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Heterogenous Energy Consumption Behavior by Firm Size: Evidence from Korean Environmental Regulations

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Abstract: We analyze the interdependencies between energy usage, energy costs, renewable energy shares, economic growth, and greenhouse gas (GHG) emissions in the Korean industrial sector by employing a time-series panel vector model. Although the topic itself about has been classic one, our research to investigate diverse dynamics between large and small-mid size businesses using micro-firm level data is the first study in literature. Since firms with different sizes are put in different policy circumstances, the aggregate-level data analysis could possibly disregard the effectiveness of environmental & renewable policies and underestimate the policy sensitivity of firms. Our findings demonstrate that the increase in energy consumption in larger firms has a greater impact on their energy costs and GHG emissions than for small and medium-sized enterprises (SMEs). Moreover, it has a significant effect on GDP. Also, the increase in renewable energy shares only has a significant influence on the energy consumption and GHG emission levels of large firms.

Keywords: panel vector autoregression (VAR); energy; industrial sector; GHG emissions; large firms; SMEs

1. Introduction

We cannot deny that energy consumption from the use of fossil fuels has been a key driver of economic growth as a driving force for industrial development, but at the same time, this is one of the main factors causing environmental degradation and human health [1–3]. Greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases (F-gases) have been released in large quantities from fossil fuel consumption in the industrial sector. Many governments attempt to reduce industrial GHG emissions from industries through environmental policies, but the environmental policies could act as deterrents to business activities. Private companies have come under financial pressure recently as many countries are trying to regulate GHG emissions [4,5]. The impact of these environmental/energy policies and their impact on the private sector might depend on the size of the entity, the type of energy used and the cost effectiveness of the energy use. A base effect depending on the size of firms could lead to a drastic difference in fuel replacement elasticity for energy prices. Hence, we aim to demonstrate in this paper different dynamics between energy related factors that affect profitability across firms' sizes.

Over the past years, many studies have investigated the impacts of energy factors on economic growth and GHG emissions by using various energy variables, such as energy consumption or portions of renewable energy to general energy consumption. Not many studies focus on heterogenous responses to exogenous shocks based on firm size; most previous research points out that SMEs have shown significantly different practices [6–8]. Most have found that there are significant and positive relationships between energy consumption and economic growth [9–18], while others have shown that the renewable electricity share negatively affects economic growth due to the cost burdens of producing renewable electric power [15,16]. In addition, most studies, such as those by Menyah and Wolde-Rufael [12], Tiwari [14], Amin et al. [15], Lee and Yue [17], Yu and Mallory [19] and Li et al. [20] have shown that energy consumption increases GHG emissions. However, Magazzino [16] has shown that the energy sector has negligible effects on GHG emissions. Silva et al. [21] and Maslyuk and Dharmarathna [22] have found that renewable energy shares in electricity generation increase GHG emissions; in contrast, Shabbir et al. [23] and Yu and Kim [24] have concluded that the rise in renewable energy consumption could decrease GHG emission levels by substituting non-renewable energy. However, Menyah and Wolde-Rufael [13] and Tiwari [14] have shown that renewable energy consumption could not contribute to the reduction of GHG emissions.

Although the energy consumption behavior under the environmental regulations has been the classic topic for decades in many country case studies, there has been no investigation on diverse dynamics between large firms and small and medium-sized enterprises (SMEs) by using micro-firm level data. Our research is the first study to analyze the relationship between energy factors, economic growth, and the GHG emissions of the Korean industrial sector using firm-level data; this country with a fossil fuel-intensive industrial structure adopting environmental regulations recently can show the observable policy effects easily. The other reason is that it has been more than 10 year after the renewable and GHG regulations have been introduced in Korea and now enough data sets have become available. We employ the panel autoregressive model during the period (2007–2016) since the Korean GHG reduction policy has been actively introduced. We expect that the estimation results from the firm-level data could remove the impact of aggregation on firms [25], as firm-level data controls the firm-specific factors that are not observed in aggregate data. It is also important to explore the interrelationships between energy factors, economic growth, and GHG emissions in the Korean industrial sector, because of complex relationships between these factors and the important role of Korea on the global energy market and the environment. Korea was the world's 9th largest energy consumer (kg of oil equivalent per capita) in 2013; 84.2% of their total energy usage was reliant on fossil fuels [26]. In addition, Korea's CO_2 emissions are only 1.7% of global CO_2 emissions [27], but the rate of increase from 1990 to 2014 was 128%. This increase rate is much higher than the Organization for Economic Co-operation and Development (OECD) average of 9.4% and is the second highest among OECD countries, following 178.7% by Chile [28].

In particular, we investigate the impact of energy factors and GHG emission patterns of firms of different sizes by focusing on the differences between samples of large firms and SMEs. In general, the overall energy consumption and GHG emission levels of individual SMEs are much lower than those of larger firms, so SMEs are often out of regulation such as emission trading scheme (ETS) or renewable portfolio standards (RPS) in Korea. However, since the contributions of larger firms to a national economy are regarded as significant compared to SMEs, many implicit subsidizing policies are often focused on larger firms. Therefore, the aggregate-level data analysis could possibly disregard the effectiveness of environmental and renewable policies and underestimate the policy sensitivity of firms. Thus, this study explores the heterogeneous dynamics among energy consumption, energy costs and GHG emissions for large firms and SMEs in addition to national gross domestic product (GDP), respectively. Hence, our paper focuses on the Korean case by combining two research threads.

The remainder of this paper is organized as follows: Section 2 describes the data and introduces our econometric model; and Section 3 estimates the panel time autoregressive model and reports the empirical results of impulse response functions (IRFs). Finally, Section 4 concludes by discussing policy implications.

2. Materials and Methods

2.1. Data Description

We use both firm-level (energy use, energy costs and GHG emission levels) and country-level (renewable energy share and GDP) annual data over the period 2007–2015 to estimate a panel model; the sample includes 240 firms with a total of 2160 observations over nine years (strongly balanced panel). The sample firms included for this study are derived from various industries, such as the petrochemical, food, construction, and automobile industries. We classified large firms and SMEs according to the Framework Act of Small and Medium Firms. A firm is classified as an SME if it has fewer than 1000 employees or its total assets are worth less than 500 billion KRW); otherwise, a firm is classified as a large firm [29]. There are 210 large firms and 30 SMEs in the sample. The descriptive statistics for all data used in this study are summarized in Tables 1 and 2.

Table 1. Data description for large firms.

	Energy Use (TJ)	Energy Cost (Million KRW)	Renewable Energy Share (%)	GDP (Billion KRW)	GHG Emissions (tCO_2eq)
MEAN	11,020.99	118,234.3	1.831556	2623.367	757,268
MAX	527,479	5,037,649	3.041	3079.2	4.03×10^7
MIN	33	0.002205	1.121	2146.7	1726
Std. Dev	46,239.4	433,012.9	0.6384264	303.3346	3,544,032
Skewness	8.554492	6.947347	0.8560407	−0.151885	9.08872
Kurtosis	82.1502	59.21138	2.358922	1.747628	89.63295
Obs	1890	1890	1890	1890	1890

Source: Bloomberg.

Table 2. Data description for SMEs.

	Energy Use (TJ)	Energy Cost (Million KRW)	Renewable Energy Share (%)	GDP (Billion KRW)	GHG Emissions (tCO_2eq)
MEAN	1050.181	11,665.87	1.831556	2623.367	95,866.36
MAX	5888	192,514	3.041	3079.2	733,338
MIN	9	153.4486	1.121	2146.7	480
Std. Dev	1119.221	19,550.6	0.6384264	303.3346	126,619.8
Skewness	2.328434	5.061909	0.8560407	−0.151885	3.089901
Kurtosis	8.147155	36.07116	2.358922	1.747628	13.24235
Obs	270	270	270	270	270

Source: Bloomberg.

The energy cost data represents the total energy costs of each firm. We derive the total energy costs of firms over one year, as opposed to the unit cost per energy usage. Figure 1 depicts the trend of energy costs for 240 Korean firms in the sample. The energy costs of firms increased by 2008, but then declined from 2008 to 2009 due to the global recession. Energy costs have increased again since 2009, but the fall in international oil prices that began in mid-2014 reduced firms' energy costs. Energy cost data was obtained from Greenhouse Gas Inventory & Research Center of Korea (GIR), Ministry of Environment [30].

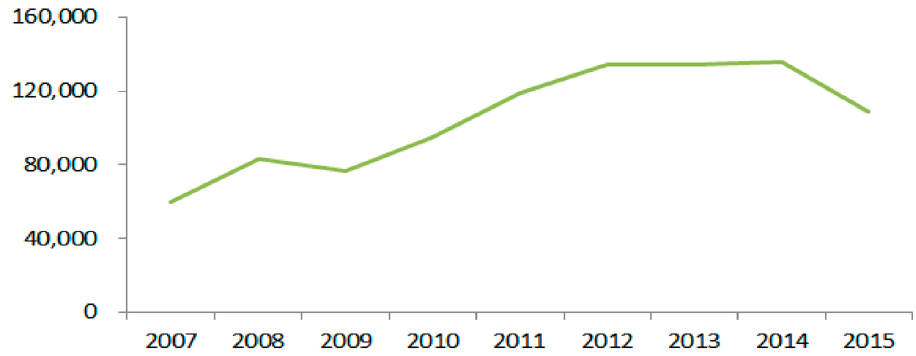

Figure 1. Trends of Energy Cost (unit: 1000 KRW) (The most recent exchange rate (5 December 2017) was $1 = 1082.80 KRW.). Source: Greenhouse Gas Inventory & Research Center of Korea (GIR).

Annual firm-level data of energy consumption describes each firm's annual energy consumption, which includes the consumption of both non-renewable and renewable energy. Terajoules (TJ) (terajoule (TJ) is a measurement unit of energy (1 tonne of oil equivalent (TOE) = 0.041868 TJ). J = $\frac{kg*m^2}{s^2}$ where kg is kilograms, m is meters and s is seconds) are employed as a measure of energy consumption to match different usage units according to energy sources. The CO_2 emission data represents the CO_2 emission levels of individual firms. Figures 2 and 3 depict the trends for energy use (average energy usage of all firms in the sample) and CO_2 emissions (average CO_2 emission levels of all firms in the sample) in the Korean industrial sector, respectively. According to Figures 2 and 3, energy use and CO_2 emission levels exhibit analogous behavior. Intuitively, it is reasonable to assume that using more energy would result in higher GHG emissions, when the proportion of fossil fuel is high in total energy consumption. The firms' energy consumption growth lowered during 2008–2009 due to decreased demand following the global economic downturn in 2008. As the economy recovers from 2009 onwards, demand rises, resulting in increased energy usage by the firms. In addition, a comparison of the trends of energy usage (Figure 2) and energy costs (Figure 1) reveals that they also appear to move together. This is because more energy usage corresponds to higher energy costs for firms. Data on energy consumption and CO_2 emissions was derived from GIR [30].

Firms' energy use patterns and their energy cost burdens were strongly affected by government energy policies, because national energy policies are directly linked with domestic energy price. Therefore, we also included the national renewable energy share variable in the model to control the stringency of Korean government's renewable energy expansion policy. (The Korean government decided to increase the share of renewable energy in national energy production from the present 8% up to 35% by 2040). The country-level renewable energy shares variable accounts for the ratio of the total renewable energy use to the national total energy use calculated in electricity generation units.

The data was obtained from the Korea Energy Agency. Furthermore, we use the real (inflation-adjusted) GDP data as a proxy for the country's economic growth obtained from Korean Statistical Information Service (KOSIS) [31].

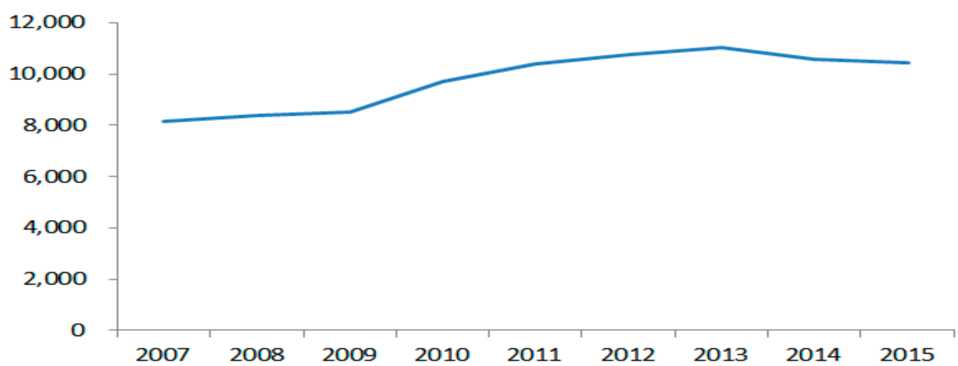

Figure 2. Trend of energy usage (unit: TJ). Source: GIR.

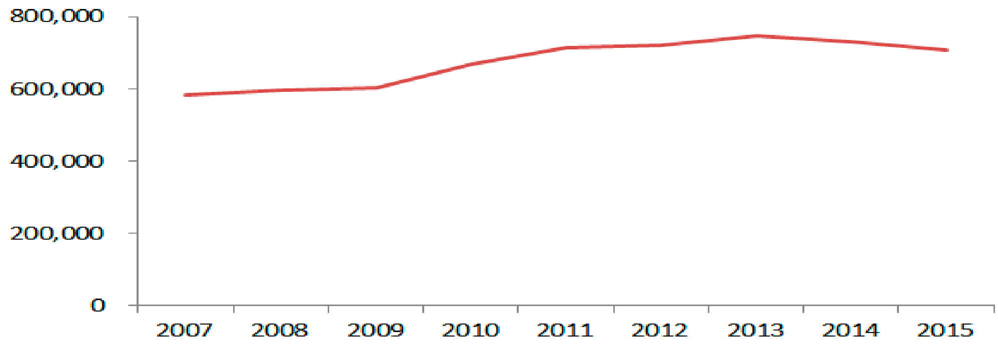

Figure 3. Trend of CO_2 emissions (unit: tons). Source: GIR.

2.2. Unit Root and Co-Integration Tests

In this study, the panel time-series technique is used to estimate the interrelationship between the five variables. We check the order of integration of each of the series, making them stationary, to obtain robust results. The Levin–Lin–Chu panel unit root test [32] is employed to determine the order of integration in each time series data. The test assumes homogeneity in the dynamics of the autoregressive coefficients for all panel units. We conduct the unit-root test on variables in levels first, and then the first differences of the variables were also tested if variables are not stationary. The null hypothesis of this test is H0: Each individual series have a unit root (non-stationary). The alternative hypothesis is Hl: Each individual series do not contain a unit root (stationary). Tables 3 and 4 show the results of the Levin–Lin–Chu test for large firms and SMEs, respectively. The results from the panel unit root tests indicate that the energy use, energy cost, GDP and CO_2 emissions variables do not have a unit root. However, renewable energy share variables have a unit root and are integrated of order 1.

Table 3. Levin–Lin–Chu Fuller unit root test (lags 1) for large firms.

Variables	**Stationary**	
	Level	**First Difference**
Energy Use	Stationary	Stationary
Energy Cost	Stationary	Stationary
Renewable Energy Share	Non-stationary	Stationary
GDP	Stationary	Stationary
CO_2 Emissions	Stationary	Stationary

Table 4. Levin–Lin–Chu Fuller unit root test (lags 1) for small and medium sized enterprises (SMEs).

Variables	**Stationary**	
	Level	**First Difference**
Energy Use	Stationary	Stationary
Energy Cost	Stationary	Stationary
Renewable Energy Share	Non-stationary	Stationary
GDP	Stationary	Stationary
CO_2 Emissions	Stationary	Stationary

Since unit root tests usually conclude that series are non-stationary, in general, the co-integration test is performed on non-stationary variables after the unit-root test. From the unit root test results, we found that only the renewable energy share variable is integrated of order 1, but the energy use, energy cost, GDP and CO_2 emission variables are integrated of order 0. Thus, we employ the energy use, energy cost, GDP, and CO_2 emission variables in levels and renewable energy share in first difference, which means that all variables in the model are stationary. This implies that we do not need to perform the co-integration estimation, and the panel vector autoregression (VAR) model is more appropriate than the vector error correction model (VECM) to analyze our data.

2.3. Empirical Model

The VAR model takes into consideration mutual effects among multiple variables and treats all variables as endogenous. To account for the existence of complex interactions among variables, the VAR framework has been widely used in the various fields. As environmental concerns and the importance of sustainable development have increased, previous studies have used VAR framework to examine the relationship between economic variables and variables related to GHG emissions. Much of these studies were on industrial sector in various countries or regions, using industry aggregate data. However, they did not capture the individual specific characteristics of firms, which could have significant implications for the economic and the environmental variables. In contrast, in this study, we adopt a panel data set to examine unobserved individual specific effects for firms where cross-sectional dimensions are added. Furthermore, we employ the panel VAR model to account for the dynamic interrelationships between energy factors, economic growth and GHG emissions, taking into account the energy consumption characteristics of different sized firms. The panel VAR methodology is well suited to investigate how various shocks in the industrial sector are transmitted across each firm by controlling for unobservable individual effects (cross-sectional heterogeneities). For example, when estimating the impact of firms' energy consumption on GHG emission levels, the individual specific characteristics, such as the degree of employee's knowledge on the environment need to be considered (controlled) to obtain unbiased results. However, it is almost impossible to find data containing all individual information we needed, and thus, the estimation methods using cross-sectional data may not have been able to capture the unobservable individual specific characteristics of firms. Fortunately, the unobservable heterogeneity across different firms can be captured by employing the dynamic panel data approach, which combines the advantage of traditional of VAR methodology with that of panel data estimation technique. (Contrary to cross-sectional and time-series data analysis, panel data allows for including the fixed effect in the model and controlling the influences from unobserved differences across individuals.).

We estimate the following panel VAR of order p:

$$y_{i\,t}\,A_o + \sum_{k=1}^{p} A_i\,y_{i\,t-k} + \alpha_i + \lambda_t + u_{i\,t} \tag{1}$$

More explicitly,

$$\mathrm{y}_{\mathrm{i\,t}} = \begin{bmatrix} \text{Energy Use}_{\,\mathrm{it}} \\ \text{Energy Cost}_{\,\mathrm{it}} \\ \text{Renewable}_{\,\mathrm{it}} \\ \text{GDP}_{\mathrm{it}} \\ \text{CO}_{2\,\mathrm{it}} \end{bmatrix};\ \mathrm{A_o} = \begin{bmatrix} \mathrm{a}_{1\,\mathrm{it}} \\ \mathrm{a}_{2\,\mathrm{it}} \\ \mathrm{a}_{3\,\mathrm{it}} \\ \mathrm{a}_{4\,\mathrm{it}} \\ \mathrm{a}_{5\,\mathrm{it}} \end{bmatrix};\ \mathrm{A_i} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} \end{bmatrix};\ \mathrm{u}_{\mathrm{i\,t}} = \begin{bmatrix} \mathrm{u}_{1\,\mathrm{it}} \\ \mathrm{u}_{2\,\mathrm{it}} \\ \mathrm{u}_{3\,\mathrm{it}} \\ \mathrm{u}_{4\,\mathrm{it}} \\ \mathrm{u}_{5\,\mathrm{it}} \end{bmatrix}$$

where p denotes maximum lag length and subscript i and t denote firm and year, respectively. The endogenous variable, $y_{i\,t}$, is a (6 × 1) vector of endogenous variables, and the lagged variable, $y_{i\,t-k}$, is a (6 × 1) vector that reflects the marginal changes from the previous year. In addition, we define the matrix, A_i, as an (6 × 6) autoregressive coefficient and the matrix, $u_{i\,t}$, as a (6 × 1) vector of errors. We also include the fixed effect (α_i) for each firm for the purpose of controlling the unobserved firm-specific effect and time effect (λ_t) that capture all unobservable time-invariant factors. Regarding the optimal number of lags, we chose a lag length of one year, which minimizes the different information criterions, to estimate the panel VAR model. We took the natural log of all variables in the model. Since the variables are integrated of order 1 and are not cointegrated, Equation (1) becomes as follows:

$$\begin{aligned} \ln \textit{Energy Use}_{\,it} \;=\; & a_{1\,it} + \sum_{k=1}^{p} A_{11\,i}\ \textit{Energy use}_{i\,t-1} + \sum_{k=1}^{p} A_{12\,i}\ \textit{Energy cost}_{i\,t-1} \\ & + \sum_{k=1}^{p} A_{13\,i}\ \textit{Renewable}_{i\,t-1} + \sum_{k=1}^{p} A_{14\,i}\ \textit{GDP}_{i\,t-1} + \sum_{k=1}^{p} A_{15\,i}\ \textit{CO}_{2\,i\,t-1} + u_{1\,it} \end{aligned} \tag{2}$$

$$\ln EnergyCost_{it} = a_{2\,it} + \sum_{k=1}^{p} A_{2\,1\,i}\ Energy\ use_{i\,t-1} + \sum_{k=1}^{p} A_{22\,i}\ Energy\ cost_{i\,t-1} + \sum_{k=1}^{p} A_{23\,i}\ Renewable_{i\,t-1} + \sum_{k=1}^{p} A_{24\,i}\ GDP_{i\,t-1} + \sum_{k=1}^{p} A_{25\,i}\ CO_{2\,i\,t-1} + u_{2\,it} \quad (3)$$

$$\ln Renewable_{it} = a_{3\,it} + \sum_{k=1}^{p} A_{3\,1\,i}\ Energy\ use_{i\,t-1} + \sum_{k=1}^{p} A_{32\,i}\ Energy\ cost_{i\,t-1} + \sum_{k=1}^{p} A_{33\,i}\ Renewable_{i\,t-1} + \sum_{k=1}^{p} A_{34\,i}\ GDP_{i\,t-1} + \sum_{k=1}^{p} A_{35\,i}\ CO_{2\,i\,t-1} + u_{3\,it} \quad (4)$$

$$\ln GDP_{it} = a_{4\,it} + \sum_{k=1}^{p} A_{41\,i}\ Energy\ use_{i\,t-1} + \sum_{k=1}^{p} A_{42\,i}\ Energy\ cost_{i\,t-1} + \sum_{k=1}^{p} A_{43\,i}\ Renewable_{i\,t-1} + \sum_{k=1}^{p} A_{44\,i}\ GDP_{i\,t-1} + \sum_{k=1}^{p} A_{45\,i}\ CO_{2\,i\,t-1} + u_{4\,it} \quad (5)$$

$$\ln CO_{2\,it} = a_{5\,it} + \sum_{k=1}^{p} A_{51\,i}\ Energy\ use_{i\,t-1} + \sum_{k=1}^{p} A_{52\,i}\ Energy\ cost_{i\,t-1} + \sum_{k=1}^{p} A_{53\,i}\ Renewable_{i\,t-1} + \sum_{k=1}^{p} A_{54\,i}\ GDP_{i\,t-1} + \sum_{k=1}^{p} A_{55\,i}\ CO_{2\,i\,t-1} + u_{5\,it} \quad (6)$$

3. Results and Discussion

We estimate the impulse-response functions (IRFs) showing responses to the shocks in other variables in the system over time. The estimated coefficients in IRF made by log-transformed data can be interpreted as elasticities. Figures 4–7 depict the IRFs from 0 to 8 years; the middle solid line represents the expected value, and the area between upper and lower solid lines represents the 95% confidence interval generated by a Monte Carlo simulation with 500 replications. The horizontal axis of IRFs represents period (year), and the vertical axis of IRFs represents the expected value of IRFs for each year.

Figures 4 and 5 depict the impulse responses of the variables to a one-unit shock in the energy use variable for large firms and SMEs, respectively. As shown in the graphs, a one-unit shock in the energy usage positively affects the energy cost of both large firms and SMEs. In particular, comparing the two groups, we note that the impact of energy consumption shock on energy cost is greater for large firms than for SMEs. Because of the large firms' rigidity in terms of energy composition, they are not easily able to change their energy use behavior (shift their consumption to alternative energy sources) in response to the variation in energy demand. Furthermore, the response of the renewable energy share to one standard deviation shock of the energy consumption is not significant for both figures, implying that energy usage shock has no significant impact on the renewable energy share variable. This could be true given that the consumption of renewable energy is strongly influenced by government policy and exogenously determined in Korea. Hence, it is reasonable to assume that firms do not have incentives to increase renewable energy shares in response to positive energy consumption shocks without government support, since renewable energy is generally still more expensive when generating electricity compared to fossil fuels [33]. In addition, since the economic activities of large firms account for a large portion of the national GDP in Korea, an increase in the energy consumption of large firms has a small but positive impact on GDP. Finally, looking at the bottom-right IRF, we found that there is a positive relationship between firms' energy consumption and CO_2 emission levels, because GHGs are mainly emitted during the fossil fuel burning process. We also found that the impact of energy consumption shocks on CO_2 emissions is greater in large firms than in SMEs.

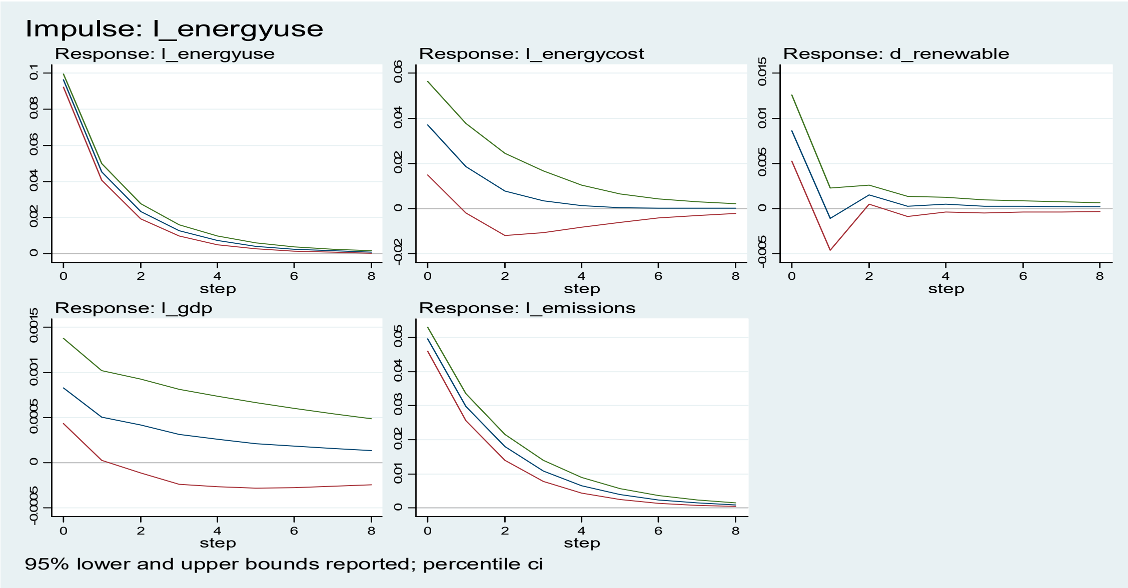

Figure 4. Response to energy use (large firms).

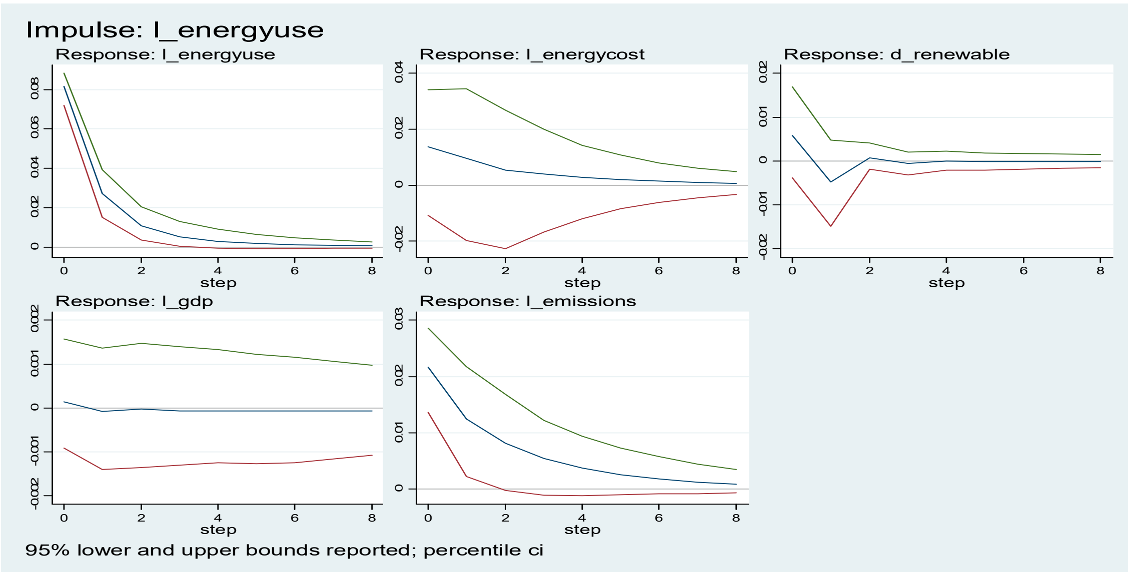

Figure 5. Response to energy use (SMEs).

Figures 6 and 7 depict the response to a shock in the energy cost of firms. We can see that the responses of the variables to the energy cost shock are quite similar for large firms and SMEs. As shown in the upper left graphs of both figures, a shock from energy cost has a positive but negligible impact on the energy use of both large firms and SMEs. This result might appear odd: Our intuition says that an increase in the energy costs of firms is expected to have a negative and significant impact on their energy usage. Nevertheless, this occurs because the impact of an energy cost shock (cost effect: An increase in energy cost raises production costs, which reduces a firm's energy usage) is smaller than the impact of a demand change shock (demand effect: An increase in GDP stimulates energy demand). (Korea's GDP has been growing by an annual average of 3.37% from 2007 to 2015 (calculated by an author using GDP data from the World Bank). Moreover, the cost effect is offset by the demand effect. Therefore, the energy cost shock has a positive but insignificant effect on the firms' total energy usage.

Additionally, from the first IRFs in the bottom row, one standard deviation shock in energy costs has a positive impact on GDP for approximately less than one year, but it declines over time.

This outcome reveals that the increase in energy costs expands the financial burden of firms, but the magnitude of the energy cost shock is not significant: The response of GDP to firms' energy cost variation is less than 0.001.

Similarly, the bottom-right IRF shows no evidence of any significant relationship between firms' energy costs and CO_2 emissions; the response of energy costs for large firms and SMEs to CO_2 emissions fades out after two years. A positive shock in a short run for firms' energy costs would not lead to significant changes in firms' energy consumption patterns or their CO_2 emission levels, which are mainly created from energy combustion.

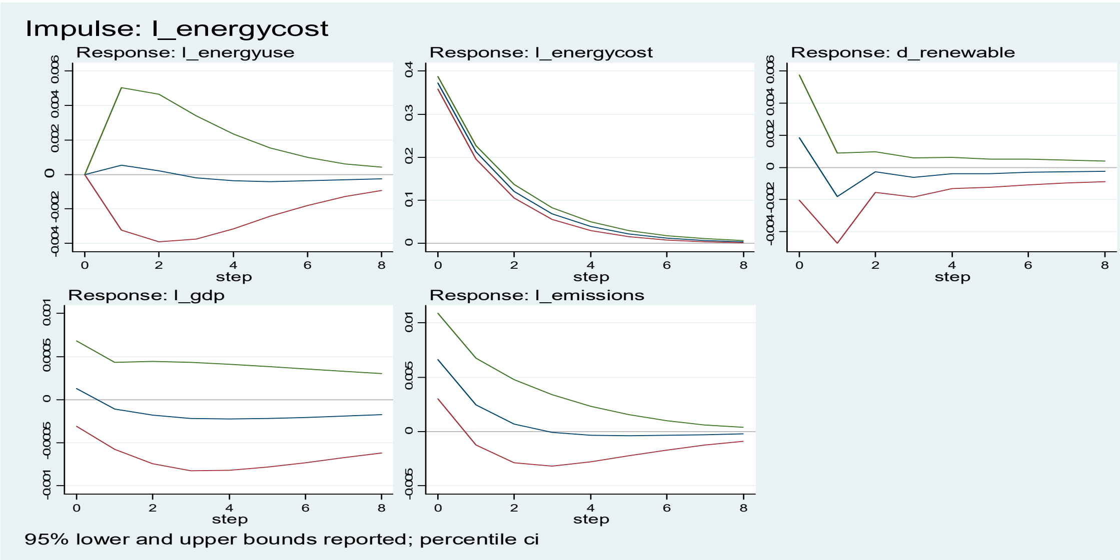

Figure 6. Response to energy cost (large companies).

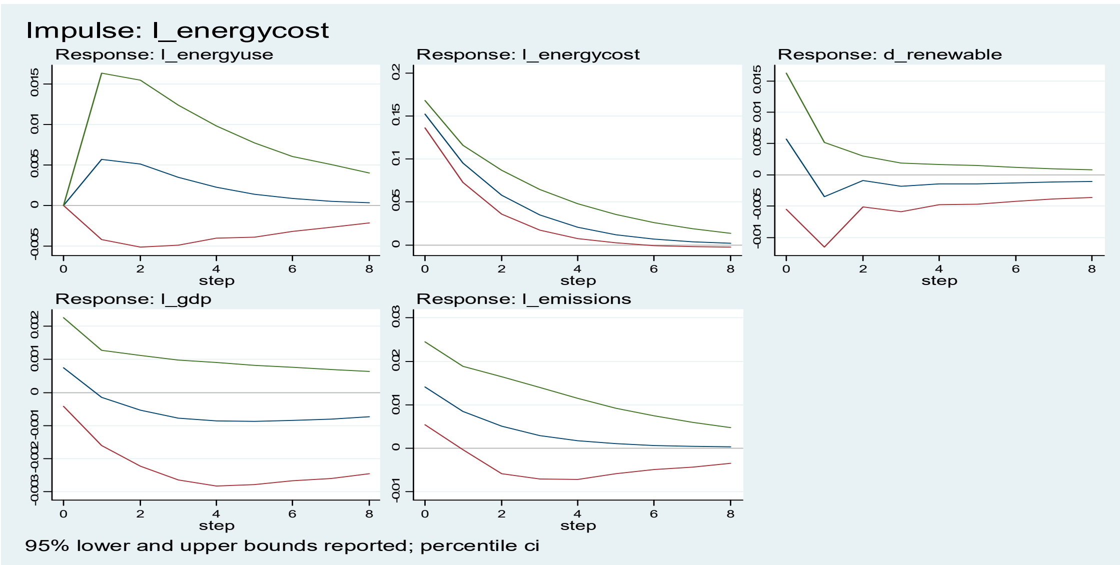

Figure 7. Response to energy cost (SMEs).

Figures 8 and 9 illustrate the panel IRFs for the energy factors and CO_2 emissions of firms and national GDP to one-unit change in renewable energy share. As shown in Figure 8, a shock in the renewable energy share only increases the energy usage for the group of large firms. One possible reason behind this is the financial burdens imposed on the use of fossil fuels that emit GHGs. After the two oil shocks in 1970s, the Korean government has been making effort to enhance energy security by diversifying energy sources. Korea currently has many policies in place, such as energy taxations, an emission trading system (ETS) and a renewables obligation to reduce GHG emissions. The pollution abatement activities usually increase the production costs of firms. However, firms could decrease environmental tax burden on fossil fuels by increasing the renewable energy share; in response to strict environmental policies, large firms can increase their total energy consumption (fossil fuel + renewable energy) without paying additional GHG reduction costs. Therefore, an increase in the renewable energy share leads to an increase in total energy consumption of large firms. On the other hand, SMEs are exempted from many energy or environmental taxation regulations, so their GHGs reduction burden is relatively smaller. Therefore, a positive shock in the renewable energy share has a negligible effect on SMEs' energy use, as demonstrated in Figure 9.

Looking at the upper-middle IRFs in Figures 8 and 9, we observe that renewable energy shocks seem to have a greater impact on large firms' energy costs than on SMEs' energy costs. This fact supports our belief that, since renewable energies, such as solar and wind power, are still more expensive than fossil fuels, firms' production costs increase as their renewable energy use among total energy consumption increases. Since large firms use more energy than SMEs, the endogenous national renewable energy expansion shock has greater financial impact on large firms than SMEs.

Figure 8 also illustrates that an increase in the renewable energy share increases CO_2 emissions for large firms over time. This is because a positive shock in renewable energy shares increases large firms' total energy usage, including non-renewable energy usage, thereby increasing the CO_2 emission levels of large firms. However, the CO_2 emissions of SMEs are not influenced by shocks in the renewable energy share. As is of the case of other figures, changes in the renewable energy share do not have a significant effect on SMEs' energy consumption; this means that there is no statistically significant relationship between the renewable energy share and SMEs' CO_2 emission levels from energy consumption.

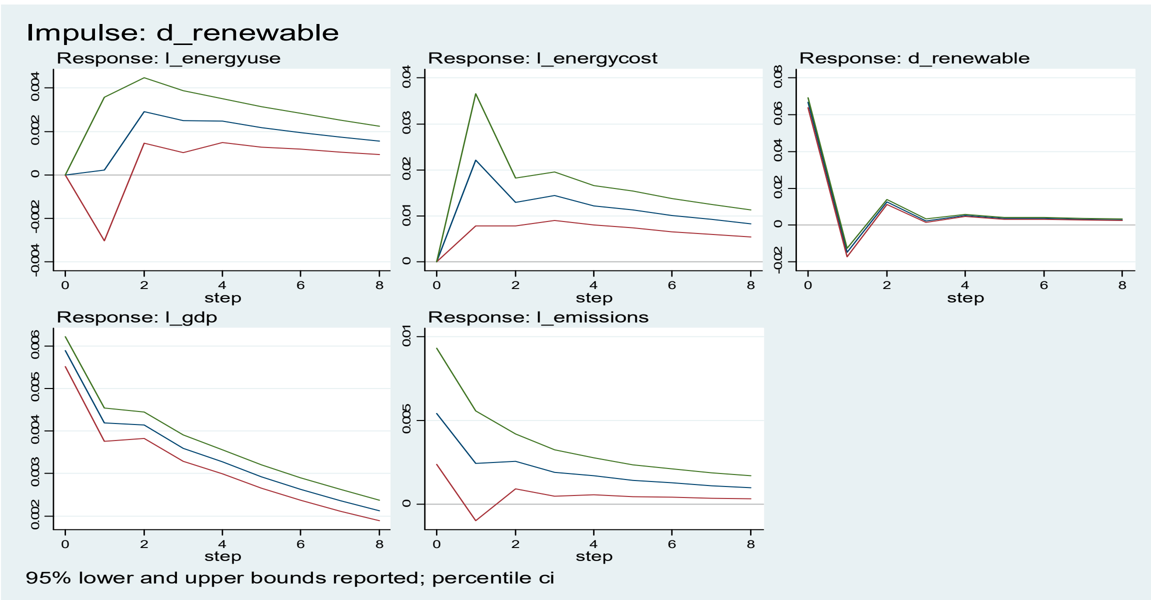

Figure 8. Response to renewable energy share (large firms).

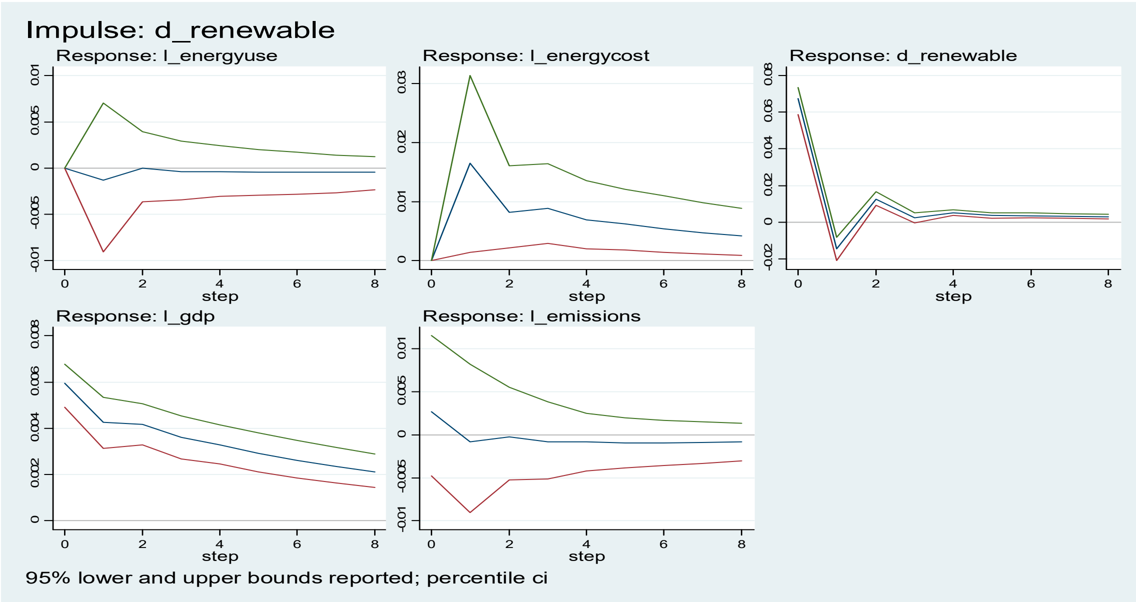

Figure 9. Response to renewable energy share (SMEs).

Figures 10 and 11, which demonstrate the GDP shock effects, show that firms' energy consumption positively reacts to a shock in GDP for both large firms and SMEs groups. However, in the case of SMEs, the reaction of SMEs' energy consumption to GDP shocks is not statistically significant (top-left IRF). As Choi and Rhee [34] have pointed out, the proportion of final products produced by large firms is higher than that by SMEs. The SMEs produce final goods and provide intermediate goods to large firms, while large firms produce final goods rather than intermediate goods. Changes in purchasing power due to changes in GDP are more likely to be directly linked to the demand for final products, rather than intermediate products, which would impact large firms' energy usage in production more than SMEs' usage. Therefore, only large firms' energy consumption increases in response to a one-unit positive shock in GDP. Looking at each upper-middle and bottom-middle IRF for both groups, it becomes apparent that the response of SMEs' energy costs to GDP is negligible, whereas the response of large firms is positively significant. Moreover, another important finding is that the impact of GDP changes on CO_2 emissions is more persistent in large firms than in SMEs, mainly because of the greater impact of GDP on the energy consumption of large firms compared to the consumption of SMEs. This effect remains positive and stable across the whole period, while it takes approximately four years to become not statistically significant for SMEs. In addition, there is a positive relationship between GDP and the renewable energy share. An increase in economic wealth increases people's demand for a better environment. As a result, the share of renewable energy of firms increases as GDP increases. This result is in line with the results of recent energy and environmental studies, which highlight that economic growth tends to improve the demand for the quality of the environment [17,35–37].

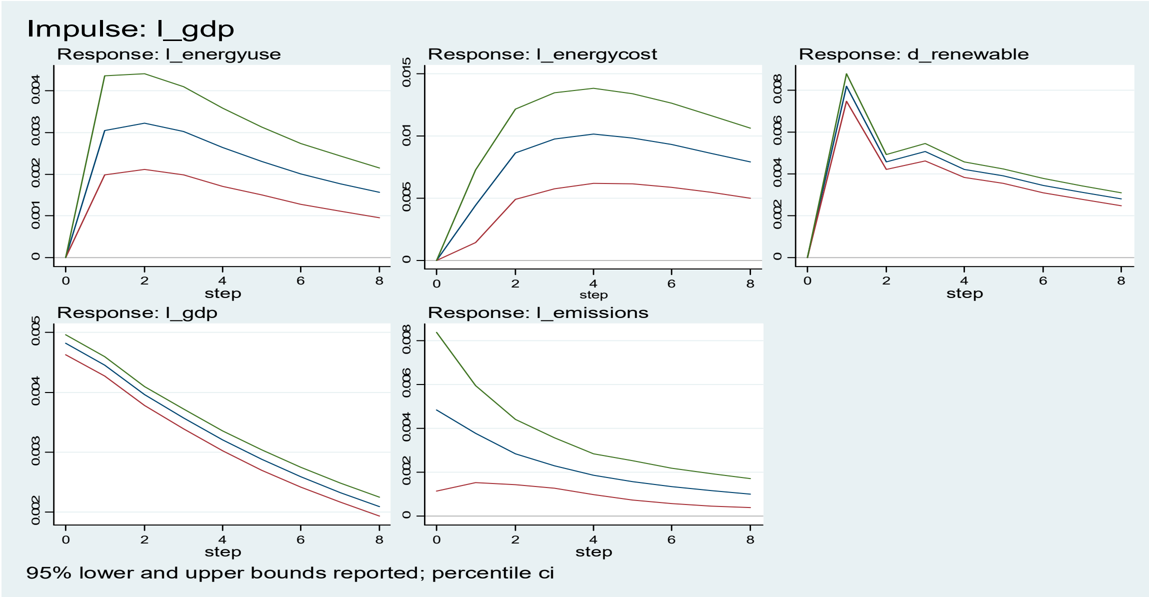

Figure 10. Response to GDP (large firms).

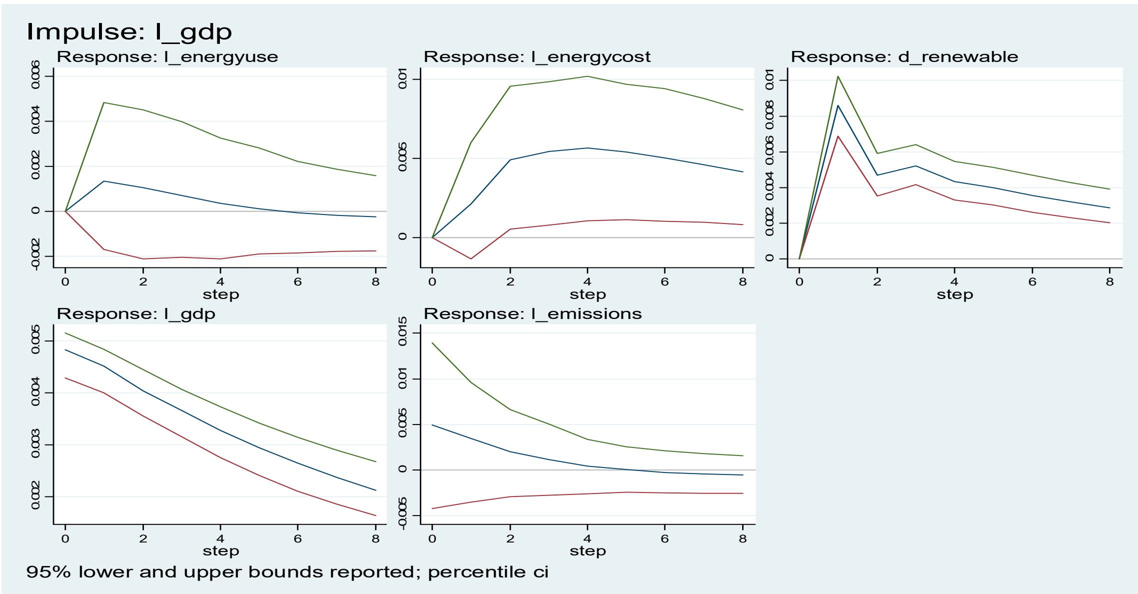

Figure 11. Response to GDP (SMEs).

4. Conclusions and Policy Implications

We showed different dynamics in energy consumption and GHG emissions under environmental regulations by firm size in the Korean industrial sector. By splitting the firm-level micro data on Korea during 2007–2015 into two groups, large firms and SMEs, we showed the heterogeneous dynamics of energy and environmental factors in each of these two groups. Differences in total assets, number of employees, or energy consumption behavior exhibited different dynamics in variables.

This study departs from previous studies on energy and environmental sectors in Korea in that we use the dynamic panel data approach with firm-level micro data. We derived the results consistent to those of previous studies using aggregate data: An increase in energy consumption increases the energy cost and CO_2 emissions, and CO_2 emission levels increase as the economy expands (positive GDP growth) for both the two groups. However, we also found different dynamics among the two groups which could not be observed in previous studies: First, the energy use of large corporations has a greater effect on their energy costs in comparison to SMEs. The main possible reason for this is the different rigidity of the energy composition of the two groups: Large corporations have a structure that makes it difficult to change the composition of energy sources in response to an increase in energy consumption shock, while SMEs' energy sources are relatively easy to replace with other energy sources due to energy costs account for a small proportion of total production costs in manufacturing SMEs (ODI, 2014). Second, large firms' energy consumption has a statistically significant positive impact on GDP, while the increase of SMEs' energy consumption brings a very small, and thus negligible, influence on GDP. In addition, a positive shock in GDP has a significant effect on the energy consumption of large firms and a much greater impact on the CO_2 emissions of large firms than those of SMEs, which reflects the large contribution of large firms to the Korean economy. Large firms' production activity, and thus their total energy usage, increases as the overall economic situation improves (positive shock in GDP), while that of SMEs does not. Third, in terms of the other different dynamics between large firms and SMEs, we found that as the share of renewable energy increases, only the energy consumption and CO_2 emission levels of large firms increase, while SMEs do not. This could be a result of the fact that renewable energy policies, such as renewable portfolio standards (according to which a part of total energy use should be composed of renewable energy), are mainly associated with large firms. Despite the popular belief that a regulation policy, such as RPS, that aims to increase the use of renewable energy leads to a decrease in fossil fuel consumption, large firms facing such regulations do not reduce GHG emissions. Rather, increasing the share of renewable energy can increase total energy consumption levels and allow for more greenhouse gas emissions. It is possible that power generation using renewables may only increase electricity reserves, without, however, affecting a firm's intention to switch fuels.

As extensions of this paper, possible future research using micro-firm data could be various: Analyzing the impact of more detailed information about firms (such as total revenue, profitability or trade dependency) on GHG emissions and energy consumption, the effect of different dependencies of firms on trade on the effectiveness of domestic policy, or having uncertainties on baseline emissions. It is also possible for GHG emissions to respond inelastically to changes in trade dependence.

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