Firm Heterogeneity and Its Implication on Chinese Climate Policies

-- A CGE Analysis based on China's National IO Table
with Firm Heterogeneity Information

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Abstract

China is pushing ahead its GHG mitigation efforts. In early stage, the policy regulations were limited to selected emitters – mainly state owned firms and large scale private firms – in order to lower the monitoring and administration costs, as well as market risks. And additionally, preferential financial supports are provided to regulated firms for "Green" investment in energy conservation and emission reduction technologies, intended to regain their market competitiveness. However, along with the growth in private sectors and the tightening of emission target in China, the double distortion caused by limited regulation coverage and unbalanced financial support may cause potential risk for climate policy effectiveness, market stability and long-term economic growth.

The private sector in China has grown rapidly with expanding number and total scale of small firms - the majority of which are not regulated by climate policies. Therefore, tighter emission targets are required for regulated firms to offset the growing "leakage" to unregulated firms, and further distort the abatement costs across emitters. On the other hand, with tightened emission targets and lower financing cost, the regulated firms would have stronger incentives for green investments while unregulated firms would be discouraged with lower energy costs. The unbalanced green investment indicates a lower efficiency and a miss allocation of financial resources.

China has pledged to further lower its carbon intensity to 35-40% of that in 2005 by 2030 so as to peak its GHG emission. In order to achieve this target, a more efficient design of climate policy mechanism is required. Whether and to what extent would the limited coverage of climate policy and the unbalanced financial support undermine the efficiency of climate policies? How would it affect the long-term economic growth? Is the planned ETS in China helpful in widening policy coverage without increasing monitoring cost? And how should the trading scheme be designed to increase its policy efficiency? Understanding these questions is important for a better design of climate policies in China, yet haven't been investigated carefully. This proposed work is intended to answer the aforementioned questions by the following steps:

1) identify heterogeneous firms based on firm-level survey data, and separate them w.r.t. ownership (state owned, foreign invested and domestic private) and firm size (large scale and mid-/small-scale) in an IO table;
2) specify behaviors of different firms in a dynamic Computable General Equilibrium (CGE) model and estimate the effect of Chinese climate policies systematically taking firm heterogeneity into consideration;
3) test alternative design of policy design, mainly focused on the policy coverage and financial support related to green investment, for their impacts on compliance costs of

GHG mitigation and long-term economic growth path; and

4) make proposition for the design of Chinese climate policy.

The proposed work can contribute to the existing literature not only by identifying firm heterogeneity in IO table, but also by specifying the producing technology, capital and energy-tech. investment behavior, market conditions, etc. of different type of firms, and thus endogenously simulate their response to policy regulations. With this work, we will be able to gain deeper insights into Chinese market and its response to climate policies, and help us to understand a better design of relative policies.

1. Introduction

China has officially submitted its 'Intended Nationally Determined Contribution (INDC)' to UNFCCC portal in Jul., presenting its aim to cut carbon intensity by 60~65% by 2030 from 2005 level. The INDC largely reinforced China's commitment made in 2014 of peaking its CO_2 emissions around 2030. Assume that China would fulfill the Copenhagen commitment and reduce its CO_2 intensity by 40-45% from 2005 levels by 2020, an average reduction of 3.27~4.11% in CO_2 intensity is required during 2010 to 2020, and 3.97~4.42% during 2020 to 2030. China has already achieved a decarbonization of its booming economy. A series of energy and climate policies put forward in its National Five-Year-Plans (FYPs) had triggered a significant energy transition with energy technology upgrading, robust renewable energy uptake and rapid industrial structure change. Since the low-hanging fruits for emission reduction is getting rarer, the economy have witted decreasing effectiveness of existing policy tools and increasing costs for decarbonization. In order to achieve a more ambitious emission target, the design of policy system have to be reinvestigated.

When faced with emission constraints, emitters can generally follow two basic strategies: either adjust their input structure on the producing technology frontier, or invest in energy technology to shift the frontier. The choice of each emitter is determined by the heterogeneous substitutability among and input share of factors, market conditions, profitability, financing costs, etc. The heterogeneity not only exists among emitters in different industries, but also within a same industry, which is usually neglected in policy analysis. In the current regulation structure of Chinese climate policies, state owned firms and large private-owned emitters are the core for emission reduction, since on one hand, they are directly regulated by the governments, and on the other hand, some of them (especially SOEs) are provided with preferential financial conditions, including free or low-interest credits, easier access to public funds, etc., for their energy technology investments. The unbalanced regulation across emitters was intended to lower the monitoring and administration costs and market risks; but in the meantime, it inevitably leads to market distortion with diversified incentives among firms. Green investments would be directed to and concentrated in regulated emitters who have the preferential financial conditions for their investments (mainly SOEs), while other regulated emitters (e.g. large private owned ones) would have to rely more on substituting energy input with other factors. Unregulated emitters (mainly small private ones) are, on the country, discouraged for their emission reduction efforts by the absence of policy regulation, lower energy prices and higher financial costs. The diversified regulation would lead to diversified marginal abatement cost (MAC) for CO_2 across firms and decrease the total efficiency in emission reduction. On the other hand, the unbalanced green investment would also diversify the marginal effects of green investments, decrease the average efficiency. Moreover, green investment is competing with fixed capital investments in forming production capacity, and affect the long-term economic growth. The private sector in China has been growing rapidly in recent decade with expanding number and total scale of firms. According to authors' calculation, emission by private small-scale firms accounted for 42% of total emission in 2010, and 17% from large private firms. It will therefore intensify the triad distortion caused by the unbalanced regulation, and undermines the effect and economic efficiency of climate policies.

Researches have been devoted to analyze the implication of firm heterogeneity on the effectiveness and efficiency of climate policies.

The existing literature on the implication of firm heterogeneity in their respond to unbalanced regulation is generally descriptive. In order to make precise policy reference, we need to answers for the following question numerically: to what extent and through what channel firm heterogeneity undermines the efficiency of climate policies and long-term economic growth under alternative regulation structure? Detailed data with firm heterogeneity information on production technology, market environment and policy regulation of different firms, as well as a structural model describing differentiated behavior of heterogeneous firms is helpful for understanding the question, both of which were not readily available. In this paper, the authors intend to fill this gap by 1) identifying heterogeneous firms, based on a firm-level survey data, and separate them in an Input-Output (IO) table; 2) specify behaviors of different firms in a Dynamic Computable General Equilibrium (CGE) model, and 3) estimate the emission and economic effect of alternative climate policy design taking firm heterogeneity into consideration.

2. Theoretical Framework

In this section, we use a stylized theoretical framework to explain the heterogeneous behavior in production and energy-technology investment of different firms, and their implication on economic performance.

Assume that there are $i \in \boldsymbol{I}$ firms in the economy, the producing technologies of each firm is addressed with a two-level nested Cob-Douglas function, as follows:

$$Y_{i,t} = A_i V_{i,t}^{1-\alpha_i} F_{i,t}^{\alpha_i}, \quad F_{i,t} = H_{i,t}^{\beta} E_{i,t}^{1-\beta} \qquad \text{eq. 1}$$

where $Y_{i,t}$ is output; $V_{i,t}$ is value-added input; $F_{i,t}$ is the energy service input, which is produced by energy input $E_{i,t}$ and energy-technology input $H_{i,t}$.

Denote price vector as $\{p_{i,t}, v_t, h_t, e_t\}$ whose elements indicate output price, value-added price, energy technology price and energy price respectively. Given the producing technology described in $Y_{i,t} = A_i V_{i,t}^{1-\alpha_i} F_{i,t}^{\alpha_i}$, $F_{i,t} = H_{i,t}^{\beta} E_{i,t}^{1-\beta}$ eq. 1, producers' optimal decision in a perfectly competing market requires:

$$\begin{cases} V_{i,t} = (1-\alpha_i)\dfrac{p_{i,t}Y_{i,t}}{v_t} \\ H_{i,t} = \alpha_i \beta \dfrac{p_{i,t}Y_{i,t}}{h_t} \\ E_{i,t} = \alpha_i (1-\beta)\dfrac{p_{i,t}Y_{i,t}}{e_t} \end{cases} \qquad \text{eq. 2}$$

where $p_{i,t}=A_i' v_t^{1-\alpha i} h_t^{\alpha i \beta} e_t^{\alpha i(1-\beta)}$, $A_i'=A_i^{-1}\alpha_i^{\alpha i}(1-\alpha_i)^{1-\alpha i}[\beta^{\beta}(1-\beta)^{(1-\beta)}]^{\alpha i}$. Output of different firms are input to produce the final demand commodity, $W_t=\prod_i Y_{i,t}^{\gamma_i}$, $(\Sigma_i \gamma_i=1)$. The corresponding demand for individual commodity is:

$$Y_{i,t} = \frac{\gamma_i}{p_{i,t}}\left(v_t \overline{V}_t + h_t \overline{H}_t + e_t \overline{E}_t\right) \qquad \text{eq. 3}$$

Substitute
$$\begin{cases} V_{i,t} = (1-\alpha_i)\dfrac{p_{i,t}Y_{i,t}}{v_t} \\ H_{i,t} = \alpha_i \beta \dfrac{p_{i,t}Y_{i,t}}{h_t} \\ E_{i,t} = \alpha_i (1-\beta)\dfrac{p_{i,t}Y_{i,t}}{e_t} \end{cases}$$
eq. 2 and
$$Y_{i,t} = \frac{\gamma_i}{p_{i,t}}\left(v_t \overline{V}_t + h_t \overline{H}_t + e_t \overline{E}_t\right)$$
eq. 3 and into the following market clearance conditions, we can close the system and get the equilibrium prices of factors for each period separately:

$$\sum_i V_{i,t} = \overline{V}_t,\ \sum_i H_{i,t} = \overline{H}_t,\ \sum_i E_{i,t} = \overline{E}_t \qquad \text{eq. 4}$$

In an effective market without any distortion, the equilibrium assures that the corresponding marginal revenue of inputs of each firm are identical to factor prices in equilibrium, i.e.:

$$\forall i,\ \begin{cases} \dfrac{\partial(p_{i,t}Y_{i,t})}{\partial V_{i,t}} = v_t \\ \dfrac{\partial(p_{i,t}Y_{i,t})}{\partial H_{i,t}} = h_t \\ \dfrac{\partial(p_{i,t}Y_{i,t})}{\partial E_{i,t}} = e_t \end{cases} \qquad \text{eq. 5}$$

The inter-temporal linkage is determined by energy technology investment in this model, which is a part of the final demand:

$$CNS_t + \hat{H}_t = W_t;\ \overline{H}_t = \delta \overline{H}_{t-1} + \hat{H}_t \qquad \text{eq. 6}$$

Which indicates that the optimal investment matches the following condition:

$$h_t + \rho\delta W_{t+1} = W_t \xrightarrow{\forall t, w_t=1} h_t = 1-\rho\delta \qquad \text{eq. 7}$$

Now we can differentiate the market and regulation conditions of firms to analyze their heterogeneous behavior. We assume that only part of the firms are regulated by emission constraints, and the cost for regulated energy input is denominated as $e_t' = \theta e_t$ ($\theta > 1$); and part of the regulated firms are subsidized for their green investments. The target of the subsidy is to reduce the input cost of energy services ($F_{i,t}$) to no-regulation level, so as to regain their competitiveness. Denominate the subsidy rate as ($0<1-\varphi<1$), and thus, the input cost for $F_{i,t}$ is: $f_{i,t}=B_i'(\varphi h_t)^{\beta}(\theta e_t)^{1-\beta}$ ($B_i'=\beta^{-\beta}(1-\beta)^{1-\beta}$). In order to return the cost to no-regulation level, $B_i' h_t^{\beta} e_t^{1-\beta}$, the subsidy rate $\varphi=\theta^{(\beta-1)/\beta}$.

With the regulation, the optimal input decision in
$$\begin{cases} V_{i,t} = (1-\alpha_i)\dfrac{p_{i,t}Y_{i,t}}{v_t} \\ H_{i,t} = \alpha_i \beta \dfrac{p_{i,t}Y_{i,t}}{h_t} \\ E_{i,t} = \alpha_i (1-\beta)\dfrac{p_{i,t}Y_{i,t}}{e_t} \end{cases}$$
eq. 2 is now

changed to:

$$\begin{cases} V_{i,t} = (1-\alpha_i)\dfrac{p'_{i,t}Y_{i,t}}{v_t} \\ H_{i,t} = \alpha_i \beta \dfrac{p'_{i,t}Y_{i,t}}{\varphi h_t} \\ E_{i,t} = \alpha_i (1-\beta)\dfrac{p'_{i,t}Y_{i,t}}{\theta e_t} \end{cases} \qquad \text{eq. 8}$$

where $p'_{i,t}= \varphi^{\alpha i\beta}\theta^{\alpha i(1-\beta)}p_{i,t}$. For un-regulated firms (denominated as $j\in \boldsymbol{I}$), $\theta=\varphi=1$; for regulated but not subsidized firms (denominated as $k\in \boldsymbol{I}$), $\theta>1$, $\varphi=1$; for regulated and subsidized firms (denominated as $m\in \boldsymbol{I}$), $\theta>1$, $\varphi=\theta^{(\beta-1)/\beta}$. And thus, the market clearance conditions are:

$$\begin{cases} \overline{V}_t = \sum_i (1-\alpha_i)\dfrac{p_{i,t}Y_{i,t}}{v_t} + \sum_k \left[\theta^{\alpha_k(1-\beta)} - 1\right](1-\alpha_k)\dfrac{p_{k,t}Y_{k,t}}{v_t} \\ \overline{H}_t = \sum_i \alpha_i \beta \dfrac{p_{i,t}Y_{i,t}}{h_t} + \sum_k \left[\theta^{\alpha_k(1-\beta)} - 1\right]\alpha_k \beta \dfrac{p_{k,t}Y_{k,t}}{h_t} + \sum_m \left(\dfrac{1}{\varphi} - 1\right)\alpha_m \beta \dfrac{p_{m,t}Y_{m,t}}{h_t} \\ \overline{E}_t = \sum_i \alpha_i (1-\beta)\dfrac{p_{i,t}Y_{i,t}}{e_t} - \sum_k \left[1-\theta^{\alpha_k(1-\beta)-1}\right]\alpha_k (1-\beta)\dfrac{p_{k,t}Y_{k,t}}{e_t} - \sum_m \left(1-\dfrac{1}{\theta}\right)\alpha_m (1-\beta)\dfrac{p_{m,t}Y_{m,t}}{e_t} \end{cases}$$

eq. 9

The first terms in the r.h.s of the three equations in

$$\begin{cases} \overline{V}_t = \sum_i (1-\alpha_i)\dfrac{p_{i,t}Y_{i,t}}{v_t} + \sum_k \left[\theta^{\alpha_k(1-\beta)} - 1\right](1-\alpha_k)\dfrac{p_{k,t}Y_{k,t}}{v_t} \\ \overline{H}_t = \sum_i \alpha_i \beta \dfrac{p_{i,t}Y_{i,t}}{h_t} + \sum_k \left[\theta^{\alpha_k(1-\beta)} - 1\right]\alpha_k \beta \dfrac{p_{k,t}Y_{k,t}}{h_t} + \sum_m \left(\dfrac{1}{\varphi} - 1\right)\alpha_m \beta \dfrac{p_{m,t}Y_{m,t}}{h_t} \\ \overline{E}_t = \sum_i \alpha_i (1-\beta)\dfrac{p_{i,t}Y_{i,t}}{e_t} - \sum_k \left[1-\theta^{\alpha_k(1-\beta)-1}\right]\alpha_k (1-\beta)\dfrac{p_{k,t}Y_{k,t}}{e_t} - \sum_m \left(1-\dfrac{1}{\theta}\right)\alpha_m (1-\beta)\dfrac{p_{m,t}Y_{m,t}}{e_t} \end{cases}$$

eq. 9 are identical to the market clearance condition in no-regulation scenario ($\sum_i V_{i,t} = \overline{V}_t$, $\sum_i H_{i,t} = \overline{H}_t$, $\sum_i E_{i,t} = \overline{E}_t$ eq. 4), and the following terms shows the impact of heterogeneous respond of different firms to the unbalanced regulation. Compared to no-regulation scenario, demand for V and H are increased while demand for E is decreased, which lead to higher v and h, but lower e. Table 1 shows the heterogeneous responses of different firms to unbalanced regulation. Unregulated firms tend to input more energy, since they are cheaper compared to no-regulation scenario, to substitute V and H, and thus, lead to carbon leakage. The marginal abatement cost for energy input, $(\theta-1)e$ is identical for regulated firms, but the approaches may be differentiated. For subsidized firms, they tend to rely solely on investing in energy technology to substitute for energy. The effect of the subsidy is so strong that energy tech. investment also squeezes out the input of V. Unsubsidized firms have to input more V to meet their energy constraints, although V gets more expensive. Thus energy input would be more concentrated in unregulated j firms; energy technology investments would be more concentrated in subsidized m firms. The unbalanced regulations lead to unequal marginal revenues of energy technology and energy input, which diversifies the economy from its optimal equilibrium. Aside from that, the green investment and the enforcement of the green investment subsidy are also competing with fixed assets investment for financial resources, which would affect the long term economic growth path. Analyzing the exact impact of the dual distortion on economic output requires a systematic numerical model, which is introduced in the next section.

Table 1. Heterogeneous Response of Firms to Unbalanced Regulation

Firm	θ	φ	MR(V)[1]	MR(H)	MR(E)	V	H	E
j	1	1	v	h	e	↓[2]	↓	↑[3]
k	>1	1	v	h	θe	↑	↑	↓
m	>1	$\theta^{(\beta-1)/\beta}$	v	φh	θe	↓	↑	↓

Note: 1. MR(·) stands for Marginal Revenue of factor input;
2. ↓ indicates decrease in factor input compared to no-regulation scenario;
3. ↑ indicates increase in factor input compared to no-regulation scenario.

3. The Model and Data

We use a computable general equilibrium to analyze the emission and economic effects of regulation, taking firm heterogeneity into consideration. In this section, we provide a brief overview of the model and database.[1] The model is a multi-sector, one regional, recursive dynamic general equilibrium model (CGE) which incorporate multiple firm type, differentiate policy regulation and endogenous energy-technology investment. The model is calibrated to the year 2010 (base year). Future periods (denominated as t) are simulated on the basis of the results of the preceding period. The model follows neo-classical macro-closure, i.e. assuming full employment of capital and labor.

3.1 Data

The basic data of the model is a Chinese IO table for the base year which includes 42 industries (denominated as i). Firms in each industry are distinguished by two dimensions: ownership (state owned, foreign invested and domestic private) and size (large and small), as shown in Table 2.

Table 2. List of Firm Types

SIZE	OWNERSHIP		
	STATE	FOREIGN	PRIVATE
LARGE	*LSOE*	*LFIE*	*LGE*
SMALL	*SSOE*	*SFIE*	*SME*

Based on a firm level survey, the authors distinguished different types of firms (denominated as f), and separated them in an IO table. The structure of the data is show in Table 3.

[1] The introduction in this section would be focused on the part related to firm heterogeneity and green investment. For other technical detail, please refer to Appendix I or contact the authors.

Table 3. Structure of the IO table with multiple firm-type

<table>
<tr><td></td><td>I</td><td colspan="3">1</td><td colspan="3">2</td><td>…</td><td colspan="3">i</td><td>Cns.</td><td>Save</td><td>Exp.</td></tr>
<tr><td></td><td>F</td><td>1</td><td>…</td><td>f</td><td>1</td><td>…</td><td>f</td><td>…</td><td>1</td><td>…</td><td>f</td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">1</td><td>1</td><td colspan="10" rowspan="10">Domestic Intermediate Input</td><td colspan="2" rowspan="10">Domestic Commodity Consumption</td><td rowspan="10">Export</td></tr>
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<tr><td>f</td></tr>
<tr><td rowspan="3">2</td><td>1</td></tr>
<tr><td>⋮</td></tr>
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<tr><td rowspan="3">i</td><td>1</td></tr>
<tr><td>⋮</td></tr>
<tr><td>f</td></tr>
<tr><td>1</td><td></td><td colspan="10" rowspan="3">Intermediate Import</td><td colspan="2" rowspan="3">Import for Final Consumption</td><td rowspan="3"></td></tr>
<tr><td>⋮</td><td></td></tr>
<tr><td>i</td><td></td></tr>
<tr><td>Wage</td><td></td><td colspan="10" rowspan="4">Value Added</td><td colspan="3" rowspan="4"></td></tr>
<tr><td>Tax</td><td></td></tr>
<tr><td>Dep.</td><td></td></tr>
<tr><td>Rev.</td><td></td></tr>
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3.2 Producing Technologies

Producing technologies of each producer is addressed by a nested constant elasticity-of-substitution (CES) function. The nesting structure follows KLEM structure: industry- and firm-specified capital ($K_{i,f}$) and labor (*L*) compose the value-added nest (*VA*), which is then nested with energy composition (ENG), which consists of different energy products. The value-added and energy composition (*VAE*) is then nested with the composition of intermediaries (*M*) to produce the final product (*Y*). The nesting structure is shown in Figure 1. The parameters in nested-CES functions of each firm type in each industry is calibrated by the IO table which contains firm heterogeneity data as Table 3.

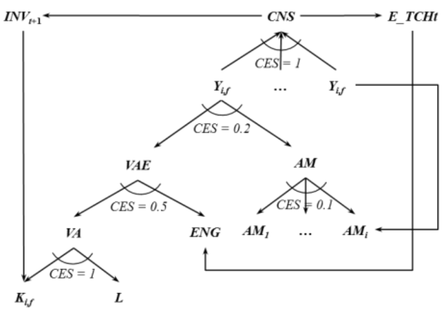

Figure 1. Nesting Structure of CES Producing Function

The product can be used for consumption (*CNS*), invest in capital which can be used in the following periods (*INV*) and invest in energy technologies which can increase energy efficiency in this and the following periods (*E_TCH*).

3.3 Energy Supply and Emission Accounting

6 energy industries are included in the model: Coal Mining, Oil Extraction, Petrochemical, Thermal Power Generation, Renewable Power Generation and Natural Gas Supply, producing raw and washed coal (*Coal*), crude oil (*Crude*), petroleum (*Ptr*), electricity (*ELE*) and natural gas (*NG*) respectively. The energy supply is also addressed in a nested-CES form, as shown in Figure 2. Energy technology (*E_TCH*) is also input in energy supply as an extra factor which is substitutable to physical energy input. And thus, higher energy price or restrains on energy input would lead to higher demand for energy technology. Energy technology investment is a decision made on firm

level and no leakage possibility is considered in the model. *E_TCH* accumulates in a similar manner as capital.

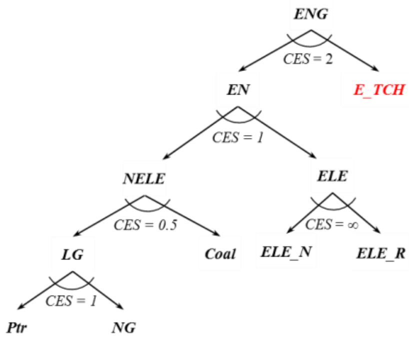

Figure 2. Energy Nesting Structure

CO_2 emission from direct combustion of fossil fuel is accounted for policy regulation. In other words, electricity usage and fossil fuel input for feed-in-stock in industries are not included in CO_2 accounting.

3.4 Investment Decision and Capital Accumulation

Investment decision is on firm level: each firm determines its investment demand according to profit rate and financial cost in the form of $g_{i,f} = \frac{\beta \exp\left[a\left(ror_{i,f} - \overline{ror}_{i,f}\right)\right]}{1+\beta \exp\left[a\left(ror_{i,f} - \overline{ror}_{i,f}\right)\right]}\left(g^{\max} - g^{\min}\right) + g^{\min}$ eq. 10.

$$g_{i,f} = \frac{\beta \exp\left[a\left(ror_{i,f} - \overline{ror}_{i,f}\right)\right]}{1+\beta \exp\left[a\left(ror_{i,f} - \overline{ror}_{i,f}\right)\right]}\left(g^{\max} - g^{\min}\right) + g^{\min} \quad \text{eq. 10}$$

where $g_{i,f}$ is the desired growth rate of capital accumulation of f firms in sector i; g^{max} and g^{min} are the upper- and lower-bound of capital growth rate, which are set exogenously in a logit curve to prevent irrationally extreme capital growth. $ror_{i,f}$ is the capital rate-of-return of firm f in industry i. $ror_{i,f}$ is calculated as follows:

$$ror_{i,f} = \frac{1-\delta + pk_{i,f}}{1+r_f} \quad \text{eq. 11}$$

where δ is the depreciation rate of capital, $pk_{i,f}$ is the rental price of firm specified capital (i.e. the profit) and r_f is the financial cost which is differentiated w.r.t. firm type. a and β are parameters estimated with statistics data.

3.5 Scenarios

Then benchmark for cross-scenario comparison is the Business-as-Usual (BAU) Scenario, where mandatory intensity targets are enforced for certain types of firms to fulfill an exogenously determined total intensity target which meets China commitment in INDC. And preferential financial conditions are provided for part of the regulated firms. The regulation coverage is refrained to SOEs and large private firms, while only the SOEs get the preferential financial conditions. The unbalanced regulation structure is shown in Table 4. Aside from BAU, a NULL scenario is also introduced with no policy regulations.

Table 4. Unbalanced Regulation Structure in BAU

SCALE	OWNERSHIP		
	STATE	FOREIGN	PRIVATE
LARGE	*LSOE*	*LFIE*	*LGE*
SMALL	*SSOE*	*SFIE*	*SME*

Note: the colored firm types are regulated, while only the darkly colored firm types are provided with preferential financial conditions.

The purpose of preferential financial conditions is to encourage their green investment and regain their market competitiveness. In order to replicate that purpose, we erase policy regulation in each period for a set of "free of regulation" energy input costs of firms, and then restore the regulations with an endogenous subsidy for SOEs' green investment to match their energy input cost with their "free of regulation" costs. Figure 3 shows the process.

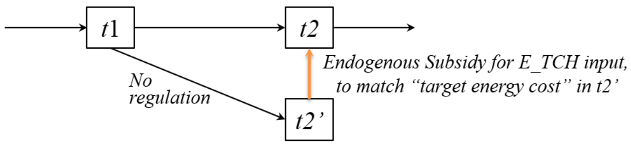

Figure 3. Simulation Process for Preferential Financial Conditions

The total intensity target is set to decrease China's CO_2 emission per GDP by 3.62% each year from 2011 and onwards. This target assures the commitment China made in its INDC to decrease the carbon intensity by 60% from 2005 level before 2030 (Figure 4).

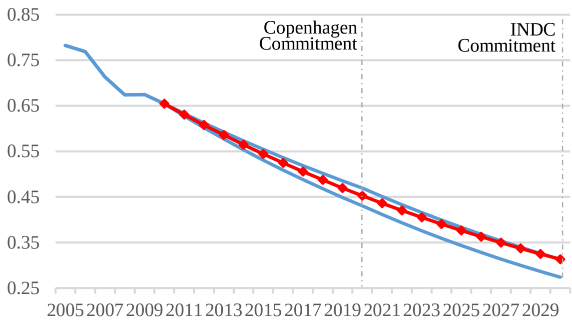

Figure 4. China's Emission Commitments and Intensity Target Setting

Aside from NULL and BAU scenarios, there're a third set of scenarios where emission trading is introduced and alternative settings for regulation coverage and financial equalization are also taken into consideration (Table 5).

Table 5. Scenarios with ETS

FINANCIAL CONDITION	REGULATION COVERAGE	
	partial	full
differentiated	*ETS_P_D*	*ETS_F_D*
equalized	*ETS_P_E*	*ETS_F_E*

In partial-coverage scenarios, only SOEs and large private firms are regulated by emission constraints and can participate in emission trading; while in full-coverage scenarios, all firms are equally regulated and be able to trade their emission in an integrated carbon market. In differentiated financial condition scenarios, the endogenous subsidy for green investments is provided for SOEs as in BAU scenario, while in equalized scenarios, the subsidy is erased.

4. Simulation Results

In this section, we compare alternative scenarios for their implication to CO_2 emission and long-term economic growth in China. We refer to differentiated green investments behavior and their efficiency of heterogeneous firms to explain the differences in emission and economic effects.

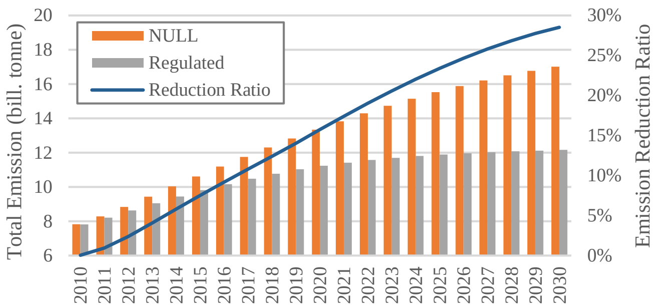

Figure 5. Emission Reduction Effect of Climate Policies

Note: the emission trajectories are set identical for all scenarios, other than NULL, to assure their comparability

4.1 Overview of Emission and Economic Effects

The model simulation implicated that if China can fulfill its commitment to reduce carbon intensity by 60% from 2005 level or lower by 2030, we can expect a peak in total emission around 2030, as shown in Figure 5. The peak level in 2030 is around 12.1 billion ton, which is 28.5% lower that the potential emission if not regulated.

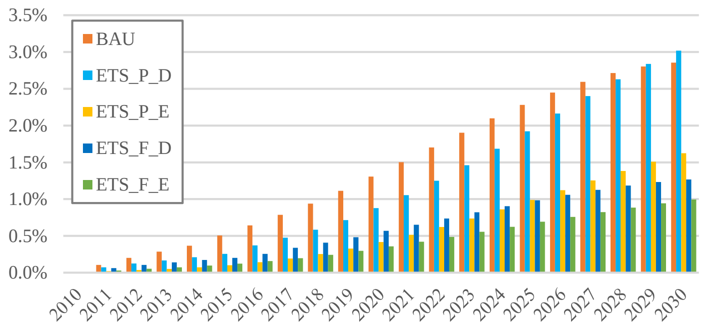

Figure 6. GDP Loss Compared to NULL

Although total emission are set identical, the economic output in alternative scenarios are different. The average yearly GDP growth in BAU is 6.26%, which is 0.15% lower than that in NULL, and that lead to a 2.9% GDP loss in 2030. Introducing ETS with original regulation structure (ETS_P_D) lowers GDP loss in early stage, but it increases faster and surpass that of BAU after 2028. The average yearly GDP growth in ETS_P_D is 6.25%. Expanding regulation coverage (ETS_F_D) or canceling unbalanced subsidy for SOEs' green investment (ETS_P_E) leads to better economic effects. The average GDP growth rate is 6.34% in ETS_F_D scenario and 6.32% in ETS_P_E scenario. The GDP losses are also lower than in BAU and ETS_P_D. And of course, in a fully balanced regulation structure (ETS_F_E), the ETS generates the best economic output with a 6.36% of yearly GDP growth. Figure 6 shows the cross-scenario comparison of the GDP losses[2] against NULL scenario.

Comparing the economic effect of ETS_P_E and ETS_F_D in Figure 6, we can conclude that canceling unbalanced green investment subsidy leads to a better economic performance in short-run, but in the long-run, balancing the regulation by expanding its coverage has the first-order effect.

4.2 Carbon Leakage and Emission Transfer

In partial-coverage scenarios, the unbalanced regulation lead to diversified marginal abatement costs (MAC) for CO_2 across firms. Diversified MAC, on one hand, directly lowers the short-term efficiency of emission reduction efforts, according to classical economics. And on the other hand, it leads to diversified incentives for green investments, and thus, affects the long-term efficiency of green investments. The carbon leakage from regulated to unregulated firms in partial-coverage scenarios shows the extent of regulation distortion, as shown in Figure 7. In full-coverage scenarios, there's no leakage since all firms are covered by the same regulation. The same index as emission increase in SFIEs and SMEs (they will be negative since SFIEs and SMEs also reduce their emission due to regulation) over emission decrease in originally regulated firms (SOEs and large firms) reveals the relative contribution of the two group of firms.

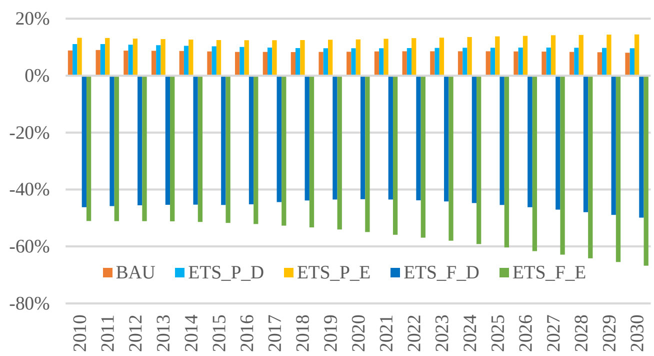

Figure 7. Carbon Leakage and Emission Transfer Rate

We can conclude from the figure that the carbon leakage in ETS_P_D is higher than BAU scenario. Considering the fact that emission target is enforced by intensity target in BAU scenario, it implicates a hidden output subsidy for emitters who can expand their output to acquire more emission permits. Without the subsidy for regulated firms in EST_P_D scenarios, the regulated firms are worse-offed in their competing with unregulated firms, which lead to higher level of leakage. The negative effect of the higher distortion level in ETS_P_D, especially in the long-run, over whelmed the positive effect of ETS, and lead to higher economic losses compared to BAU scenario. Canceling the preferential subsidy for SOEs' green investment in ETS_P_E further worsen-off the competing conditions for regulated firms, and thus intensifies the distortion. Although the positive effect of canceling unbalanced financial subsidy lead to higher economic output in short-run, we can find a high growth-rate in the GDP loss, as shown in Figure 6.

Another interesting conclusion we can make from Figure 7 is that the effects of canceling the unbalanced subsidy for green investments in partial- and full-coverage scenarios are actually

[2] GDP Loss rather than GDP is used since the GDP differences across scenarios are very small compared to the absolute level of GDP, and using GDP loss can make the differences visible in the figure.

opposite to each other. There're two effects involved: canceling the subsidy worsens-off the competition conditions of SOEs, and thus tend to be substituted by non-state owned firms in larger extent, and lead to higher leakage; meanwhile, canceling the unbalanced subsidy would direct more financial resource to small firms which would encourage their emission reduction efforts. The first effect dominates in partial-coverage scenarios while the latter dominates in the full-coverage scenarios, which caused the opposite net effect.

4.3 Green Investment Allocation and Efficiency

The unbalanced financial conditions for different firms causes another type of distortion. The partial regulation increases the incentives for green investments in regulated firms, and furthermore, the preferential financial conditions further distort green investments towards SOEs. As introduced in the theoretical model, the concentration of green investments in regulated firms, especially subsidized SOEs lead to unequal marginal revenues across firms, and decrease the average efficiency of green investments. Aside from that, the higher demand of green investment is competing with fixed capital investment which will further affect the long-term economic growth.

Figure 8 shows the trajectory of total green investment (left panel) and its efficiency (right panel) which illustrate the argument abovementioned. In BAU and ETS_P_D scenarios, green investment increases quickly as the tightening of emission targets. The total amount of accumulated green investments till 2030 accounted for about 8% of GDP. But the effects of green investments, defined as the change of carbon intensity from NULL scenario over the amount of green investment per unit of energy input, are decreasing dramatically, especially after 2025. Both expanding coverage of regulation (ETS_F_D) and canceling the subsidy for SOEs' green investments (ETS_P_E) can lower the total demand for green investment, while its efficiency is significantly increased. In ETS_P_E scenario, the accumulated green investment accounts for 4.4% of GDP in 2030, and 5.5% in ETS_F_D scenario; while their efficiency in 2030 is 69% and 39% higher than that of BAU. With the fully balanced regulation structure (ETS_F_E), the total green investment is the lowest among the alternative scenarios, which accounts for 4% of GDP in 2030. While the green investment efficiency is the highest among alternative scenarios, which is 84% higher than the BAU level.

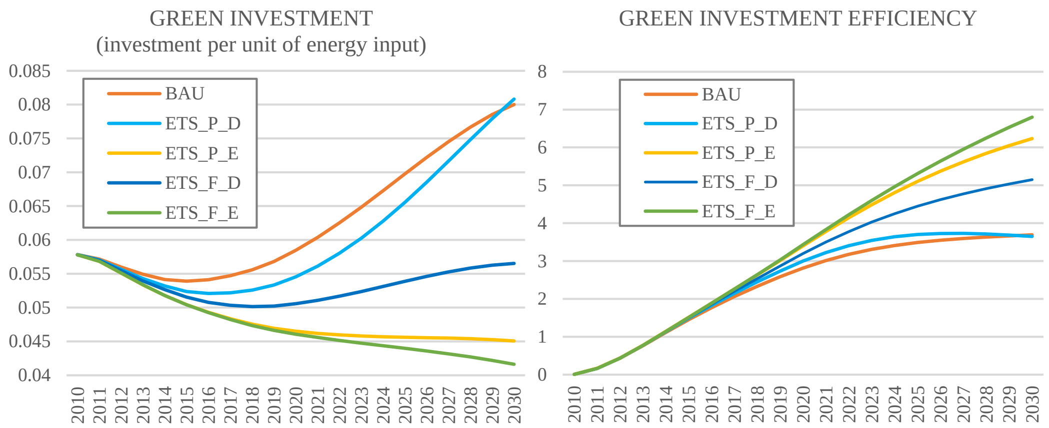

Figure 8. Total Green Investment and Efficiency

Note: green investment efficiency is defined as the change of CO_2 *intensity from NULL scenario over the amount of green investment per unit of energy input.*

Figure 9 shows the distribution of green investments in 2030. It indicates that with fully balanced regulation (ETS_F_E), the total amount of green investments account for about 4% of GDP in 2030, the largest share (about 1/3) of which is made in private small firms (SME). However, when small firms are exempted from emission constraints, they lose their incentives to make further invest in energy technology. Meanwhile, the higher demand from regulated firms for energy technology lead to higher costs for green investments, which further discourages the green investments of small firms. From Figure 9 we can find that in ETS_P_E scenario, the share of green investments of regulated firms increase, while those of unregulated small firms decrease. The preferential subsidy for SOEs' has stronger effect in distorting the total demand and allocation of green investments. In ETS_E_D scenario, the shares of green investments of all the other firms except SOEs are decreased, while those for SOEs increased significantly, which overwhelmed the decrease in other firms. And in BAU and ETS_P_D scenarios, the joint effect of dual distortion further distort the allocation of green investments. The total amount of green investments with dual distortion (BAU and ETS_PD) account for about 8% of GDP in 2030, among which over 65% are invested by SOEs.

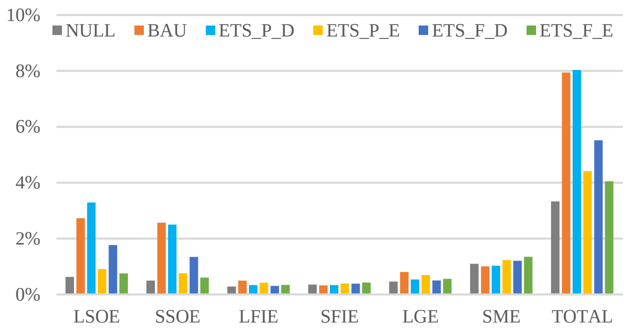

Figure 9. Total Green Investment (Share in GDP, 2030)

4.4 Economic Cost for Enforcing Preferential Green Investment

The preferential subsidy not only distort the allocation of green investments, but also requires remarkable public financing resources to enforce it. As introduced in the theoretical model, the subsidy rate is determined the gap between the energy input costs of SOEs in regulated and unregulated scenarios. Figure 10 shows the expenditure of the subsidy in alternative scenarios. The expenditure grows along with the tightening of the emission targets. In BAU scenario, it accounts for 3.2% of GDP in 2030 and 3.6% in ETS_P_D scenario. The expenditure in ETS_F_D scenario is significantly decreased to 1.4% of GDP in 2030, since small firms share a large burden of the emission reduction in the full coverage of emission constraints which lowers the input cost of energy for SOEs.

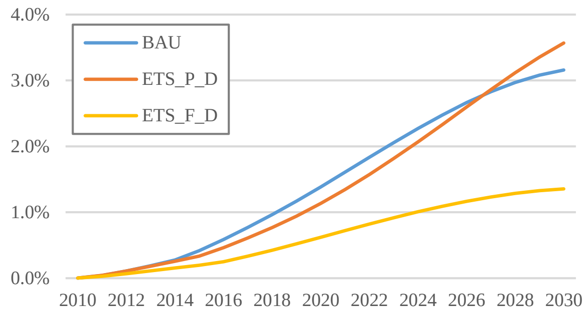

Figure 10. Green Investment Subsidy (Share in GDP)

4.5 Implication to the Fulfilment of Emission Targets

As shown in Figure 6, with partial regulation coverage and preferential green investment subsidy, the distortion in the allocation of emission reduction burden and green investment across firms would lead to extra economic losses. The level of distortion is partly determined by the share of emission of regulated firms – the smaller the share of regulated firms are, the tighter their emission targets are required. Meanwhile, the diversification between regulated and unregulated firms in energy input costs will deteriorate the competition condition of regulated firms and lose in their market share. And thus, the emission targets of regulated firms need to be further tightened to fulfill the same total emission target, which would widen the diversification. Preferential green investment subsidy can, to some extent, compensate for the loss in competitiveness of SOEs, but in the meantime, it decreases the demand for energy which would decrease energy prices, which would also lead to decrease in the share of regulated firms' emission. The loop is triggered and intensified by tighter emission target, which accelerates the growth of economic losses of emission reduction.

On the other hand, the emission reduction commitments made by China are all in terms of carbon intensity. Since it's calculated as emission over economic output, decrease in economic output would require corresponding decrease in total emission to keep up with the intensity target. Considering the effect of the loop of regulation divergence and emission leakage, the unbalanced regulation significantly limited the potential for China's emission reduction efforts. According to the simulation results, in BAU scenario the upper bound of China's emission commitment (65% decrease in carbon intensity from 2005 level by 2030) is unreachable, as shown in Figure 11. Further tightening the intensity target for regulated firms in BAU scenario by 1~10% lead to both decrease in total emission and GDP. However the decrease of GDP accelerates as the emission target gets tighter, and surpass that of total emission, which lead to an upward curve of total carbon intensity before reaching the target. While in full coverage scenarios, the same situation is not observed.

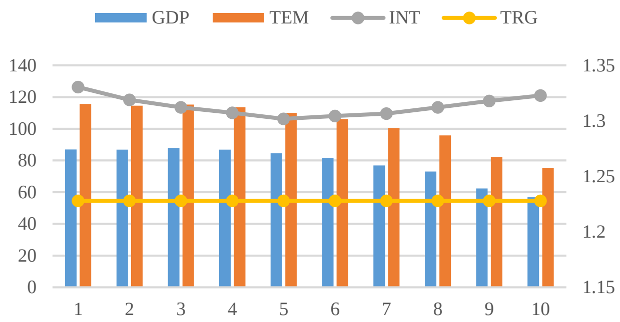

Figure 11. Implication of Tighter Emission Target (BAU, 2022)

Concluding Remarks

The firm heterogeneity in producing technologies, market conditions leads to differentiated responds of firms to policy regulations, which has significant implication on the effectiveness and economic efficiency of the policies. In this paper, we distinguish different types of firms with respect to their ownerships and sizes on the basis of a firm level survey data, and separated them in the form of an IO table. A multi-sector, multi-period CGE model is applied to analyze the behavior of firms under unbalanced regulation and differentiated market conditions. Small private firms are mainly exempted from the emission constraints in current climate policy regulation structure while state owned firms and large firms are regulated by mandatory CO_2 intensity targets. Besides, part of the regulated firms, mainly the SOEs, are provided with preferential financial conditions, including low-interest-rate or free credits and access to public funds, to recover their market competitiveness. The numerical model simulation indicate that the exemption of small private firms from policy regulation leads to carbon leakage from regulated to unregulated firms, which intensifies the diversification in burden sharing of emission reduction and incentives for green investments. SOEs have the highest incentives and make the majority of green investments to lower their CO_2 intensity, while other regulated large private firms mainly rely on substituting fossil energy with other input factors to fulfill their emission targets. Unregulated firms are discouraged for their emission reduction efforts and green investments by lower energy prices and higher green investment costs, which leads to carbon leakage from regulated to unregulated firms. The leakage further intensifies the diversification in emission reduction burden sharing and green investment allocation, since it decreases the market share of regulated firms, and lowers the average efficiency of emission reduction efforts and green investment. On the other hand, the higher demand for green investment and the subsidy expenditure for enforcing the preferential financial conditions for SOEs are competing with capital investment for financial resources which affects economic growth in the long-run. According to the scenario simulation results, the mandatory intensity target in BAU scenario can decrease the total CO_2 emission by 30% at the cost of 3% GDP loss in 2030.

Introducing emission trading does not necessarily lead to higher economic efficiency of emission reduction, since the trading mechanism leads to stronger leakage from the regulated to the unregulated firms which intensifies the diversification in emission reduction efforts, and lowers the average efficiency, especially in the long-run. Canceling the preferential subsidy for green investments or expanding regulation coverage can significantly increase the economic efficiency in emission reduction. Canceling the preferential subsidy for SOEs equalizes the financial costs for green investments across firms and mitigates the distortion in the allocation of green investments. In ETS_P_E scenario, the green investment in SOEs is significantly decreased which is mainly relocated to large private firms. The total green investment is 64% lower than that in BAU, while its average efficiency in improving energy efficiency is 71% higher. The lower total amount and higher efficiency of green investment, together with the saved subsidy expenditure, lead to a higher economic growth rate (6.32%). Comparatively, expanding the coverage of emission constraint leads to higher economic efficiency, since it not only recovers the distortion in emission reduction burden sharing by equalizing the MACs of different type of firms, but also mitigate the miss-allocation of green investment by narrowing the gap between energy input costs of different firms. In ETS_F_D scenario, the total green investment is higher than that in ETS_P_E, and its efficiency is lower. However, the small private firms, who are exempted from regulation in ETS_P_E scenario, contributed about 1/3 of the total emission reduction. The average yearly GDP growth is thus higher (6.34%). And in a perfectly balanced regulation structure with full coverage of emission constraint and equivalent financial conditions for green investments, the economic efficiency of emission reduction is the highest (yearly GDP growth at 6.36%) where the total efficiency of green investment is also the highest.

Summarizing the results abovementioned, we can conclude that under the unbalanced regulation structure, the differentiated emission reduction strategies of different type of firms is significantly affecting the effectiveness and economic efficiency of climate policies in China. Expanding the policy coverage has the first-order effect in improving economic efficiency of emission reduction efforts. On the other hand, over invest in energy technologies in a limited part of the firms may decreases the total efficiency of investments and dampens long-term economic growth by competing with fixed-capital investment for financial resources. A market oriented arrangement of emission reduction burden sharing and green investment allocation mechanism is crucial for China to achieve a more ambitious emission target in the long-run.

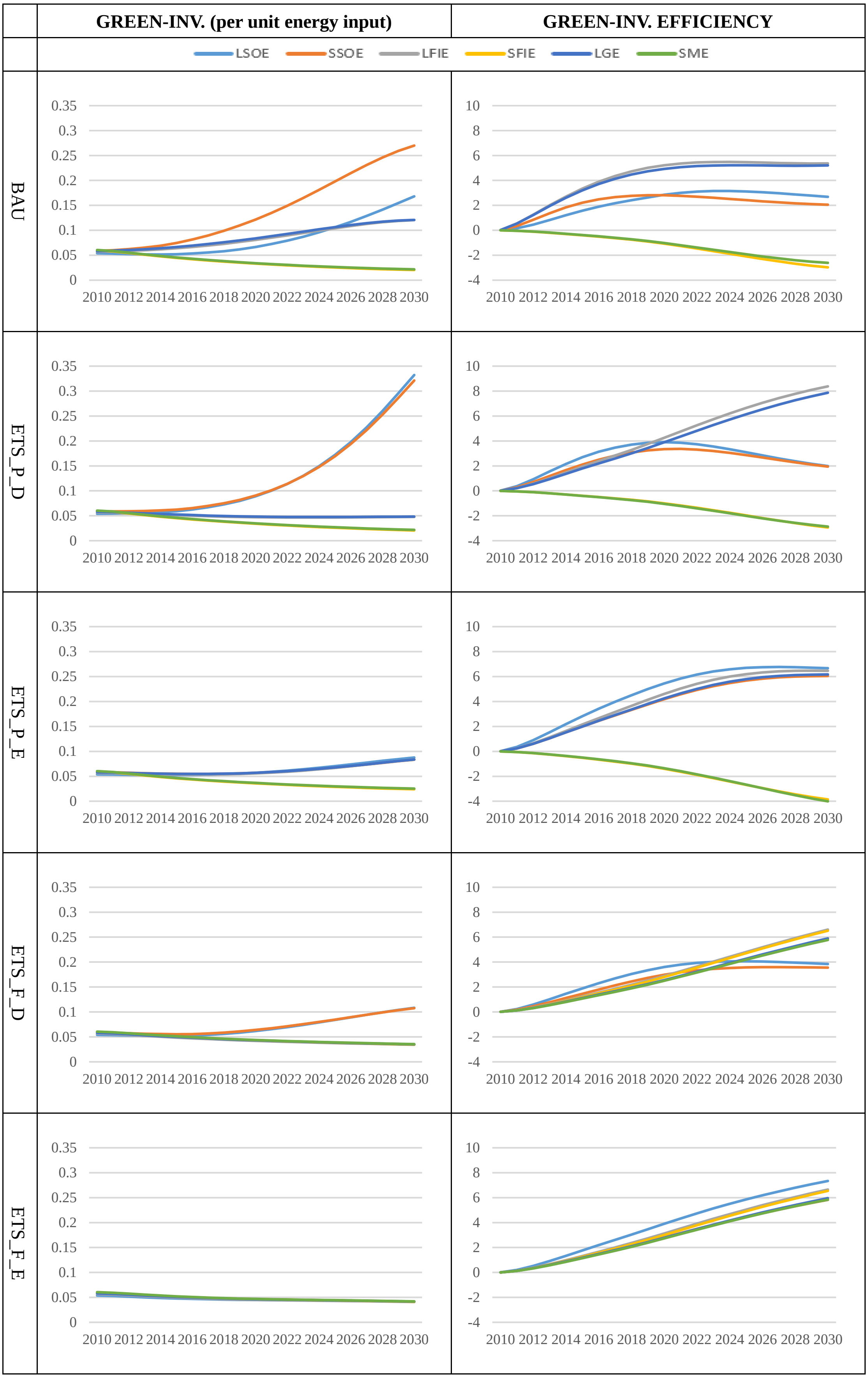

Figure 12. Green Investment and Efficiency by Firm Type