis et al., 2000; Bilbao-Ubillos, 2013; Bolcárová & Kološta, 2015). Sociologists emphasize how structural systems, including markets, policy, moral standards, science, and technology can maximize the cohesiveness of nature and society into sustainable development (Ma et al., 2015). Although the research perspectives on sustainable development are different in these various fields, their essence and goals are the same: sustainable development requires the coordination of economic, social, and environmental development with the goal to balance intra-generational welfare and maximize the total welfare of all generations (Jin et al., 2020).

A growing body of economic studies have analyzed the potential role of a list of factors as determinants of sustainable development. First, a number of studies have established that non-renewable energy consumption and excessive dependence on natural resources are not conducive to sustainable development (Atkinson & Hamilton, 2003; Koirala & Pradhan, 2019). A related literature explores the impact of the electric power industry on sustainable development (Swain & Karimu, 2020). Others have researched how information and communication technology, by reducing information communication costs, helps decrease energy consumption and leads to more sustainable development (Danish et al., 2019). Additionally, positive institutional environments, democracy, greater social fairness, higher education, and human capital growth have been found to be important drivers of sustainable development (Gnegne, 2009; Finnveden et al., 2019). From a developing country perspective, several other studies have found foreign direct investment, corruption, quality of governance, the legal system, and violent conflict to be significant determinants of sustainable development (Reiter & Steensma, 2010).

More closely related to our goal in this paper, a number of papers have explored the effect of several dimensions of fiscal policy on sustainable development. López and Figueroa

(2016) and Güney (2017) highlight the role of good governance on social, economic, and environmental development, and ultimately on sustainable development. Barbier and Burgess (2020) look at the role of subsidized clean energy and increased taxation on the use of fossil energy to promote sustainable development in developing countries. None of these works, however, look at the decentralization aspect of fiscal management.

Based purely on existing theory, fiscal decentralization may be an important factor affecting the national sustainable development. Since Tiebout's (1956) seminal paper, a large number of researchers have considered the impact of fiscal decentralization on economic development, such as Alesina and Rodrik (1994), Qian and Roland (1998), Thiessen (2003), Enikolopov and Zhuravskaya (2007), Bodman (2011), Gemmell et al. (2013), and Canavire-Bacarreza et al. (2020). Another strand of the literature on fiscal decentralization has emphasized how intergovernmental competition may distort fiscal choices toward "productive expenditures" with direct economic benefits, such as infrastructure, rather than other areas lacking direct economic benefits, such as environmental protection, public health, or education, further affecting national development in various dimensions (Keen & Marchand, 1997; Qian & Roland, 1998; Kappeler et al., 2013; Sacchi & Salotti, 2014; Arze et al., 2016; Jin & Qian, 2020).

Combining the insights of these branches of literature, it may be theorized that decentralization could have an inverted U-shaped impact on national sustainable development, and that selecting an appropriate degree of decentralization is important to successful sustainability efforts. The essence of the concept of sustainable development is that we should pursue social and economic development to ensure the welfare of present generations, while protecting the ecological environment and rationally utilizing natural resources to ensure the welfare of future generations. If we were to focus only on protecting the environment, but ignore

economic growth, that would also not a sustainable development mode, as it would lead to increased pressure to exploit resources for short-term survival. Neither can near-term economic development be the only goal, as the rapid exhaustion of finite resources would leaving nothing on which future generations could survive. Much like the balancing act of sustainable development itself, so an appropriate degree of fiscal decentralization trades off the welfare of present and future generations and facilitates achievement of national sustainable development.

3. Theoretical Framework

As discussed above, sustainable development implies the coordination of economic, social, and environmental development to balance intra-generational welfare and the maximization of the total welfare of generations. This concept can be expressed in economic terms as the maximization of the total utility of generations. This paper studies the relationship between sustainable development and fiscal expenditure decentralization by analyzing what the optimal level of expenditure decentralization is to maximize intergenerational utility. In doing so, we express the representative agent's utility function by Eq. (1) (following Barro [1990] and Zhang and Zou [2001]):

$$U = \int_0^{\infty} u(c, g) e^{-\rho t} dt \quad (1)$$

Where c is per capita private consumption, g is fiscal expenditure, and ρ is the (positive) time discount rate. The utility function $u(c, g)$ is a concave function monotonically increasing in private consumption and fiscal expenditure. Fiscal expenditure captures the supply of all public goods and services.

To allow for multiple tiers of governments and thereby expenditure decentralization, we further divide expenditure g into central government expenditure n and sub-national government expenditure l , following Wang et al. (2018). Assuming that there are I countries in this model,

there will be I central governments, and so the central government expenditure vector n can be obtained, as shown in Eq (2), as can the sub-national government expenditure vector l ($J > I$) as given by Eq (3).

$$n = (n_1, \dots, n_i, \dots, n_I) \quad (2)$$

$$l = (l_1, \dots, l_j, \dots, l_J) \quad (3)$$

The production function is built according to the Cobb-Douglas approach:

$$y = k^\alpha [\prod_{i=1}^I n_i]^\beta [\prod_{j=1}^J l_j]^\gamma \quad (4)$$

where y is per capita capital output, k is per capita capital stock, $1 > \alpha > 0$, $1 > \beta > 0$, $1 > \gamma > 0$, and $\alpha + \beta + \gamma = 1$. The expenditure budgets of central government and sub-national government are given by Eq (5) and Eq (6):

$$\sum_{i=1}^I n_i = \theta_n g \quad (5)$$

$$\sum_{j=1}^J l_j = \theta_l g \quad (6)$$

Let $\theta_n + \theta_l = 1$, $0 < \theta_n < 1$, $0 < \theta_l < 1$, where θ_n indicates the share of central government expenditure in general government expenditure and θ_l indicates the share of sub-national government expenditure in general government expenditure. We further assume that the central government spends a share of δ_i ($i = 1, \dots, I$) on its i th item n_i , and that the sub-national government spends a share of δ_j ($j = 1, \dots, J$) on its j th item l_j , as shown in Eq (7) and Eq (8):

$$n_i = \delta_i \theta_n g, \sum_{i=1}^I \delta_i = 1 \quad (7)$$

$$l_j = \delta_j \theta_l g, \sum_{j=1}^J \delta_j = 1 \quad (8)$$

Under the assumption of fiscal equilibrium, the share of revenue in GDP (τ) is equal to the share of expenditure (g) in GDP, that is, $\tau = g/y$. At the same time, substituting n and l into the utility function Eq (1), we obtain the following:

$$U = \int_0^\infty u(c, n, l) e^{-\rho t} dt \quad (9)$$

Thus, we can now get the dynamic budget constraint for utility (U) maximization, as in Eq (10):

$$\frac{dk}{dt} = (1 - \tau)y - c = (1 - \tau)[\prod_{i=1}^I n_i^{\beta_i}]^\beta [\prod_{j=1}^J l_j^{\gamma_j}]^\gamma - c \quad (10)$$

For convenience, let the utility function be:

$$u(c, n, l) = \ln c + \sigma_n \ln \prod_{i=1}^I n_i^{\beta_i} + \sigma_l \ln \prod_{j=1}^J l_j^{\gamma_j} \quad (11)$$

where σ_n and σ_l are positive. When the output rate of fiscal expenditures (n and l) are measured by β and γ respectively, then their impact on the agent's utility can be measured by σ_n and σ_l .

Assuming that τ is exogenous and fixed (as well as the $\frac{g}{y}$ ratio), we obtain the following:

$$\frac{y}{k} = \frac{g}{\tau k} = \tau \frac{1-\alpha}{\alpha} [\prod_{i=1}^I n_i^{\beta_i}]^{\frac{\beta}{\alpha}} [\prod_{j=1}^J l_j^{\gamma_j}]^{\frac{\gamma}{\alpha}} \theta_n^{\frac{\beta}{\alpha} \sum_{i=1}^I \beta_i} \theta_l^{\frac{\gamma}{\alpha} \sum_{j=1}^J \gamma_j} \quad (12)$$

Therefore, when the total intergenerational utility is maximized, and the sustainable development mode and the balanced growth path are achieved, the growth rate of per capita capital is:

$$\frac{dy/dt}{y} = \alpha(1 - \tau) \frac{y}{k} - \rho \quad (13)$$

or:

$$\frac{dy/dt}{y} = \alpha(1 - \tau) \tau \frac{1-\alpha}{\alpha} [\prod_{i=1}^I n_i^{\beta_i}]^{\frac{\beta}{\alpha}} [\prod_{j=1}^J l_j^{\gamma_j}]^{\frac{\gamma}{\alpha}} \theta_n^{\frac{\beta}{\alpha} \sum_{i=1}^I \beta_i} \theta_l^{\frac{\gamma}{\alpha} \sum_{j=1}^J \gamma_j} - \rho \quad (14)$$

since $\sum_{i=1}^I \beta_i = 1$ and $\sum_{j=1}^J \gamma_j = 1$, Eq (14) can be simplified as Eq (15):

$$\frac{dy/dt}{y} = \alpha(1 - \tau) \tau \frac{1-\alpha}{\alpha} [\prod_{i=1}^I n_i^{\beta_i}]^{\frac{\beta}{\alpha}} [\prod_{j=1}^J l_j^{\gamma_j}]^{\frac{\gamma}{\alpha}} \theta_n^{\frac{\beta}{\alpha}} \theta_l^{\frac{\gamma}{\alpha}} - \rho \quad (15)$$

According to Eq (14) and Eq (15), the maximization of total intergenerational utility is closely related to fiscal revenue and expenditure decentralization, which implies that expenditure decentralization is a determinant of sustainable development. Therefore, when the total intergenerational utility is maximized, the optimal expenditure ratios of the central and sub-national governments can be rendered as:

$$\theta_n^* = \frac{\beta}{\beta + \gamma} \quad (16)$$

$$\theta_l^* = \frac{\gamma}{\beta + \gamma} \quad (17)$$

where, therefore, $\frac{\beta}{\beta + \gamma}$ and $\frac{\gamma}{\beta + \gamma}$ are the optimal expenditure ratios of the central government and

sub-national government, respectively. This means that we can take $\frac{\gamma}{\beta + \gamma}$ as the optimal

expenditure decentralization: when the share of sub-national expenditure exceeds $\frac{\gamma}{\beta+\gamma}$, reducing the share of sub-national expenditure is conducive to increased sustainable development; when the share of sub-national expenditure is lower than $\frac{\gamma}{\beta+\gamma}$, increasing it is conducive to increased sustainable development. So, we can state the following hypothesis:

H: there is a hump-shaped relationship between expenditure decentralization and sustainable development.

In fact, it is quite intuitive to understand this hump-shaped relationship; if the degree of expenditure decentralization is too high or too low, it will lead to a reduction of efficiency and therefore to the loss of utility (Janeba & Wilson, 2011). To illustrate this point, we can take two extreme cases: absolute fiscal expenditure decentralization or complete centralization, as follows:

The absolute expenditure decentralization case, that is, where local governments bear all fiscal expenditures and responsibilities, will lead to three types of issues. First, it will reduce the scale economies effect of some public goods' supply (Oates, 1972; Rodden, 2003), such as national defense, legislation, diplomacy, etc. Second, it will intensify some issues about cross-regional public goods' supply. For example, local governments will bicker about and free-ride on cross-regional pollution prevention without the coordination and control of the central government. More generally, it will reduce the supply efficiency of some public goods (Keen & Marchand, 1997; Zhang & Zou, 1998). Third, it will aggravate the imbalance and inequality of public goods' supply among regions. For regions with developed economies and abundant resource endowments, public goods' supply will be guaranteed in quality and quantity, likely accelerating the further development of these areas. Meanwhile, disadvantaged areas lacking those positive conditions will have less access to public goods and develop relatively more slowly. This will lead to a vicious cycle and to the continuous expansion of regional fiscal and economic imbalance and inequity (Qian et al., 1996; Ferrario & Zanardi, 2011).

In the absolute centralization case, the central government bears all fiscal expenditures and responsibilities, which in turn will also lead to three types of issues. First, it will dampen local governments' initiative. For example, in the early days of modern China, the central government took charge of almost everything, leading to the low participation of local agents and the low efficiency of (local) public goods' supply (Qian & Xu, 1993). Second, local governments' information advantage will be wasted, again leading to the reduced efficiency of public goods supply (Tiebout, 1956; Oates, 1999). Third, it will

make it difficult to guarantee the adaptation of public goods' supply to regional differences, since the central government may provide public goods uniformly to all regions, thus reducing the welfare and utility of residents. This is especially the case for geographically diverse and/or multi-ethnic countries, in which residents from different biomes or ethnic groups have different customs, needs, and preferences, so they need personalized and differentiated public goods.

In short, excessive expenditure decentralization is not conducive to adequate macro-economic control effect and taking advantage of scale economies, while insufficient expenditure decentralization is not conducive to giving full play to the initiative and information advantages of local governments. Both situations lead to the decrease of efficiency and the loss of residents' welfare (Janeba & Wilson, 2011; Oates, 1972; Chen et al., 2002; Thiessen, 2003).

4. Methodology and Data

4.1 The National Sustainable Development Index

This paper measures sustainable development by using the National Sustainable Development Index (NSDI) previously constructed by Jin et al. (2020). However, because of the availability of new data, we make several minor modifications and refinements based on their work. Specifically, we introduce “population using at least basic drinking water sources (%)”, “population using at least basic sanitary facilities (%)” and “expected years of schooling” for indicating drinking water, sanitation facilities, and education, respectively. The upgraded NSDI, including 3 dimensions and 12 factors, as shown in columns 1 to 3 in Table 1.

(1) Economic Dimension of the NSDI

The expectation is that governments should pursue the goals of relatively high and fair income for residents, together with a good potential for economic growth and a reasonable economic structure to improve the welfare of the present generation. Accordingly, indicators for income level, economic growth, and economic structure need to be set. On the one hand, the income level indicates the current level of economic development. Of course, this current level

will affect further development in the future. On the other hand, economic growth and economic structure represent the potential for future economic development. These two indicators reflect the competitiveness of the country's economic activities (Kondyli, 2010). This competitiveness shapes an economic base that is supported by dynamic local activities.

Table 1. The Sustainable Development Evaluation Index

Index	Dimension	Factor	Indicator	Premise
National Sustainable Development Index (NSDI)	Economic dimension (Eco_NSDI)	Economic growth	Real GDP growth	+
		Income level	Income index	+
		Economic structure	Employment in services (% of total employment)	+
	Resource and environmental dimension (RE_NSDI)	Climate	CO ₂ emissions per capita	-
		Air quality	PM2.5	-
		Forest	Forest area (% of total land area)	+
		Arable land	Arable land per person	+
		Energy	Renewable energy consumption (% of total final energy consumption)	+
	Social Dimension (Social_NSDI)	Education	Expected years of schooling	+
		Health	Life expectancy index	+
		Drinking water	Population using at least basic drinking-water sources (%)	+
		Sanitation facilities	Population using at least basic sanitation facilities (%)	+

Note: The descriptions and data source of the 12 indicators can be found in Appendix Table A1.

(2) Resource and Environmental Dimension of the NSDI

The utilization of resources and the protection of the environment, through the services they provide to society and the economy, have effects on the performance of economic activities and on the psychosomatic condition of residents (Kondyli, 2010). Moreover, this dimension of sustainability also reflects a welfare guarantee for future generations. Hence, the protection of environment and the utilization of resources are important and associated with the preservation of their quantitative and qualitative characteristics. The climate and air quality not only reflect the living conditions and quality of human beings in the present generation, but also affect that of future generations. In addition, forest acreage, arable land, and energy consumption represent

current resources and environmental conditions, affecting the performance of current economic activities. In all, these five factors also reflect the insurance of welfare for future generations.

(3) Social Dimension of the NSDI

The expectation is that governments should pursue the goal of social fairness providing education and health services, as well as basic sanitation and drinking water. For the members of poor families, education is an important channel for their future development, while health care services are the basic guarantee for their productive life. Additionally, basic sanitation and drinking water are the most basic requirements for human survival. Therefore, the above four factors not only reflect on the current level of social welfare, but also represent the consideration government provides for social fairness and harmony.

Jin et al. (2020) calculate the weights of 12 indicators on the basis of the Entropy method from basic information theory, which is generally used to calculate the weight of indicators in a composite index. Specifically, information is a measure of the degree of order in a system and entropy is a measure of the degree of disorder in a system; therefore, the smaller the indicator's entropy, the greater the information provided by the indicator, the greater the effect in the comprehensive evaluation, and the higher the weight (Wang et al., 2019). According to Ma et al. (2015), the weight calculated by the Entropy method represents the relative rate of change of the indicator in the composite indicators system, while the relative level of each indicator should be figured by the standardized value of its data. Thus, the Entropy method is an objective weighting method that makes weight judgments based on the size of the data information load. It can reduce the influence of human subjectivity on the evaluation results and makes those results more realistic (Wang et al., 2019; Jin et al., 2020).

To apply the Entropy method, first, we need to relate the different variables measured in

different units with a dimensionless scale from 0 to 1. As shown in Eq. (18), x_{ij} is the indicator j of country i , and \tilde{x}_{ij} is the result of the dimensionless treatment. It should be noted that for some indicators, like per capita CO₂ emissions, higher values mean a poorer performance of sustainable development, and therefore they need to be treated as shown in Eq. (19):

$$\tilde{x}_{ij} = \frac{x_{ij} - \min X_{ij}}{\max X_{ij} - \min X_{ij}} \quad (18)$$

$$\tilde{x}_{ij} = 1 - \frac{x_{ij} - \min X_{ij}}{\max X_{ij} - \min X_{ij}} \quad (19)$$

Second, by calculating the entropy value of each indicator, as shown in Eq. (20) and Eq. (21), the entropy value of each indicator is given by e_j :

$$q = 1 / \ln(n) \quad (20)$$

$$e_j = -q \sum_{i=1}^n \tilde{x}_{ij} \ln \tilde{x}_{ij} \quad (21)$$

Third, we calculate the information utility value of each indicator, h_j as:

$$h_j = 1 - e_j \quad (22)$$

Finally, the weight for indicator j , namely ω_j , is obtained as shown in Eq. (23).

$$\omega_j = h_j / \sum_{j=1}^p h_j \quad (23)$$

We adopt the NSDI to measure sustainable development for three reasons. Firstly, the NSDI includes economic, environmental, and social dimensions, which fits the connotation and concept of sustainable development. Secondly, compared with other existing well-known indices, like the Human Development Index (HDI), the Human Sustainable Development Index (HSDI) (Bravo, 2014) and the Human Green Development Index (HGDI) (Li et al., 2014), the NSDI is more complete, comprehensive, and accessible. Thirdly, the weights of indicators in NSDI are measured by the Entropy method, which is more objective.

4.2 Empirical Framework

For estimating the impact of expenditure decentralization on sustainable development, we

use an expanded Barro’s model (1990) that has become the standard approach in the fiscal decentralization and economic growth literatures (e.g., Zhang & Zou, 2001; Enikolopov & Zhuravskaya, 2007; Canavire-Bacarreza et al., 2020), where our variable of interest is fiscal decentralization accompanied by the necessary canonical list of control variables.

In our empirical analysis, we use several estimation methods. First, we study the effects of cross-sectional variation about the fiscal expenditure decentralization and sustainable development across countries with the Ordinary Least Square method (OLS). Second, our main estimation method to explore the effects of over-time variation about fiscal expenditure decentralization and sustainable development across countries is that of panel fixed effects regressions (FE), since this method is statistically preferred. Third, we estimate the influential effect of over-time variation with panel random effects regressions (RE). Fourth, the LSDV (Least Square Dummy Variables) estimate method is used in any case of cross-section correlation problems in the model. Finally, because fiscal decentralization is potentially endogenous with sustainable development, we also use an IV approach, where our instrument for fiscal expenditure decentralization is the Geographic Fragmentation Index (GFI) first introduced by Canavire-Bacarreza et al. (2020).

The base regression model is given by:

$$SD_i = \alpha_1 + \alpha_2 D_i + \alpha_3 D_i * D_i + \alpha_3 X_i + \varepsilon_i \quad (24)$$

This paper also uses panel regressions with random effects and fixed effects to estimate the effects of over-time variation:

$$SD_{it} = \alpha_i + \beta_2 D_{it} + \beta_3 D_{it} * D_{it} + \beta_3 X_{it} + \varepsilon_{it} \quad (25)$$

$$SD_{it} = \alpha_i + \mu_t + \gamma_2 D_{it} + \gamma_3 D_{it} * D_{it} + \gamma_3 X_{it} + \varepsilon_{it} \quad (26)$$

where i and t indicate countries and years respectively; SD is an index of the sustainable development, D denotes a measure of expenditure decentralization. This paper introduces the

square of D to test the inverted U-shaped relationship between fiscal expenditure decentralization and sustainable development. X is a set of dummy variables and control variables which will be described in detail below. The detailed description and data source of these variables can be found in Appendix Table A2.

4.3 Variables

(1) Dependent Variables

Our main interest lies in explaining how the National Sustainable Development Index (NSDI) is affected by the level of fiscal decentralization after controlling for other determinants. Additionally, we also use the Human Development Index as an alternative dependent variable for the robustness check. The definitions of these and the other variables are shown in Table A2 in the Appendix.

(2) Fiscal Expenditure Decentralization

Our main explanatory variable of interest is the share of subnational expenditures in total government expenditures as the measure of fiscal expenditure decentralization. This measure is the most widely used in the empirical literature on the effects of fiscal decentralization (e.g., Thiessen, 2003; Enikolopov & Zhuravskaya, 2007; Gemmell et al, 2013; Ligthart & Oudheusden, 2017; Canavire-Bacarreza et al., 2020). However, this is still an imperfect and controversial measure, so it is necessary to state why this measure of expenditure decentralization was chosen.

Several criticisms have been addressed to this GFS-based measure,¹ and alternative measurements of fiscal decentralization have been suggested. The main criticism is that

¹ GFS, which is short for the Government Finance Statistics produced by the International Monetary Fund, uses the share of subnational expenditures (or revenues, taxes) in total government expenditures (or revenues, taxes) as the measure of fiscal decentralization. With the wide use of this measure in empirical studies, many researchers simply call it “GFS- based measure” for short.

expenditure decentralization does not well capture the real autonomy of subnational governments, whose actual level of expenditure decentralization the variable will tend to overstate, since they may be restricted or controlled by the central government (Rodden 2004; Baskaran & Feld, 2013). Therefore, considerable effort has been dedicated to measuring fiscal decentralization in a more precise way; for example, Schneider (2003) and Hooghe et al. (2010) construct indices of fiscal decentralization, which strive to account for the actual autonomy of subnational governments, and these two indices have been used in a variety of empirical papers (e.g., Rodríguez-Pose & Ezcurra, 2011; Baskaran & Feld, 2013).

However, these fiscal decentralization indices are not panaceas and can also present problems in their application for empirical study. One main issue is that the data used in these indices are relatively difficult to obtain. Typically, we can only get the required data for a small number of countries, most of which are developed countries. Accordingly, the indices are commonly used for the empirical study of OECD countries or European Union countries, as is the case in Rodríguez-Pose and Ezcurra (2011), Baskaran and Feld (2013), and Slavinskaitė (2017). This issue of data unavailability raises the possibility of a different kind of estimation error when the effects of fiscal decentralization in developed countries is generalized to larger samples including developing countries. In this regard, alternative measures of fiscal decentralization should not only consider its concept and connotation, but also the availability of data (Martinez-Vazquez et al., 2017).

In addition, Ligthart and Oudheusden (2017) have argued that there is no evidence that index measures are more effective than other measures nor that they yield more consistent results. And, on the other hand, there is no empirical evidence that the GFS-based measure is less effective as a proxy for the relative level of countries' fiscal decentralization nor that it is subject

to systematic measurement error across countries (Enikolopov & Zhuravskaya, 2007; Canavire-Bacarreza et al., 2020).

To sum up, we choose the GFS-based measure of expenditure decentralization and accept its imperfection, because it allows us to utilize larger samples that include more developing countries, and thus helps us obtain empirical results with more general significance. Additionally, although we focus on the effect of expenditure decentralization, which is expected to have greater bearing on sustainable development, for robustness we will also use a variable measuring overall degree of fiscal decentralization including both expenditure and revenue decentralization (see Table A2).

(3) Endogeneity Problem and Instrumental Variables

Many past studies of the impact of fiscal decentralization on economic growth have suffered from an endogeneity problem (Martinez-Vazquez et al., 2017); while fiscal decentralization may directly and indirectly affect economic growth, many governments have embarked in decentralization reforms in the pursuit of accelerated economic growth. In order to address this two-way causal relationship between fiscal decentralization and economic growth past studies have used a variety of techniques including system-GMM and IV approaches (Enikolopov & Zhuravskaya, 2007; Kyriacou et al., 2015; Canavire-Bacarreza et al., 2016; Ligthart & Oudheusden, 2017).

In the case of fiscal decentralization and sustainable development we can similarly expect the presence of a two-way causal relationship. On the one hand, fiscal decentralization will affect economic growth, environmental protection, public health, education, social welfare, and other determinants of national sustainable development (Qiao et al., 2005; Fu, 2010; Granado et al., 2016; Jin & Qian, 2020). On the other hand, governments may seek to enhance sustainable

development by adjusting their decentralization policies in areas such as health, education, social welfare, and so on, leading to the endogeneity problem.

In order to solve the potential endogeneity of decentralization, we use the Geographic Fragmentation Index (GFI) developed by Canavire-Bacarreza et al. (2016) as an instrumental variable. The GFI was proved to be a good instrumental variable for empirical research on fiscal decentralization (Canavire-Bacarreza et al., 2020). It is not only strongly correlated with fiscal decentralization, but it is also an exogenous variable to the economic system.

The GFI reflects the weighted probability that two individuals taken at random in the country do not live in similar altitude zones, with the weight matrix calculated as the average distance between altitudes. Thus, the index is simply calculated as:

$$1 - \sum_{j=1}^J \sum_{i=1}^N \left(w_{ij} \frac{n_i}{N} \right)^2 \quad (27)$$

where $\frac{n_i}{N}$ is the share of the population by elevation and w_{ij} measures the distance between altitude i and altitude j . This measure goes from zero, which corresponds to a case where all the population is settled in the same altitude zone, to one which corresponds to the implausible case where each person lives at a different altitude. In general, geographical fragmentation will increase with the number of altitude-zones.

The data for the GFI are acquired from NASA's Earth Observing System Data and Information System (EOSDIS) hosted by the Center for International Earth Science Information Network (CIESIN) at Columbia University. The data are available for years 1990, 1995, 2000 and 2010. Since there is low variation in the GFI over time, to address the missing values for 2001-2005, we assume them to be the same as for 2006-2010. In addition, because the data of GFI are available only in those 5 periods, we also apply the lag period of expenditure

decentralization as an alternative instrumental variable.

(4) Control Variables

First, we control for variables commonly used in the canonical specification in empirical research analyzing economic growth issues, namely human capital, population, and openness (Levine & Renelt, 1992). Specifically, we adopt the secondary school enrollment rate as the measure of human capital (following Thiessen, 2003; Baskaran & Feld, 2013; Ligthart & Oudheusden, 2017, among others); population is measured by the natural logarithm of the actual population; and openness is measured by the proportion of total import and export trade to total GDP (Enikolopov & Zhuravskaya, 2007; Gnegne, 2009; Ligthart & Oudheusden, 2017; Canavire-Bacarreza et al., 2020, among others). Within that canonical specification we also include democracy, corruption, civil liberty, and ethnolinguistic fractionalization as proxies for the institutional environment (as for example in Enikolopov & Zhuravskaya, 2007; Gnegne, 2009; Reiter & Steensma, 2010; Bodman, 2011; Canavire-Bacarreza et al., 2020). Specifically, democracy is measured by the democracy index from Polity IV Dataset; corruption is measured by the Transparency International Corruption Perceptions Indices from Transparency International; civil liberty is from the Freedom House; and ethnic fractionalization is measured by the Ethnolinguistic Fractionalization (ELF) Indices (Roeder, 2001).

Second, even though is not regularly considered in the empirical study of the effects of fiscal decentralization, we control for government size as measured by the revenue to GDP ratio. Fiscal decentralization is generally constrained by the government's financial capacity (Bodman, 2011; Kneller et al., 1999), and if fiscal decentralization leads to a lower public sector size (because of the increased competition among levels of administration) and there is a negative relationship between the public sector size and growth, then there will be a positive bias in the

estimation (Gemmell et al., 2013).

Third, we control for the dependence on natural resources, measured by the share natural resources rent in GDP, since their presence is likely to affect sustainable development (Pardi et al., 2015). Revenues from natural resources such as fossil fuels and minerals can make up a significant proportion of GDP, but their exploitation in the present will not only lower future development and living standards but it is also likely to cause environmental pollution and ecosystem damage (Koirala & Pradhan, 2019).

Last, we introduce time and region dummy variables to avoid the missing variable problems caused by time or region differences (Ligthart & Oudheusden, 2017). The regional dummy variables are created following the World Bank's conventional division.²

4.4 Data

Given the existing data information constraints, we put together a panel of 52 countries (see Table A3 in the Appendix for the complete list), which includes 20 developed countries and 32 developing countries, mainly distributed in six regions, namely Europe & Central Asia, Latin America & Caribbean, Sub-Saharan Africa, North America, East Asia & Pacific, and Middle East & North Africa. Two main considerations determined the selection of countries in the sample: (i) ensuring data integrity of the NSDI, meaning that the selected countries must have accurate data for 10 or more indicators; and (ii) confirming the selected countries have data for expenditure decentralization and other control variables.

In order to explore the short-run and long-run effects of expenditure decentralization on sustainable development, this paper uses two samples, as follows:

² Namely, Europe & Central Asia, Latin America & Caribbean, East Asia & Pacific, Sub-Saharan Africa, North America, South Asia, and Middle East & North Africa.

(1) Sample for Short-Run Effect (2010-2016)

This sample is a panel (time-series cross-country) dataset for 52 countries in the period of 2010-2016, which allows us to control for unobserved sources of country differences. Due to some missing data about variables in this period for some countries, we adopt different complementary methods,³ but fortunately, there are not many missing data in this sample. The summary statistics of this sample are shown in Table A4 in the Appendix.

(2) Sample for Long-Run Effect (1991-2015)

For this longer panel we average the values for five-year periods to smooth the data over the macroeconomic cycle, and to allow us to explore the long-run effects (Canavire-Bacarreza et al., 2020), Therefore we get a cross-country panel data covering five periods, namely 1991-1995, 1996-2000, 2001-2005, 2006-2010 and 2011-2015. As the time span of this sample is relatively large and there are more cases of missing data, we add an interpolation method based on three methods above;⁴ however, in some cases we are not able to interpolate and thus we end up with a slightly unbalanced panel data set. The summary statistics for this sample are reported also in Table A4 in the Appendix.

5. Results

5.1 Measurement of the NSDI

³ Specifically, we use first the mean value interpolation method. For example, if the data of 2010 and 2012 are available, but the data of 2011 is missing, we use the average value of 2010 and 2012 to replace the value of 2011. Second, the nearest neighbor interpolation method. This method is used to deal with missing data for the variables that are very stable over time, like the natural logarithm of total population. Third, the clustering mean interpolation method. The missing value is supplemented by the mean value of the region or organization to which the country belongs.

⁴ If data for a variable is partially missing in a certain period (5 years), for example, there are only 3 years of data, we take the average value of these 3 years as the data of this period. Specifically, in the period of 2006-2010, Turkey has only fiscal expenditure decentralization data in 2008, 2009 and 2010, thus we use the average value of these three years as the average value of this period. Since this method is done over a long period of time and across all countries, it does not raise any major problems. In addition, for some variables with serious missing data issues, we do not make any supplement or modification. For example, the expenditure decentralization data of United Arab Emirates before 2011 are all missing, and therefore we do not make any interpolation.

This paper measures the NSDI and its variation about 52 countries (see Appendix Figures A1 and A2). As the Appendix Table A5 shows, the weights for the economic dimension, social dimension, and resource-environmental dimension respectively account for 24.60%, 23.93% and 51.46%. The sum of the weights of the economic and social dimensions is almost equal to the weights of the resource-environmental dimensions, the latter more closely representing the concept and essence of sustainable development. These weights of three dimensions reflect the welfare of the present and future generations is equally important.

Figure A1 shows the measuring result of NSDI covering 5 periods from 1991-2015. If the sample countries are ranked by the average value of NSDI in these five periods, the top five countries are Sweden (0.717), Australia (0.698), Canada (0.681), Iceland (0.660) and Norway (0.659), and the bottom five countries are United Arab Emirates (0.445), China (0.402), Kiribati (0.387), Mongolia (0.381) and Afghanistan (0.292). In this period, the ten countries with the largest growth rate of NSDI are Azerbaijan (0.116), Moldova (0.114), Kiribati (0.108), Romania (0.096), Lithuania (0.090), Latvia (0.090), Afghanistan (0.086), Armenia (0.078), Estonia (0.077), and China (0.074). It means that the level of sustainable development in China, Kiribati, and Afghanistan is low but has been greatly improved during this period.

Figure A2 shows the NSDI covering the recent 7 years from 2010-2016. Similarly, we rank these countries according to the average value of NSDI in this period. The top five countries still are Sweden (0.722), Australia (0.691), Iceland (0.671), Canada (0.661), and Norway (0.642), but the order has changed. The bottom five countries are same as for the larger sample above, namely United Arab Emirates (0.431), Kiribati (0.391), China (0.385), Mongolia (0.326), and Afghanistan (0.245). In this period, the ten countries with the largest growth rate of NSDI are Romania (0.059), China (0.054), Malta (0.052), Bosnia and Herzegovina (0.051), Kiribati

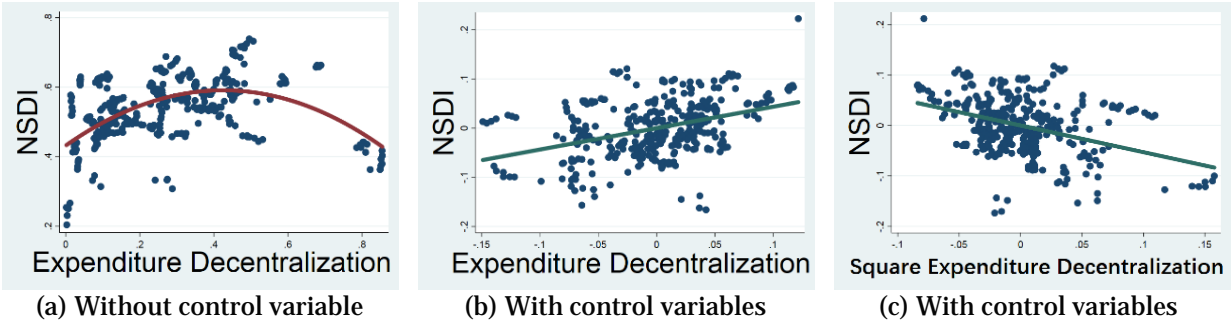
(0.050), Latvia (0.047), Iceland (0.043), Lithuania (0.042), Spain (0.041), and Australia (0.039).

Overall, the measurement of NSDI shows distinct characteristics in economic level and geographical distribution. First, the high NSDI countries tend to be developed countries mainly in Europe and North America, while the countries with lower NSDI are all developing countries mainly in Asia and Africa. Second, the NSDI is also relatively low in those rich Middle East countries, because of their low score in the resource and environmental dimension. This result is similar with alternative measures such as the HSDI (Bravo, 2014) and the HGDI (Li et al., 2014).

5.2 Short-Run Effect

Figure 1 gives a first impression of the relationship between expenditure decentralization and sustainable development. As Figure 1a shows, there is a hump-shaped relationship between expenditure decentralization and NSDI when we have not yet introduced the control variables and expenditure decentralization square term. However, Figure 1a can only provide a conjecture or hypothesis of a hump-shaped relationship. In Figures 1b and 1c, the x-axis respectively represents “Expenditure Decentralization” and “Square Expenditure Decentralization.” Figures 1b and 1c show that, after bringing the expenditure decentralization square term and all the control variables into the model, there is a positive correlation between expenditure decentralization and NSDI, and a negative correlation between expenditure decentralization square and NSDI. It means: (i) there is a hump-shaped relationship between expenditure decentralization and NSDI, even after controlling for the other relevant variables; and (ii) it further supports the conjecture or hypothesis in Figure 1a. However, the hump-shaped relationship between expenditure decentralization and sustainable development in the short run still needs to be tested empirically.

Figure 1. The Relationships of NSDI and Expenditure Decent. in the Short-Run Sample



We start with the OLS, FE, and RE estimations for empirical analysis of the short-run sample (as Table 2 shows). While some of these estimation methods are likely biased, we still include all of them: (1) to compare with each other and select the most suitable estimation method for our sample, and (2) to compare the coefficients of various methods and discuss the potential direction of bias.

The results of OLS estimation are reported in the second and third columns of Table 2. The results of Model 1.1 show that the coefficients of expenditure decentralization and expenditure decentralization square are 0.435 and -0.529 respectively, and both pass the significance test at the level of 1%. Model 1.2 introduces time dummy variables and regional dummy variables based on Model 1.1. Its results show that the coefficients of expenditure decentralization and expenditure decentralization square are significantly positive and negative respectively, and the absolute values of the two coefficients are smaller than those of Model 1.1. It means that our models may miss some variables that affect national sustainable development, and these missing variables are related to time and region. For example, since the temperature in different latitudes is different, the consumption of fossil energy and carbon dioxide emissions are also different, and these are factors affecting the sustainable development. Therefore, we need to control the time and region dummies to solve the estimation bias caused by missing variables to the extent possible. In addition, it should be noted that these empirical results need to be treated cautiously, because OLS estimation cannot effectively control the time and individual effects.

Model 1.3 and Model 1.4 show that the coefficients of expenditure decentralization and expenditure decentralization square are significantly positive and negative respectively, and the absolute values of two coefficients are obviously reduced compared with Model 1.1 and Model 1.2. This means that the time effect and individual effect will cause the estimation bias of regression results in these models and indicates that the two-way FE estimation is preferred. In addition, the F-test values of model 1.3 and model 1.4 are 215.25 and 391.58 respectively, which further indicates that FE estimation is more suitable for this sample than OLS estimation. It should be noted that the indicators used to measure ethnic fractionalization, corruption, and civil liberties change very little over time, so they are not brought into the FE estimation.⁵

Having found evidence of the need for a panel effects approach, we need to make a choice between FE and RE models using the Hausman test. However, the Hausman test will fail if the model has cross-section correlation problems; therefore, we have to test the cross-section correlation first. Three cross-section correlation test methods are widely used, namely Pesaran's test, Friedman's test, and Free's test, all of which have different applicable conditions. Among them, Free's test is the most suitable, because the data are balanced panel data and the time effect needs to be considered in this model. The result of Free's test shows that the model has a cross-section correlation problem. To handle this situation, we perform an auxiliary regression estimation and then conduct a joint significance test for the deviation of all within-subject variables. In fact, this test can be seen as an enhanced version of the Hausman test which could be called the "robust Hausman test". As the result of robust Hausman test shows, the estimation gap between FE and RE is too large, which indicates that FE results are consistent while RE

⁵ These are measured by the Ethnolinguistic Fractionalization Index, Transparency International Corruption Perceptions Index, and the level of civil liberties (see Appendix Table A2), and see Enikolopov and Zhuravskaya (2007) and Canavire-Bacarreza et al. (2020) for further discussion.

results are biased, so FE should be selected.

Table 2. Regression Results in the Short Run Sample (2010-2016), NSDI

	(1.1)	(1.2)	(1.3)	(1.4)	(1.5)	(1.6)	(1.7)	(1.8)
	OLS		FE		RE	LSDV	FE2SLS	EC2SLS
Expenditure	0.435***	0.371***	0.221***	0.128***	0.096**	0.128***	0.128***	0.115**
Decent.	(0.055)	(0.055)	(0.064)	(0.048)	(0.047)	(0.026)	(0.031)	(0.041)
Expenditure	-0.529***	-0.444***	-0.285***	-0.205**	-0.148**	-0.205***	-0.263***	-0.271***
Decent. ²	(0.068)	(0.071)	(0.105)	(0.079)	(0.073)	(0.057)	(0.066)	(0.080)
Government	-0.149***	-0.106***	0.027**	0.003	0.002	0.003	-0.007	-0.009
size	(0.023)	(0.022)	(0.013)	(0.010)	(0.010)	(0.017)	(0.011)	(0.012)
Human capital	0.080***	0.086***	0.024***	-0.005	-0.004	-0.005	0.004	0.002
	(0.019)	(0.018)	(0.008)	(0.006)	(0.006)	(0.004)	(0.010)	(0.007)
Population	-0.007***	-0.008***	-0.139***	-0.055**	0.002	-0.055**	-0.038	-0.002
	(0.002)	(0.002)	(0.029)	(0.025)	(0.005)	(0.015)	(0.031)	(0.004)
Openness	-0.023***	-0.020***	-0.009	-0.012*	-0.009	-0.012*	-0.010	-0.004
	(0.007)	(0.007)	(0.009)	(0.007)	(0.007)	(0.006)	(0.008)	(0.007)
Dependence on	-0.237***	-0.214***	-0.069**	0.034	0.039*	0.034	0.044*	0.051**
nat. resources	(0.044)	(0.040)	(0.028)	(0.022)	(0.022)	(0.026)	(0.023)	(0.022)
Ethnic	-0.036***	-0.037***			0.017	0.429***		0.007
Fractionaliziatio	(0.014)	(0.014)			(0.038)	(0.176)		(0.031)
n								
Democracy	-0.002	-0.006***	-0.001	-0.001	-0.001	0.001***	-0.001**	-0.001*
	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)
Corruption	0.015***	0.019***			0.022***	0.151***		0.024***
	(0.002)	(0.002)			(0.006)	(0.028)		(0.005)
Civil Liberties	0.001*	0.001*			0.001	0.012**		0.001
	(0.000)	(0.000)			(0.001)	(0.004)		(0.001)
Constant	0.511***	0.509***	-1.715***	1.454***	0.367***		1.157***	0.354***
	(0.049)	(0.043)	(0.465)	(0.406)	(0.093)		(0.253)	(0.048)
Time dummy	No	Yes	No	Yes	Yes	Yes	Yes	Yes
Region dummy	No	Yes	No	Yes	Yes	Yes	Yes	Yes
R ²	0.668	0.760	-	-		0.994		
F	64.36***	48.94***	215.25***	391.58***		934.55***	204.18***	
Wald							605.62***	447.76***
Robust Hausman					29.19***			
No. of countries	52	52	52	52	52	52	52	52
Observations	364	364	364	364	364	364	312	312

Note: Standard errors in parentheses, * p < 0.1, ** p < 0.05, *** p < 0.01.

As mentioned above, there is a cross-section correlation problem in FE, so we use LSDV estimation to solve this problem (see Model 1.6). The coefficients of expenditure decentralization and expenditure decentralization square are 0.128 and -0.205 respectively, which are consistent with the coefficients in Model 1.4, and significant at the level of 1% and 5%. These results are very stable, but still they need to be taken with caution because of the

potential endogeneity problem.

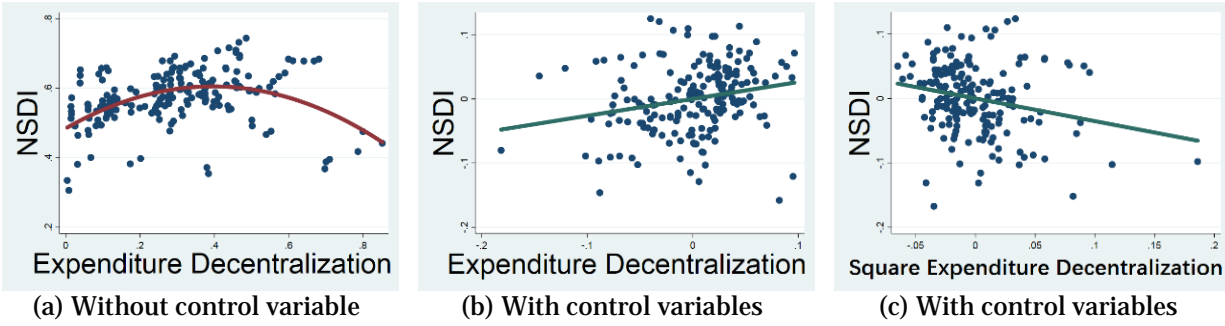
Last, in order to address the endogeneity problem, we use FE2SLS and EC2SLS approaches with the lag period of expenditure decentralization as an instrumental variable. The result of FE2SLS as Model 1.7 shows, the coefficients of expenditure decentralization and expenditure decentralization square are 0.128 and -0.263 respectively, which are close to the results of Models 1.4 and 1.6. The EC2SLS, an error corrected IV-approach, can be used to estimate the variable which does not change with time as an improved scheme of FE2SLS. Both the results of FE2SLS and EC2SLS show that the effect of expenditure decentralization on sustainable development is hump-shaped in short term.

Additionally, we can also observe the results for some control variables in Models 1.6, 1.7, and 1.8. Population growth and trade openness have a significant negative correlation with the NSDI in the short term. There is a significant positive correlation between ethnic fractionalization and NSDI. The rest of the control variables are statistically insignificant.

5.3 Long-Run Effect

Figure 2 shows the scatter plot and regression line in the long-run sample. Figure 2a is the scatter plot and regression line without control variables, b and c are the scatter plots and regression lines after regression estimation with control variables. This figure preliminarily validates our basic hypothesis. By comparing Figure 2 and Figure 1, it can be seen that the scatter plot in the long-run sample is much looser than that of short-run sample, which may be because of the fewer observations and more missing values in long-run sample (see Appendix Table A4). In addition, the slope of regression lines in Figure 2 is not steep as that in Figure 1, which may be because the long-run sample helps to smooth the data over the macroeconomic cycle and weakens the impact of short-run economic fluctuations.

Figure 2. The Relationships of NSDI and Expenditure Decent. in the Long-Run Sample



We also employ OLS, RE, and FE to estimate the long-run impact of expenditure decentralization on sustainable development (results as Table 3 presents). Our interest is to find the most suitable estimation method for the long-run sample, but also to be able to compare the long-run and short-run effects of expenditure decentralization on sustainable development.

The F-test values again indicate that two-way FE estimation is better than OLS estimation for the long-run sample. Before the further selection between FE and RE, it is necessary to examine the cross-section correlation problems of the models. The Pesaran’s test and Free’s test both need to be used for the cross-section correlation test, because the data used in the models is not strongly balanced panel data. The test results confirm the presence of cross-section correlation problems, so the robust Hausman test is used to compare FE and RE. Finally, we find that the estimation gap between FE and RE is too large, hence FE is the most suitable choice.

Table 3. Regression Results in the Long-Run Sample (1991-2015), NSDI

	(2.1)	(2.2)	(2.3)	(2.4)	(2.5)	(2.6)	(2.7)	(2.8)
	OLS	OLS	FE	FE	RE	LSDV	FE2SLS	EC2SLS
Expenditure	0.363***	0.319***	0.192**	0.106**	0.085**	0.106**	0.748***	0.669***
Decent.	(0.085)	(0.083)	(0.087)	(0.055)	(0.037)	(0.043)	(0.190)	(0.194)

Expenditure	-0.453***	-0.417***	-0.251*	-0.167*	-0.134**	-0.167**	-0.858***	-0.968***
Decent. ²	(0.114)	(0.113)	(0.163)	(0.101)	(0.063)	(0.067)	(0.239)	(0.268)
Government	-0.103**	-0.058	0.136***	0.132***	0.108***	0.132***	0.163***	0.058**
size	(0.041)	(0.038)	(0.040)	(0.024)	(0.024)	(0.019)	(0.057)	(0.040)
Human capital	0.108***	0.099***	0.081***	0.028***	0.029***	0.028***	0.024	0.040
	(0.030)	(0.027)	(0.017)	(0.011)	(0.011)	(0.008)	(0.019)	(0.020)
Population	-0.006	-0.007**	-0.061***	-0.052***	-0.003	-0.052***	-0.053**	-0.057***
	(0.004)	(0.003)	(0.020)	(0.014)	(0.005)	(0.011)	(0.025)	(0.016)
Openness	-0.026**	-0.022**	0.058***	0.014**	0.015**	0.014**	0.006	0.004
	(0.011)	(0.010)	(0.008)	(0.006)	(0.006)	(0.005)	(0.014)	(0.009)
Dependence on	-0.131*	-0.147**	0.019	-0.031	-0.040	-0.031	0.106	0.016
nat. resources	(0.072)	(0.060)	(0.051)	(0.032)	(0.033)	(0.023)	(0.181)	(0.058)
Ethnic	-0.012	-0.028			0.013	0.142***		-0.026
Fractionalizio	(0.019)	(0.018)			(0.038)	(0.023)		(0.032)
n								
Democracy	-0.000	-0.003	0.001	0.001	0.001	0.001***	0.001	0.001
	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)
Corruption	0.015***	0.018***			0.020***	0.074***		0.025***
	(0.004)	(0.003)			(0.006)	(0.012)		(0.006)
Civil Liberties	-0.000	-0.000			-0.001	0.011***		0.002**
	(0.001)	(0.001)			(0.001)	(0.004)		(0.001)
Constant	0.526***	0.509***	-0.617*	1.282***	0.404***		1.201***	0.446***
	(0.069)	(0.058)	(0.320)	(0.226)	(0.090)		(0.408)	(0.090)
Time dummy	No	Yes	No	Yes	Yes	Yes	Yes	Yes
Region dummy	No	Yes	No	Yes	Yes	Yes	Yes	Yes
R ²	0.531	0.700				0.993		
F/Wald	17.61***	18.93***	62.60***	176.92***		244.23***	133.64***	302.10***
							/ 336.20***	
Robust Hausman				35.413***				
No. of countries	52	52	52	52	52	52	52	52
Observations	183	183	183	183	183	183	183	183

Note: Standard errors in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

The LSDV estimation is also used in Model 2.6 to solve the cross-section correlation problem. The result of Model 2.6 reports that the coefficients of expenditure decentralization and expenditure decentralization square are 0.106 and -0.167 respectively, which are significant at the level of 5%. It should be noted that the absolute values of the coefficients of expenditure decentralization and expenditure decentralization square in Model 2.6 are smaller than those in Model 1.6 and the significance level is not as good as that in Model 1.6. The first reason for this situation is the issue of missing data. There are many missing values in the long-run sample (see Appendix Table A4), and the data are not a strongly balanced panel. Second, short-run economic

fluctuation disturbs the estimation results, because it also affects the national sustainable development. If a country has severe macroeconomic fluctuations in a short period, this is obviously not conducive to national sustainable development. For example, the international financial crisis that started in 2008 affected the macroeconomic stability of most countries in the world, leading to many problems that restrict national sustainable development, such as the decline of GDP, the rise of the unemployment rate, the increase of social instability factors, etc.

To solve the endogeneity problem in the long-run sample, we use FE2SLS and EC2SLS approaches with the GFI as the instrumental variable. The results of FE2SLS and EC2SLS are as Models 2.7 and 2.8 show, the coefficients of expenditure decentralization and expenditure decentralization square are positive and negative respectively, and both pass the significance test of 1%. By comparing the results of FE, LSDV, and 2SLS, we find that there is a significant hump-shaped relationship between expenditure decentralization and sustainable development in the long run and the empirical results are very robust, meaning that our basic hypothesis has been well tested in long-run samples too.

Additionally, we can also observe the results for some control variables in Models 2.6, 2.7, and 2.8. Government size, human capital, and civil liberties have significant positive correlations with NSDI in the long-run sample, but these are not significant in the short-run sample. Population and corruption have significant negative correlations with sustainable development in the long-run sample. Note that corruption is measured by the Transparency International Corruption Perceptions Indices, with higher values corresponding to lower levels of corruption. The other control variables are not significant.

5.4 Robustness Checks

We conduct two robustness checks. First, we use the overall degree of fiscal

decentralization, so as to account for both expenditure and revenue decentralization, as an alternative independent variable. The overall degree of fiscal decentralization is measured by the weighted average value of the share of subnational expenditure in total government expenditure and the share of subnational revenue in total government revenue.

In the second robustness check, we adopt the HDI (Human Development Index) as an alternative dependent variable for measuring sustainable development. The NSDI is a relatively complete and systematic index for measuring sustainable development, but it is newer and less tested. The HDI is reported annually as part of the Human Development Report of UNDP (United Nations Development Programme) and has gradually been used widely as a sustainability assessment index due to its simple composition and rich connotation (Bilbao-Ubillos, 2013; Li et al., 2014).

Considering the potential presence of endogeneity and the limited space to replicate the entire analysis, we directly use EC2SLS estimation to carry out the robustness check (see Table 4). The results of the first robustness check approach are reported in Models 3.1 and 3.2 in Table 4, which confirm that the overall degree of fiscal decentralization is hump-shaped related with NSDI both in the short term or long term. Models 3.3 and 3.4 report the results of the second robustness check approach. These two models also show a hump-shaped relationship between expenditure decentralization and HDI. These results not only support our theoretical analysis, but also show that the empirical results in Tables 2 and 3 are robust.

Table 4. Robustness Checks, EC2SLS

First Robustness Check:	Second Robustness Check:
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	Overall Level of FD		HDI as Dependent Variable	
	NSDI		HDI	
	Short-run (3.1)	Long-run (3.2)	Short-run (3.3)	Long-run (3.4)
Expenditure			0.131**	0.284**
Decentralization			(0.050)	(0.123)
Expenditure			-0.226**	-0.381**
Decentralization ²			(0.080)	(0.183)
Fiscal	0.222**	0.635**		
Decentralization	(0.104)	(0.303)		
Fiscal	-0.345**	-0.996**		
Decentralization ²	(0.144)	(0.420)		
Government size	0.021	0.020	0.007	-0.182***
	(0.016)	(0.059)	(0.007)	(0.027)
Human capital	0.010	0.033**	0.033***	0.164***
	(0.010)	(0.016)	(0.006)	(0.021)
Population	-0.002	-0.012	0.008**	0.008**
	(0.005)	(0.009)	(0.004)	(0.003)
Openness	-0.001	0.010	0.001	0.015*
	(0.008)	(0.008)	(0.005)	(0.008)
Dependence on natural resources	0.066***	0.027	-0.029**	0.153***
	(0.024)	(0.071)	(0.014)	(0.045)
Ethnic	-0.004	-0.024	-0.045*	-0.099***
Fractionalization	(0.037)	(0.054)	(0.027)	(0.014)
Democracy	-0.001	0.001	0.001	0.005**
	(0.001)	(0.001)	(0.001)	(0.002)
Corruption	0.024***	0.027***	0.028***	0.025***
	(0.006)	(0.009)	(0.004)	(0.003)
Civil Liberties	0.001	-0.002	0.001	0.001***
	(0.001)	(0.002)	(0.001)	(0.000)
Constant	0.402***	0.553***	0.489***	0.335***
	(0.095)	(0.136)	(0.066)	(0.054)
Time dummy	YES	YES	YES	YES
Region dummy	YES	YES	YES	YES
Wald	381.40***	435.34***	602.30***	780.31***
Number of countries	52	52	52	52
Observations	302	181	312	183

Note: Standard errors in parentheses, * p < 0.1, ** p < 0.05, *** p < 0.01.

5.5 Estimation of the Optimal Level of Expenditure Decentralization

This paper brings expenditure decentralization and expenditure decentralization square into the model simultaneously, which is a common method to test a U-shaped relationship in empirical research. However, Lind and Mehlum (2010) have questioned this method. They find that when the real relationship between independent and dependent variables is “convex and monotonous,” the above test method will also hold. This means that the inverted U-shaped

relationship could not be guaranteed with this traditional empirical method, because the presence of just a “convex and monotonous” relationship is also possible. Lind and Mehlum (2010) put forward a new method to test a U-shaped (or inverted U-shaped) relationship by simulating the relationship curve of two variables as well the extreme point, then verifying the correlation of the curves on both sides of the extreme point.

The Lind-Mehlum method has two advantages over the traditional method of fitting a quadratic form. First, it can make up for the defects of the traditional empirical method and accurately test whether the two variables are related in a U-shaped (or inverted U-shaped) relationship or rather just have a “convex and monotonous” relationship. Second, it can easily be used to estimate the minimum point of the simulated U-shaped curve or the maximum point of simulated inverted U-shaped curve; hence, it can be used to estimate the optimal level of expenditure decentralization.

Table 5. The Estimation of the Optimal Expenditure Decentralization

Model	SD	U-Shape	Lower Bound Slope	Upper Bound Slope	Optimal point
1.6	NSDI	Yes	0.127***	-0.223***	0.311
1.7	NSDI	Yes	0.127***	-0.312***	0.309
1.8	NSDI	Yes	0.118**	-0.325***	0.315
2.6	NSDI	Yes	0.084**	-0.121*	0.319
2.7	NSDI	Yes	0.741***	-0.715***	0.335
2.8	NSDI	Yes	0.661***	-0.981***	0.345
3.3	HDI	Yes	0.145**	-0.278**	0.381
3.4	HDI	Yes	0.280**	-0.366**	0.395

Note: (1) * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. (2) SD indicates the sustainable development metric, for which NSDI and HDI are both used in this paper.

In particular, we employ the Lind-Mehlum method to test Models 1.6-1.8, 2.6-2.8, and 3.3-3.4 for the presence of an inverted U-shaped relationship and also to estimate the optimal degree of expenditure decentralization. The U-shaped test results in Columns 3-5 of Table 5 show that expenditure decentralization has an inverted U-shaped relationship with NSDI and HDI and Column 6 of Table 5 presents the optimal degree of expenditure decentralization for

each model. When sustainable development is measured by the NSDI, the optimal expenditure decentralization levels in the short-term and long-term samples are between 0.309 and 0.345. When sustainable development is measured by the HDI, the optimal expenditure decentralization levels in the short-term and long-term samples are 0.381 and 0.395, respectively. Not only are the optimal points quite similar, but the differences can be easily explained by the content of the two indexes: while NSDI includes economic, resource, environmental, and social dimensions, the HDI mainly considers the social-economic dimension.

Despite the quantitative precision of the estimates in Table 5, we need to be reminded that the optimal expenditure decentralization level is not a static and absolute proposition, but rather a dynamic one, responding to the actual conditions and the economic development of a country. First, a country's actual conditions must be considered to determine the optimal degree of expenditure decentralization. In particular, country size is an important determinant of fiscal decentralization (Panizza, 1999; Arzaghi & Henderson, 2005; Enikolopov & Zhuravskaya, 2007). The larger the country size, the farther apart the residents and administrative center will be, and therefore the more powers need to be allocated to local governments to manage their affairs far away from the center. In the same direction, Baskaran and Feld (2013) and Ligthart and Oudheusden (2017) suggest that Federal countries need to allocate more power to local governments than Unitary countries. Panizza (1999) and Canavire-Bacarreza et al. (2020) also show that the higher the degree of ethnic fractionalization, the more fiscal decentralization is needed. Jilek (2018) points out that population and country size jointly affect fiscal decentralization, which means that countries with higher population density need higher degrees of fiscal decentralization. Therefore, at the least, the determination of the optimal expenditure decentralization level needs to consider the country size, national structure, ethnic

fractionalization, population density, and other actual conditions.

Second, the economic development level of the country must be considered to determine the optimal degree of expenditure decentralization regarding the NSDI and HDI, as reflected in the results in Table 5. In fact, as we have seen, the NSDI and HDI imply different development policies and goals. The NSDI includes 12 indicators of economic, environmental, and social dimensions, which implies comprehensive development policy and goals in all aspects. By contrast, the HDI only includes economic and social indicators, which makes many rich countries with high energy consumption and high emissions also be identified as high HDI countries. In fact, this is one of the important reasons why the HDI is a controversial measure of sustainable development. Clearly, the optimal expenditure decentralization level under the guidance of different development policy objectives will be, and has been empirically found to be (Table 5), different. For example, a country in the initial development stage may adopt a development policy with economic growth as the main goal and carry out decentralization reforms to narrowly promote economic growth, which has happened in many developing countries.

6. Conclusion

The key finding in this paper is that fiscal expenditure decentralization has a hump-shaped relationship with sustainable development, implying that there is an optimal degree of expenditure decentralization. In this paper, we first theoretically introduce the expenditure of central government and sub-national government into Barro's model (1990) and derive a hump-shaped relationship between expenditure and sustainable development as well as the optimal expenditure decentralization level. Second, we empirically validate this hump-shaped relationship both in the short and long runs in relation to the National Sustainable Development Index, based on a panel dataset of 52 countries over the period 1991 to 2016, utilizing a variety

of estimation approaches and the Geographic Fragmentation Index as an instrumental variable. Our empirical results are robust to alternative specifications, namely the Human Development Index instead of the NSDI and the use of the overall degree of fiscal decentralization rather than just that of expenditure decentralization. Finally, we estimate the optimal level of expenditure decentralization with the Lind-Mehlum method.

These findings have some tentative policy implications. The hump-shaped relationship implies that excessive expenditure decentralization will weaken the macro-control ability of a central government and the scale effect of public goods' supply, while insufficient expenditure decentralization will restrain the benefits from autonomy and the diverse initiatives of local governments. These two situations both reduce the efficiency of public goods' supply and residents' welfare, undermining national sustainable development. However, there is no universal degree of optimal decentralization since policymakers must consider the development level of the country and its actual conditions along several dimensions such as country size, population density, ethnic diversity, and so on, when calculating that country's optimal decentralization.

In short, policymakers need to calibrate the appropriate level of expenditure decentralization to achieve sustainable development. For countries with insufficient expenditure decentralization, further fiscal decentralization reform is called for. For countries with excessive expenditure decentralization, the recentralization of government's expenditure and responsibilities is called for. Although examples of the former may be more common, there are also examples of the latter. For example, in China, the share of sub-national government expenditure is higher than 85 percent in recent years, which likely means excessive expenditure decentralization, with marked emphasis on infrastructure spending for regional economic growth at the cost of spending on education, environmental protection, public health, social welfare, etc.,

thereby eroding sustainable development. As to what degree of decentralization is appropriate for China or any other specific country, the question will need further study considering the current development level and actual conditions of the country of interest.

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Appendix

Table A1. The Descriptions and Data Sources of the 12 Indicators in NSDI

Indicator	Description	Source
GDP Growth	Real GDP growth.	World Bank
Income index	According to Atkinson (1970), calculating the income index can reflect fairness and equality, in the case of unequal distribution factors, based on the disposable income or consumption of per capita family. The higher the income index is, the better the economic situation of the country is, and the more equal and fairer the income distribution of country is.	UNDP
Employment in services (% of total employment)	The proportion of employments of the tertiary industry in total employments which is used to measure the economic structure.	UNDP
Per capita CO ₂ emissions	It refers to the CO ₂ emission generated by the combustion of energy such as coal, oil, natural gas and so on (Unit: ton per person).	IEA
PM2.5	It represents the concentration of fine suspended particles with a diameter less than 2.5 microns in the atmosphere, which can penetrate the respiratory tract and cause serious health damage (Unit: microgram / m ³).	World Bank
Forest coverage rate	The forest coverage rate is the proportion of forest area in the total land area. While the forest area refers to the land covered by upright trees (at least 5m) which grow naturally or are planted artificially.	UNDP
Arable land per person	Arable land includes temporary crop land (double cropping rice field is calculated once), temporary grassland for mowing or pasture, market or kitchen garden land and temporary fallow land, but excludes the land abandoned due to rotation.	World Bank
Renewable energy consumption	It refers to the proportion of renewable energy consumption in total energy consumption. The higher the proportion is, the more conducive to the sustainable development in resources and environmental dimension.	UNDP
Expected years of schooling	Expected year of education (unit: years). Number of years of schooling that a child of school entrance age can expect to receive if prevailing patterns of age-specific enrolment rates persist throughout the child's life.	UNDP
Life expectancy index	According to Atkinson (1970), calculating the life expectancy index can reflect fairness and equality, in the case of unequal distribution factors, based on the data of UN life table. The higher the index value, the better the health status of residents, the more equal and fairer the access to health for residents.	UNDP
Population using at least basic drinking-water	The population that drinks water from an improved source, provided collection time is not more than 30 minutes for a round trip. This indicator encompasses people using basic drinking-water services as well as those using safely managed drinking-water services. Improved water sources include piped water, boreholes or tube wells, protected	WHO

sources (%)	dug wells, protected springs, and packaged or delivered water.	
Population using at least basic sanitation facilities (%)	Percentage of the population using at least basic sanitation services, that is, improved sanitation facilities that are not shared with other households. This indicator encompasses people using basic sanitation services as well as those using safely managed sanitation services. Improved sanitation facilities include flush/pour flush toilets connected to piped sewer systems, septic tanks or pit latrines; pit latrines with slabs (including ventilated pit latrines); and composting toilets.	WHO

Note: the UNDP, IEA, and WHO are short for the United Nations Development Program, the International Energy Agency, and the World Health Organization, respectively.

Table A2. Description and Sources of Variables used in Regressions

Variable	Description	Source
NSDI	The National Sustainable Development Index constructed by Jin et al. (2020). Its value ranges from 0 to 1, with higher values corresponding to better performance in national comprehensive sustainable development.	See Table A1
Eco_NSNDI	The sub-index of NSDI in economic dimension.	See Table A1
RE_NSNDI	The sub-index of NSDI in resource and environmental dimension.	See Table A1
Social_NSNDI	The sub-index of NSDI in social dimension.	See Table A1
HDI	The Human Development Index. Its value ranges from 0 to 1, with higher values corresponding to better performance in national human development.	UNDP
Expenditure decentralization	Share of subnational expenditure in total government expenditure (%).	IMF-GFS
Fiscal decentralization	The overall degree of fiscal decentralization in expenditure and revenue. The average value of the share of subnational expenditure in total government expenditure and the share of subnational revenue in total government revenue.	IMF-GFS
Geographic Fragmentation Index (GFI)	The GFI reflects the weighted probability that two individuals taken at random in the country do not live in similar altitude zones, with the weight matrix calculated as the average distance between altitudes.	Canavire-Bacarreza et al. (2016)
Government size	Share of fiscal revenue in GDP (%).	IMF-GFS
Human capital	Secondary school enrollment (% gross).	World Bank
Population	Natural logarithm of actual population.	World Bank
Openness	The share of export and import in GDP (%).	UNCTAD
Dependence on natural resources	The share of total natural resources rents in GDP (%). Total natural resources rents are the sum of oil rents, natural gas rents, coal rents (hard and soft), mineral rents, and forest rents. The higher the value, the more dependent the country is on natural resources.	World Bank
Ethnic	The Ethnolinguistic Fractionalization Indices for the year	Roeder

Fractionalization	1985. Its value ranges from 0 to 1.	(2001)
Democracy	Current level of democracy. Scale from 0 to 10, with higher values corresponding to higher democratic level.	Polity IV Dataset
Corruption	The Transparency International Corruption Perceptions Indices for year 2008. Its value ranges from 0 to 10, with higher values corresponding to lower level of corruption.	Transparency International
Civil liberties	The level of civil liberties. Civil liberties allow for the freedoms of expression and belief, associational and organizational rights, rule of law, and personal autonomy without interference from the state. Its value ranges from 0 to 6, with higher values corresponding to higher level of civil liberties.	Freedom House
Time dummy	In the sample of short-run effect, time dummies are created by the years from 2010 to 2016. In the sample of long-run effect, time dummies are created by 5 periods, namely 1991-1995, 1996-2000, 2001-2005, 2006-2010, 2011-2015.	—
Region dummy	Scale from 1 to 6, respectively represents Europe & Central Asia, Latin America & Caribbean, Sub-Saharan Africa, North America, East Asia & Pacific, Middle East & North Africa.	World Bank

Note: (1) the UNCTAD is short for the United Nations Conference on Trade and Development. (2) The Ethnolinguistic Fractionalization Indices could be found: <http://weber.ucsd.edu/~proeder/elf.htm>. (3) The Transparency International Corruption Perceptions Indices could be found: <http://www.gwdg.de/~uwwv/>.

Table A3. Sample of Countries by Development Level and Region

Country	Region	DC	Country	Region	DC
Afghanistan	Middle East & North Africa	N	South Korea	East Asia & Pacific	Y
Albania	Europe & Central Asia	N	Latvia	Europe & Central Asia	N
Armenia	Europe & Central Asia	N	Lithuania	Europe & Central Asia	N
Australia	East Asia & Pacific	Y	North Macedonia	Europe & Central Asia	N
Austria	Europe & Central Asia	Y	Malta	Europe & Central Asia	Y
Azerbaijan	Europe & Central Asia	N	Mauritius	Sub-Saharan Africa	N
Belarus	Europe & Central Asia	N	Moldova	Europe & Central Asia	N
Belgium	Europe & Central Asia	Y	Mongolia	East Asia & Pacific	N
Bosnia and Herzegovina	Europe & Central Asia	N	Myanmar	East Asia & Pacific	N
Brazil	Latin America & Caribbean	N	Netherlands	Europe & Central Asia	Y
Canada	North America	Y	New Zealand	East Asia & Pacific	Y
Chile	Latin America & Caribbean	N	Norway	Europe & Central Asia	Y
China	East Asia & Pacific	N	Paraguay	Latin America & Caribbean	N
Colombia	Latin America &	N	Peru	Latin America &	N

	Caribbean			Caribbean	
Costa Rica	Latin America & Caribbean	N	Romania	Europe & Central Asia	N
El Salvador	Latin America & Caribbean	N	Russian Federation	Europe & Central Asia	N
Estonia	Europe & Central Asia	Y	South Africa	Sub-Saharan Africa	N
Georgia	Europe & Central Asia	N	Spain	Europe & Central Asia	Y
Germany	Europe & Central Asia	Y	Sweden	Europe & Central Asia	Y
Honduras	Latin America & Caribbean	N	Switzerland	Europe & Central Asia	Y
Hungary	Europe & Central Asia	Y	Thailand	East Asia & Pacific	N
Iceland	Europe & Central Asia	Y	Turkey	Europe & Central Asia	N
Israel	Middle East & North Africa	Y	Ukraine	Europe & Central Asia	N
Japan	East Asia & Pacific	Y	United Arab Emirates	Middle East & North Africa	N
Kazakhstan	Europe & Central Asia	N	United Kingdom	Europe & Central Asia	Y
Kiribati	East Asia & Pacific	N	United States	North America	Y

Note: DC indicates whether it is a developed country, according to the standards of CIA's the World Fact Book and IMF, where Y is short for yes and N is short for no.

Table A4. Summary Statistics

Variables	Sample of Short-Run Effect (2010-2016)			Sample of Long-Run Effect (1991-2015)		
	Obs	Mean	Std. Dev.	Obs	Mean	Std. Dev.
NSDI	364	0.54	0.09	260	0.55	0.09
Eco_NSDI	364	0.15	0.04	260	0.15	0.04
RE_NSDI	364	0.23	0.05	260	0.23	0.05
Social_NSDI	364	0.16	0.03	260	0.17	0.04
HDI	364	0.80	0.11	260	0.75	0.12
Expenditure decent.	364	0.28	0.19	190	0.30	0.18
Fiscal decentralization	354	0.23	0.18	185	0.24	0.16
Geographic Fragmentation Index				260	0.35	0.08
Government size	364	0.36	0.14	200	0.35	0.11
Human capital	364	1.00	0.20	253	0.91	0.24
Population	364	16.31	1.76	260	16.24	1.76
Openness	364	0.90	0.48	258	0.84	0.43
Depend. on nat. resources	364	0.04	0.07	258	0.04	0.06
Ethnic fractionalization	364	0.37	0.22	260	0.37	0.22
Democracy	364	7.38	3.48	260	7.19	3.43
Corruption	364	5.18	2.39	260	5.18	2.39
Civil liberties	364	4.19	1.57	260	4.19	1.57

Table A5. The Weights of 12 Indicators in NSDI

Index	Dimension	Factor	Indicator	Weights
National Sustainable Development Index (NSDI)	Economic dimension (Eco_NSDI)	Economic growth	Real GDP growth	6.09%
		Income level	Income index	9.20%
		Economic structure	Employment in services (% of total employment)	9.31%
	Resource and environmental dimension (RE_NSDI)	Climate	CO2 emissions per capita	12.30%
		Air quality	PM2.5	7.55%
		Forest	Forest area (% of total land area)	8.74%
		Arable land	Arable land per person	14.49%
	Social Dimension (Social_NSDI)	Energy	Renewable energy consumption (% of total final energy consumption)	8.38%
		Education	Expected years of schooling	7.14%
		Health	Life expectancy index	7.39%
		Drinking-water	Population using at least basic drinking-water sources (%)	4.95%
		Sanitation	Population using at least basic sanitation facilities (%)	4.45%

Note: The weights of 12 indicators are following the work of Jin et al. (2020).

Figure A1. The NSDI of 52 Countries in the 5 Periods from 1991-2015



Figure A2. The Variation Trend of NSDI of 52 Countries from 2010-2016

