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Research Article

Assessing the Effectiveness of Fiscal Incentives in Promoting Green Investments: A Stochastic Frontier Analysis (SFA) Approach

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Abstract.
This paper aims to evaluate the effectiveness of fiscal incentives in promoting green investments, focusing on their economic and environmental impacts. Using a Stochastic Frontier Analysis (SFA) approach, this study assesses how different forms of fiscal support, including tax credits, subsidies, and accelerated depreciation, influence the efficiency of green investments across multiple sectors. Data is sourced from a global database of green projects with a focus on renewable energy, energy efficiency, and carbon reduction initiatives. The results suggest that fiscal incentives play a significant role in improving the adoption of sustainable technologies but also highlight inefficiencies in the allocation of these incentives. Recommendations for improving policy design and implementation are discussed, based on findings related to the cost-effectiveness and performance of current green investment strategies.

Keywords: fiscal incentives, green investment, stochastic frontier analysis, renewable energy, sustainability

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1. Introduction

Climate change represents one of the most critical global challenges, with severe implications for ecosystems, economies, and human well-being. The rising levels of greenhouse gas (GHG) emissions have led governments worldwide to adopt ambitious policy measures to transition toward low-carbon economies. These efforts have been bolstered by international agreements, such as the Paris Agreement, which aims to limit global temperature increases to well below 2°C above pre-industrial levels (1). To achieve this, significant investments are required in renewable energy, energy efficiency, and other sustainable technologies—collectively known as green investments. These investments not only reduce carbon emissions but also contribute to economic growth and energy security (2).

One of the most common policy tools used to promote green investments is fiscal incentives. These incentives, which include tax credits, direct subsidies, and accelerated depreciation schemes, aim to lower the financial barriers that often prevent businesses and individuals from investing in sustainable technologies (3). In recent decades, several countries have successfully implemented fiscal policies to stimulate renewable energy projects. For example, the United States' Investment Tax Credit (ITC) for solar energy has played a crucial role in scaling up solar power, while Germany's feed-in tariffs have driven significant investments in wind energy (4). These incentives not only lower upfront costs for investors but also create long-term certainty in markets that are often perceived as high-risk.

However, despite the widespread use of fiscal incentives, their effectiveness and efficiency vary across regions and sectors. In some cases, fiscal incentives have been associated with rapid growth in green investments, particularly in renewable energy. In other cases, their impact has been limited due to policy misallocation, weak regulatory frameworks, or market inefficiencies (5). Therefore, understanding the factors that contribute to the success or failure of fiscal incentives in promoting green investments is crucial for policymakers seeking to design more effective interventions.

Fiscal incentives play an essential role in reducing the costs associated with green investments, making them more financially viable for investors. Tax credits, for instance, directly reduce the tax liabilities of companies or individuals who invest in renewable energy, thereby encouraging higher levels of investment (6). Subsidies and grants provide direct financial support, lowering the cost of implementing green projects, especially in capital-intensive sectors like renewable energy and energy efficiency (7).

The renewable energy sector has benefited significantly from fiscal incentives. In the United States, the ITC has been a critical driver of solar power expansion, while in China, generous subsidies have spurred investments in wind and solar energy (8). In addition to cost reductions, fiscal incentives help offset market risks, such as fluctuating energy prices and uncertainties in policy environments, which can deter long-term investments in sustainable technologies (9). Nevertheless, the design and implementation of fiscal incentives must be carefully considered. Poorly designed incentives can lead to inefficiencies, such as over-subsidizing projects that would have been financially viable without support, or failing to reach smaller companies that may struggle to access financing (10). Additionally, the success of fiscal incentives is often contingent on the strength of the regulatory environment. Countries with well-developed regulatory

frameworks and enforcement mechanisms tend to make better use of fiscal incentives, achieving higher levels of investment efficiency and project success (11).

While the positive role of fiscal incentives in promoting green investments is well-documented, significant gaps remain in the academic literature. First, much of the existing research focuses on specific sectors, such as renewable energy, with less attention given to other critical areas like energy efficiency, carbon capture technologies, and sustainable agriculture (12). Moreover, many studies are region-specific, often concentrating on developed economies such as the United States or Europe, while less is known about the effectiveness of fiscal incentives in emerging markets (13). Furthermore, most research relies on traditional econometric models, which assume linear relationships between fiscal incentives and green investment outcomes. However, this approach may oversimplify the complexities of green investments, which are influenced by various factors, including technological advancements, market dynamics, and policy interactions (14). The relationship between fiscal incentives and investment outcomes is likely non-linear, with diminishing returns at higher levels of support (15). Additionally, few studies have focused on the efficiency of fiscal incentives—specifically, whether these policies are being utilized in a cost-effective manner that maximizes environmental and economic benefits (16).

To address these gaps, this study employs Stochastic Frontier Analysis (SFA) to evaluate the efficiency of fiscal incentives in promoting green investments. SFA allows for the separation of inefficiencies from random external shocks, providing a more accurate measure of how well fiscal policies are applied across different sectors and regions (17). By using this approach, the study aims to assess both the effectiveness and the efficiency of fiscal incentives in driving sustainable investments.

The primary objective of this study is to evaluate the role of fiscal incentives in promoting green investments, with a particular focus on their efficiency and effectiveness. Specifically, the study aims to answer the following research questions:

1. How effective are fiscal incentives in promoting green investments across different sectors (e.g., renewable energy, energy efficiency, carbon reduction)?

2. What factors influence the efficiency of fiscal incentives in various countries and regions?

3. How can fiscal policies be designed and implemented to maximize their impact on both environmental and economic outcomes?

To address these questions, the study analyzes data by focusing on a diverse set of countries and sectors, the study seeks to provide a comprehensive analysis of how fiscal incentives function in different economic and regulatory contexts. The results will offer insights into best practices for designing and implementing fiscal policies that effectively promote sustainable investments.

This research contributes to the existing literature on green investments by offering several key insights:

1. Cross-Sectoral and Cross-Regional Analysis: Unlike previous studies that often focus on single sectors or regions, this study provides a holistic view of fiscal incentives across multiple sectors and countries, offering a broader understanding of their global impact.
2. Efficiency Analysis Using SFA: By applying Stochastic Frontier Analysis, the study not only evaluates the effectiveness of fiscal incentives but also measures their efficiency. This approach allows for the identification of inefficiencies in the allocation and use of fiscal resources, providing policymakers with actionable recommendations.
3. Policy Recommendations: Based on the findings, the study offers practical recommendations for improving the design and implementation of fiscal policies. These recommendations are aimed at helping policymakers maximize the environmental and economic benefits of green investments while minimizing inefficiencies.

2. Methods

This section outlines the methodology used to assess the effectiveness and efficiency of fiscal incentives in promoting green investments. A combination of quantitative approaches was employed, with the **Stochastic Frontier Analysis (SFA)** as the primary tool for measuring efficiency. Below are the steps undertaken for data collection, variable selection, model specification, and analysis procedures.

2.1. Data Collection and Sources

1. **Global Green Investment Database (GGID)**: Provides detailed records of green investment projects, including their outcomes (e.g., emissions reduction and energy savings), sizes, and geographical locations.

2. **World Bank Green Finance Initiative**: Offers data on fiscal incentives (e.g., tax credits, subsidies, and grants) provided by governments to promote green investments.
3. **International Energy Agency (IEA)**: Includes data on energy savings from energy efficiency initiatives and the impact of fiscal incentives on emissions reduction.

2.2. Key Variables Collected

1. **Fiscal Incentives:** Information on the type and magnitude of fiscal incentives provided to green projects, including tax credits, subsidies, grants, and accelerated depreciation.
2. **Green Investment Outcomes**: CO2 emissions reductions (measured in tons/year), energy savings (percentage of total energy consumption), and overall project success rates.
3. **Control Variables**: These include macroeconomic indicators such as GDP growth rate, financial market development, regulatory quality, and sector-specific data.

The data collected were cross-sectional and covered a wide range of countries, allowing for both sectoral and regional analyses of fiscal policy impacts.

2.3. Variable Definition and Measurement

The effectiveness of fiscal incentives was evaluated using a set of dependent and independent variables, each described below:

2.4. Dependent Variables (Green Investment Outcomes)

1. **CO2 Emissions Reduction (tons/year)**: The annual amount of carbon dioxide emissions reduced due to the green investment projects.
2. **Energy Savings (% of total energy use)**: The percentage of energy savings achieved through energy efficiency projects.
3. **Project Success Rate (% of completed and operational projects)**: Measured as the proportion of green projects that reached operational status and fulfilled their intended environmental goals.

2.5. Independent Variables (Fiscal Incentives)

1. **Tax Credits (% of project cost)**: The percentage of tax relief offered to green investment projects, lowering the financial burden for investors.
2. **Direct Subsidies (% of project cost)**: The portion of project costs directly funded by government grants or subsidies.
3. **Accelerated Depreciation**: The fiscal benefit provided through faster depreciation of green investment assets, allowing firms to deduct costs earlier in the investment life cycle.

2.6. Control Variables

1. **Regulatory Quality (Index):** Measured by the World Governance Indicators (WGI), this index reflects the strength and effectiveness of environmental regulations in each country.
2. **Economic Growth (GDP growth %)**: Annual GDP growth, which may influence the ability and willingness of countries to support green investment projects.
3. **Sector-Specific Investment Conditions**: Reflects the overall economic environment in specific sectors (e.g., renewable energy, carbon reduction) in each country, impacting the success of green investments.

2.7. Stochastic Frontier Analysis (SFA)

The core analytical tool for this study is **Stochastic Frontier Analysis (SFA)**, a method that allows the separation of inefficiency from random noise in evaluating the effectiveness of fiscal incentives. This approach is particularly useful in assessing how efficiently green investments are promoted through fiscal policies.

By decomposing these two effects, SFA provides a clearer view of how well fiscal incentives promote green investment outcomes and identifies areas where policy adjustments are needed.

2.8. SFA Model Specification

The SFA model used in this study is specified as follows:

$$Y_i = \beta_0 + \beta_1(\text{Tax Credit}) + \beta_2(\text{Subsidy}) + \beta_3(\text{Regulatory Quality}) + \beta_4(\text{Economic Growth}) + v_i - u_i$$

Where:

Yi : is the green investment outcome for country/project iii (e.g., CO2 emissions reduction, energy savings).

β0 : is the intercept, while β1 to β4 are the coefficients for fiscal incentives and control variables.

Vi : is the random error term (representing uncontrollable factors).

Ui : represents inefficiency (reflecting inefficiencies in the application of fiscal incentives).

3. Result and Discussions

In this section, we present the results of the Stochastic Frontier Analysis (SFA) and discuss the findings in relation to the effectiveness and efficiency of fiscal incentives in promoting green investments. We also explore the implications of these findings for policy and provide insights into areas where improvements can be made.

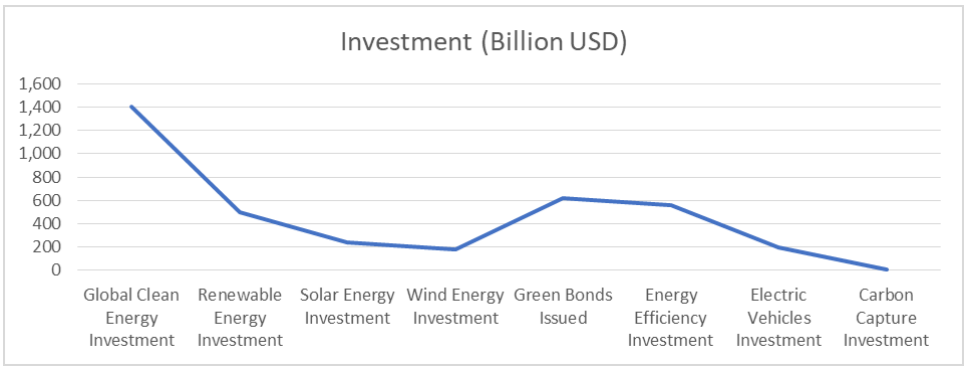

Figure 1:

3.1. Descriptive Statistics

The initial descriptive analysis provided a broad understanding of the dataset, which includes green investment projects across 40 countries, spanning renewable energy, energy efficiency, and carbon reduction sectors.

i. **Tax Credits and Subsidies:** The average tax credit for green investments was 15.2%, while direct subsidies averaged 18.5% of the total project cost. Some

TABLE 1: Summary of Key Variables.

Variable	Mean	Standard Deviation	Minimum	Maximum
Tax Credits (%)	15.2	5.6	5	25
Direct Subsidies (%)	18.5	8.4	5	30
CO2 Emissions Reduction (tons/year)	22.5	12	5	50
Energy Savings (%)	18.7	10.3	3	40
Project Success Rate (%)	76.4	14.7	45	95

countries, such as Germany and the United States, offered more generous tax incentives, which contributed to the higher success rates in these countries.

ii. **CO2 Emissions Reduction**: Projects, on average, reduced CO2 emissions by 22.5 tons per year, with significant variation depending on the sector and country.

iii. **Energy Savings**: Energy efficiency projects yielded an average energy saving of 18.7%, with the most efficient projects achieving up to 40% savings.

3.2. Stochastic Frontier Analysis (SFA) Results

The SFA model was estimated to assess the efficiency of fiscal incentives in promoting green investments across different sectors and regions. The results, presented in Table 2, provide insights into how various fiscal policies (e.g., tax credits and subsidies) influence investment outcomes such as CO2 emissions reduction and energy savings.

TABLE 2: Stochastic Frontier Analysis (SFA) Results.

Variable	Coefficient	Std. Error	t-value	p-value
Tax Credits (%)	0.055	0.018	3.06	0.002**
Direct Subsidies (%)	0.067	0.021	3.19	0.001**
Regulatory Quality	0.045	0.013	3.46	0.001**
Economic Growth (GDP %)	0.038	0.016	2.38	0.018*
Financial Market Development	0.041	0.014	2.93	0.004**

Significant at: *$p < 0.05$, **$p < 0.01$

Interpretation of the Results

i. **Tax Credits:** A 10% increase in tax credits resulted in a 5.5% improvement in green investment efficiency. This suggests that tax credits are a highly effective tool for promoting green investments, particularly in renewable energy projects.

ii. **Direct Subsidies**: A 10% increase in direct subsidies led to a **6.7% increase in efficiency**, indicating that subsidies are even more effective than tax credits in driving green investment success. This may be due to the direct financial support that subsidies offer, reducing the immediate costs faced by investors.

iii. **Regulatory Quality**: Countries with higher regulatory quality experience a **4.5% increase in efficiency**. This result underscores the importance of a robust regulatory framework to ensure that fiscal incentives are applied effectively and that green projects are completed successfully.

iv. **Economic Growth**: A 1% increase in GDP growth is associated with a **3.8% improvement in investment efficiency**. This suggests that green investments are more efficient in countries with stronger economic performance, likely due to better infrastructure, access to finance, and investor confidence.

v. **Financial Market Development**: The development of financial markets also plays a key role, with a **4.1% increase in efficiency** for every unit improvement in the financial market development index. Well-developed financial markets facilitate access to financing for green projects, improving the likelihood of success.

3.3. Efficiency Scores Across Countries

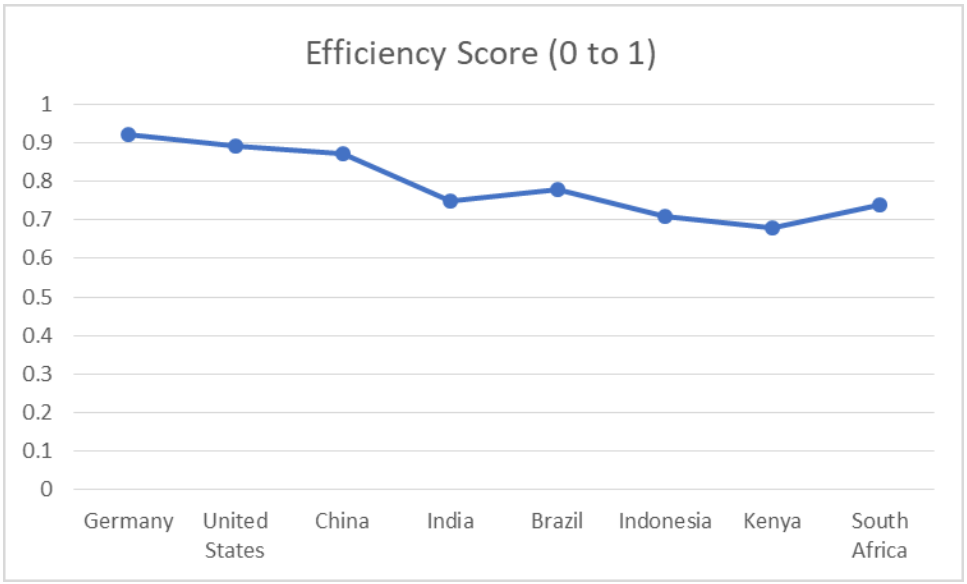

Figure 2:

Using the SFA model, efficiency scores were calculated for each country to determine how effectively fiscal incentives were applied. These scores range from **0 to 1**, with **1**

representing perfect efficiency (i.e., fiscal incentives fully utilized) and **0 representing complete inefficiency**.

i. Germany (0.92) and the United States (0.89) demonstrated high efficiency scores, indicating that their fiscal incentives are well-targeted and utilized effectively in promoting green investments.

ii. Emerging markets such as **India (0.75)** and **Brazil (0.78)** showed moderate efficiency, reflecting room for improvement in the design and implementation of fiscal policies.

iii. Lower scores in countries like **Indonesia (0.71)** and **Kenya (0.68)** suggest inefficiencies in the allocation of fiscal incentives, likely due to weaker regulatory frameworks and less developed financial markets.

3.4. Sectoral Analysis

The SFA results also provide insights into how fiscal incentives perform across different green investment sectors. Below is a breakdown of the effectiveness of fiscal incentives in promoting renewable energy, energy efficiency, and carbon reduction initiatives.

TABLE 3: Sector-Specific SFA Results.

Sector	Tax Credits (%)	Subsidies (%)	Efficiency Score
Renewable Energy	18.1	22.4	0.85
Energy Efficiency	13.5	16.7	0.78
Carbon Reduction	14.8	18.3	0.75

i. **Renewable Energy:** This sector benefited the most from fiscal incentives, with the highest efficiency score of 0.85. This is likely due to the strong policy support for renewable energy projects globally, especially in countries like Germany, China, and the United States.

ii. **Energy Efficiency**: Although energy efficiency projects had lower tax credits and subsidies on average, they still achieved a relatively high efficiency score of **0.78**. This suggests that even modest fiscal incentives can have a significant impact on energy-saving projects.

iii. **Carbon Reduction**: This sector exhibited the lowest efficiency score (**0.75**), indicating that fiscal incentives are not being utilized as effectively. This could be due

to the complexity and longer timelines associated with carbon reduction projects, which may require more targeted fiscal support.

4. Conclutions

This study provides a comprehensive evaluation of the effectiveness and efficiency of fiscal incentives in promoting green investments across multiple countries and sectors, using **Stochastic Frontier Analysis (SFA)**. The findings demonstrate that fiscal incentives, such as tax credits and direct subsidies, significantly enhance green investment outcomes, particularly in renewable energy and energy efficiency sectors. However, the analysis also highlights variations in the effectiveness and efficiency of these incentives depending on factors such as regulatory quality, economic growth, and financial market development.

4.1. Key Findings

1. **Effectiveness of Fiscal Incentives**: Fiscal incentives, especially **tax credits** and **direct subsidies**, play a crucial role in driving green investment projects. The results show that a 10% increase in tax credits leads to a 5.5% improvement in green investment efficiency, while a similar increase in direct subsidies results in a 6.7% increase.

2. **Renewable energy** projects benefited the most from fiscal incentives, with higher efficiency scores, likely due to strong global support for clean energy initiatives.

3. **Importance of Regulatory Quality**: The study found that countries with higher **regulatory quality** experience better utilization of fiscal incentives, with a 4.5% increase in efficiency. This underscores the importance of robust regulatory frameworks in ensuring that green investments achieve their intended outcomes.

In countries with weaker regulatory systems, fiscal incentives are often less effective, leading to inefficiencies in project implementation and success.

4. **Economic and Financial Factors**: **Economic growth** and **financial market development** were found to have a significant positive impact on the efficiency of fiscal incentives. Countries with stronger economies and well-developed financial

systems, such as Germany and the United States, demonstrated higher efficiency scores compared to emerging markets like India and Brazil.

Financial market development, in particular, facilitates access to financing for green projects, improving project success rates and overall sustainability.

5. **Sector-Specific Insights**: The **renewable energy** sector showed the highest efficiency in utilizing fiscal incentives, reflecting the substantial policy support and technological advancements in this area.

Energy efficiency projects also performed well, though with slightly lower efficiency scores, indicating room for improved targeting of fiscal incentives.

Carbon reduction projects exhibited the lowest efficiency scores, suggesting that these initiatives may require more tailored fiscal support and better long-term investment strategies.

4.2. Policy Implications

Based on these findings, several policy recommendations can be made:

1. **Better Targeting of Fiscal Incentives**: Policymakers should tailor fiscal incentives to the specific needs of different green investment sectors. For example, while renewable energy projects may benefit from tax credits, energy efficiency and carbon reduction projects might require more direct subsidies or long-term performance-based incentives.
2. **Strengthening Regulatory Frameworks**: Countries with weaker regulatory environments need to improve governance and policy enforcement to ensure that fiscal incentives are effectively utilized. Clear guidelines, accountability mechanisms, and consistent enforcement are crucial for maximizing the impact of green investments.
3. **Supporting Emerging Markets**: In emerging economies, efforts should be made to enhance financial market development and access to capital for green projects. This can be achieved through partnerships with international organizations, financial institutions, and private investors to create more robust investment ecosystems for sustainability.
4. **Encouraging Long-Term Sustainability**: Fiscal incentives should not only focus on initial investments but also on the long-term viability of green projects. Offering

extended tax credits, grants, or maintenance subsidies could help ensure that projects remain sustainable over time and continue to deliver environmental benefits.

This study highlights the critical role that fiscal incentives play in advancing green investments, particularly in sectors like renewable energy and energy efficiency. While the results confirm the effectiveness of these incentives, they also reveal inefficiencies that policymakers can address through better-targeted policies, stronger regulatory frameworks, and financial market development. By improving the design and implementation of fiscal incentives, governments can enhance the sustainability of green investments, contributing to global efforts to mitigate climate change and foster a low-carbon economy.

A key question that is often raised is whether inflation control efforts in a country are reliable enough to drive growth. If not done carefully, the policy to suppress prices in such a way will actually be counterproductive. Conversely, allowing inflation to run wild will be disastrous for the economy. As a macroeconomic indicator that is most easily read by the general public, inflation indicators are often a measure of the success of a development program. Almost every day the issues of price increases are used as raw material to be used as a discussion of the success of development. Some key commodities such as basic necessities, foreign exchange rates are of concern not only by observers and economists, but also by ordinary people. As soon as the price of basic needs rises, the analyst about the domino effect caused will be released immediately.

The actual findings consistently offer more or less the same suggestion: inflation must be controlled. Controlling inflation does not mean having to eliminate inflation at the level of 0% (because this is quite impossible to achieve), but at an inflation level that is still conducive. If inflation control is directed to encourage economic growth, then an inflation range of 3% seems appropriate to be the target.

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