자원 · 환경경제연구 제 29 권 제 4 호
Environmental and Resource Economics Review
Volume 29, Number 4, December 2020 : pp. 499~520
DOI: https://doi.org/10.15266/KEREA.2020.29.4.499

Dynamic Analysis on Electricity Demands for the Steel Industry in Korea: Comparison between SMEs and Large Firms

Dmitriy Li* and Jeong Hwan Bae**

ABSTRACT : Input ratio of electricity to other production inputs in the Korean manufacturing sector has been higher than for the other OECD countries. In addition, electricity prices in Korea has been relatively lower than the average of OECD countries. Moreover, electricity sector is responsible for most CO2 emissions in Korea as coal and natural gas account 41.9% and 26.8% of electricity production as of 2018. Therefore, it looks inevitable to raise the electricity tariff for the manufacturing sector in Korea, but there is a concern that increase in the electricity tariff might affect small and medium enterprises (SMEs) more than large firms. This study estimates electricity demand's price and output elasticities for large firms and SMEs in steel industry by employing a time varying parameter model (Kalman filter). The analysis shows that changes in output levels regardless of firms' size affect electricity demands more significantly than do changes in electricity prices. Second, large firms have higher variances for both price and output elasticities of electricity demand. Third, large firms have higher price elasticity but lower output elasticity of electricity demand relative to SMEs. Policy implications are suggested in association with how to reduce electricity demands in the energy-intensive industry.

Keywords : Electricity demand, Output elasticity, Price elasticity, Kalman filter, Energy-intensive industry, Firm size

JEL Classification : C2, N7

Received: September 1, 2020. Revised: December 4, 2020. Accepted: December 9, 2020.

* Part-time Instructor, Department of Economics, Chonnam National University, First author(e-mail: lddima82@yahoo.com)

** Professor, Department of Economics, Chonnam National University, Corresponding author(e-mail: jhbae@chonnam.ac.kr)

우리나라 철강산업의 전력수요에 대한 동태 분석: 중소기업과 대기업 간 비교

이 드미트리* · 배정환**

요 약 : 우리나라 제조업 부문의 상대적 전력투입비율은 OECD 국가들에 비해 높은 편이며 이는 전력가격이 OECD 평균보다 상대적으로 낮은 데에 기인한다. 또한 전력부문은 한국에서 온실가스 배출의 상당한 비중을 점유하고 있는데, 2018년 기준으로 전력생산의 투입연료로 석탄과 천연가스가 41.9%와 26.8%를 차지하기 때문이다. 따라서 우리나라 제조 부문에서 전력가격을 인상할 필요가 있으나 중소기업이 대기업보다 상대적으로 더 많은 영향을 받을 것이라는 우려가 있다. 본 연구는 시간가변적 파라메터 모형인 Kalman Filter 추정법을 이용하여 철강산업에서 대기업과 중소기업 전력수요의 가격 탄력성과 산출 탄력성을 추정하였다. 분석 결과, 기업의 크기에 상관없이 산출량 변화가 가격변화보다 전력수요에 더 많은 영향을 미치는 것으로 나타났다. 또한 대기업에서 전력수요에 대한 가격탄력성뿐만 아니라 산출탄력성의 분산이 중소기업보다 더 큰 것으로 추정되었다. 정책적 함의는 철강산업과 같은 에너지다소비 업종에서 어떻게 전력수요를 감축할 것인지에 관련되어 있다.

주제어 : 전력수요, 산출탄력성, 가격탄력성, Kalman Filter, 에너지다소비업종, 기업 규모

접수일(2020년 9월 1일), 수정일(2020년 12월 4일), 게재확정일(2020년 12월 9일)

* 전남대학교 경제학부 시간강사, 제1저자(e-mail: lddima82@yahoo.com)
** 전남대학교 경제학부 교수, 교신저자(e-mail: jhbae@chonnam.ac.kr)

I. Introduction

Industrial sector in Korea has been heavily dependent on electricity as a fuel to produce manufacturing goods. In 2013, the proportion of electricity consumption to the total final consumption (TFC) of Korean manufacturing was 46.7%, whereas the average TFCs of Organization of Economic Cooperation and Development (OECD) and non-OECD countries were 34.5% and 32.3%, respectively (International Energy Agency, 2015). However, most energy resources such as coal, petroleum, natural gas, and uranium used to produce electricity in Korea have been imported from the rest of the world, so electricity production costs are more expensive than in countries where energy resources are available domestically.

Recently, there has been an emerging argument on sectoral disparity in electricity prices that have required increases in industrial electricity prices. As of 2017, the price of electricity for the industrial sector was 107 KRW/kWh, which was lower than that of the residential (109 KRW/kWh) and commercial (130 KRW/kWh) sectors, and streetlights (113 KRW/kWh) (Electric Power Statistics Information System, 2018). One reason for lowering the industrial electricity tariff by the Korean government is to maintain the competitiveness of Korean manufacturing firms against foreign companies. In Korea the retail electricity rates for agricultural and industrial users are lower than electricity production cost, while those for other users are above the electricity production cost. As a result, energy intensive firms in Korea have had incentives to rely heavily on electricity as an input for production, so the input ratio of electricity to other inputs in Korean industry has been higher than in the other OECD countries. Another reason is that the lower industrial electricity price with high stability of electricity supply in Korea has been an incentive for locating foreign companies to Korea.

Recent changes in international as well as domestic environments have required to increase the overall electricity prices in Korea. From the international perspective, it is important to not only save energy, but also improve energy efficiency in order to reduce emission of greenhouse gases (GHGs). In this regard, lower electricity prices can lead to excessive and inefficient electricity uses. Concerning the domestic point of view, the present Korean government drives an energy-transition policy from fossil fuels to renewable ones in the electricity sector. In this context, a long-term goal of the Korean government until 2030 is to raise the proportion of green electricity produced by using renewable energy up to 20% of the total electricity production. Because electricity production costs of renewable energy sources in Korea have been higher than those from fossil energy sources, it will be inevitable to raise electricity prices regardless of types of sectors. However, if the overall electricity price increases, there is a concern about the relative effects of industrial electricity prices on different firm sizes. Unlike large companies, small and medium enterprises (hereafter SMEs) can suffer from higher burdens because of increases in the electricity prices. Although one of the major goals for increasing the electricity price is to improve the energy efficiency of industry, the SMEs would not be able to change from the current energy technology to a more efficient one. Then the government would confront strong resistance from the SMEs if industrial electricity prices increase above the shutdown levels of those firms.

In this context, it is important to compare the price elasticities for the SMEs with that for the large firms in order to find out if the SMEs can suffer more heavily from the increases in the industrial electricity prices than the large firms would. Moreover, most studies that estimated price elasticity of electricity demand for industrial sector also consider the output elasticity of electricity demand, as electricity is one of the important input in the industry sector. Thus, this study derives electricity demands of the energy-intensive steel industry in Korea and compares the time-varying price and output elasticities of electricity demands for the SMEs and the large firms by applying Kalman filter approach for the period January 2005-December, 2017. Korean steel industry is one of the nation’s key industries with high impact on other industries such as automobiles, shipbuilding, containers, railroads, construction, and others. Korean steel production expanded substantially from 2.55 million tons in 1975 to 48.5 million tons in

2006, as a result Korea becomes the world's fifth largest steel producer. The Pohang Iron and Steel Company (POSCO) is the biggest steel company in Korea which increased the supply of domestic steel from 20 percent of consumption in the 1970s to more than 90 percent in 2000. But at the same time, steel industry in Korea has been one of the major carbon emission sources.

Based on the estimation results, we would like to answer the following research questions:

1) Will SMEs be affected more heavily than are the large firms by the electricity price increases?
2) Will SMEs respond more than the large firms to change in industrial output?
3) How price and output elasticities of electricity demand change over the time periods?

As far as we know, there have been few studies that have attempted to examine differences in the price elasticities of electricity demands for specific industries at different firm sizes. In this context, we believe that our study will contribute the extant literature on the empirical estimation of the price elasticity of electricity demands.

The next section provides a literature review of present studies on the estimation of industrial electricity demands. Section 3 presents estimation method, model specification, and data. Section 4 provides estimation results, and the final section represents summary of this study and policy implications.

II. Literature Review

During the last several decades, the electricity industry has received great attention. Global electricity consumption continues to increase. In the case of Korea, electricity demand tripled over the period 1987-1997 and continued to rise (OECD, 2000). Moreover, according to world energy statistics from IEA (Energy Information Administration), fossil fuels remain the main source of electricity production and accounted for 68% of world electricity generation. Such electricity sector expansion has been raising concerns about the effects of the rising electricity demands on the environment as well as on climate change through the increase of fossil energy consumption as fuels to produce electricity. On the other hand, electricity and energy as a whole is an engine of economic growth. Thus, it is critical to find out which factors affect increases in the electricity demand. For this reason, price and income elasticities of electricity demand have been investigated for different countries by using different time periods and estimation approaches.

Most previous studies on the price elasticity of electricity demand have focused on residential electricity demand, and little attention has been given to the price elasticity of industrial electricity demand. Our literature review in this study focuses on the empirical results and estimation methods of the previous studies that estimated the price or output elasticities of electricity demands for the industrial sector.

The early studies of electricity demand elasticities were based on least-square estimation approaches. For instance, Inglesi-Lotz and Blignaut (2011) used a Seemingly Unrelated Regression (SUR) model to examine South African price and output elasticities of electricity consumption in five sectors for the period 1993 to 2006. Their result suggested that only the industrial sector had a significant coefficient of price elasticity, whereas sectoral output was found to be a significant factor for the industrial and commercial sectors.

Recent studies mostly used more advanced econometric approaches to estimate price and income elasticities of electricity demand such as instrumental variable and non-instrumental single-equation approaches (Burke and Abayasekara, 2017; Csereklyei, 2020), the first-difference generalized method of moments (GMM) estimator (Cialani and Mortazavi, 2018; Otsuka, 2015; Chang et al., 2019), panel system GMM approach (Chang et al., 2019), maximum likelihood approaches (Cialani and Mortazavi, 2018), Johansen approach (Faisal and Eatzaz, 2011) and other.

Another set of studies on estimating electricity demand distinguish between short-run elasticities and long-run elasticities by applying the autoregressive distributed lag (ARDL) model (Ishaque, 2018; Halicioglu, 2007; Ziramba, 2008; Amusa et al., 2009). According to the economic theory for a necessary good like electricity, the long-run elasticities are usually larger than the short-run (Paul et al., 2009).

However, all approaches mentioned above still follow a common hypothesis that price and income elasticities are constant over time. As summarized in Table 2, the estimation results of price and income elasticities of electricity demand in the industrial sector are not conclusive. That difference in the elasticity varies depending on the country and more importantly, the period investigated. Arisoy and Ozturk (2014) argued that price and income elasticities are unlikely to remain constant over time as the nature of demand and the tastes of consumers are time varying. Thus, to overcome the fixed coefficient assumption, more recent studies have been utilized time varying parameter (TVP) model using the Kalman filter to estimate the elasticities of electricity demand (Thamae et al., 2015; Inglesi-Lotz, 2011; Wang and Mogi, 2017; Wakashiro, 2019). Most studies that use the TVP model found that price and income elasticities of electricity demand are time varying.

However, studies on price and output elasticities of electricity demand in industrial sector for Korea is rare. For example, Na and Seo (2000) implemented different cointegration approaches to estimate the production index elasticity and the price elasticity of electricity demand in Korean industrial sector, and showed that the production index elasticity and the price elasticity of electricity demand in Korea are 0.13 and -0.40, respectively. More recently, Chang et. al (2014) examined price and income elasticities of electricity demand for residential, commercial and industrial sectors by allowing only income (output) coefficient varying over time. Moreover, only a few studies have estimated elasticities for individual sectors. For example, Wakashiro (2019) by using Kalman filter estimated the price elasticity of the electricity demand in major manufacturing industries (textile mill, plastic, rubber, leather, steel etc.) and showed that for industries in which electricity is a necessary good such as iron, steel, non-ferrous metals and products price elasticity of electricity demand is less elastic (-0.251).

By contrast with Chang et. al (2014) and Wakashiro (2019), this study allows varying both price and output elasticities of electricity demand. Moreover, we consider electricity demand for a particular energy-incentive steel industry and distinguish firms by their size (large firms and SMEs).

〈Table 1〉 Summary of studies on the estimation of the income and price elasticities of electricity demand in industrial sector

Author(s)	Country and time period	Estimation method	Elasticity	Long-run	Short-run
Csereklyei (2020)	European Union 1996-2016	IV model	Price	-0.75 and -1.01	
			Income	0.76 and 1.08	
Inglesi-Lotz and Blignaut (2011)	South Africa 1993-2006	SUR model	Price	-0.87	
			Income	0.71	
Burke and Abayasekara (2017)	United States 2003-2015	IV and single equation estimate	Price	-1.71 and -1.17	-0.09
			Income	Insignificant	0.35
Cialani and Mortazavi (2018)	29 European countries 1995–2015	First-difference GMM and ML estimator	Price	-0.12 and -0.19	-0.03 and -0.05
			Income	0.73 and 0.64	0.18 and 0.17
Otsuka (2015)	47 Japanese prefectures 1990–2010	First-difference GMM	Price	-0.146	-0.034
			Income	1.169	0.274
Chang et al (2019)	20 OECD countries 1978-2013	First-difference GMM	Price	-0.206	-0.096
			Income	0.899	0.418
		System GMM	Price	-0.128	-0.029
			Income	1.23	0.283
Faisal and Eatzaz (2011)	Pakistan 1961–2008	Johansen approach	Price	-1.22	Insignificant
			Income	1.61	0.64
Ishaque (2018)	Pakistan 1972-2013	ARDL approach	Price	-0.431	-0.21
			Income	0.599	0.60
Wang and Mogi (2017)	Japan 1989-2014	Kalman filter	Price Income	Time-varying	-0.16 1.025
Chang et. al (2014)	Korea 1985:01-2012:12	TVP cointegration approach	Price Income	-0.48 0.89	-0.12 0.45-0.65

III. Model and Data

1. Estimation Model

The Kalman filter methodology allows coefficients to vary stochastically over time. Morisson and Pike (1977) argue that if estimated parameters do not vary over time the Kalman filter and the least squares approach are expected to produce similar results, but in the presence of parameter instability, the Kalman filter can be proven superior to the least squares model. Therefore, before estimation of Kalman filter we utilized Hansen (1992) parameter instability test, which uses L_C test statistics from the theory of Lagrange Multiplier tests for parameter instability. The null hypothesis of Hansen instability test is that parameters are stable, and if the null hypothesis is rejected, then the Kalman filter is the most appropriate method. Moreover, the analyzed period includes the world financial crisis, so Kalman filter approach can detect whether there was a structural break or not. In addition, as this paper uses monthly data, here might be some seasonal volatility in the electricity price and demand, but Kalman filter is specially designed for estimation of true value in the presence of unpredicted or random error, uncertainty or variation. However, Kalman filter has one important limitation. If the model has many variables the prediction and update of the covariance matrix can become computationally unaffordable. Therefore, most studies that used Kalman filter for estimation of elasticities of electricity demand used one or two time-varying variables (Thamae et al., 2015; Inglesi-Lotz, 2011; Wang and Mogi, 2017; Wakashiro, 2019).

The Kalman filter approach is based on the estimation of state-space models. This approach has been applied to model unobserved variables where electricity demand might be affected by consumer preference, availability of substitutes, change in relevant technology and policy, and regional climate condition (Wang and Mogi, 2017).

The Gaussian state-space form includes two equations: observation or measurement equation (1), and state or transition equation (2).

$$y_t = H'\vartheta_t + e_t \tag{1}$$

$$\vartheta_{t+1} = F\vartheta_t + \mu_t \tag{2}$$

Where, y_t is an (n×1) vector of variables observed at date t, ϑ_t is an (r×1) state vector, *F,* and H' are matrices of parameters of dimension (r×r), and (n×r) respectively. The (r×1) vector μ, and the (n×1) vector e are disturbances with white noise. The disturbances μ_t and e_t are assumed to be uncorrelated at all lags. For more detail about state-space model and Kalman filter see, Hamilton (1994).

To explain the electricity demand the literature uses the prices of electricity, output or income variables and vector of other explanatory variables **X**[1]. Thus, estimation equation takes the following form:

$$\mathrm{Ln}ED_t = \alpha + \beta_1 \mathrm{Ln}P_t + \beta_2 \mathrm{Ln}\,Y_t + \gamma_X X_t + \varepsilon_t \tag{3}$$

Where, $\mathrm{Ln}ED$ is a natural log of electricity demand; $\mathrm{Ln}P$ is a natural log of electricity price; $\mathrm{Ln}\,Y$ is a natural log of industry production index that is used as a proxy for output; α is an intersect; β_1 and β_2 are price and output elasticities respectively; γ_X is a vector of coefficients of the other explanatory variables; and ε_t is an error term. The estimation of equation (3) would result in constant parameters of β_1 and β_2. This paper applies the Kalman filer, which allows price and output elasticities vary over time. Hence, instead of single equation it estimates the following state space:

1) As mentioned above on the Kalman filter estimation, the number of explanatory variables is limited. In addition to price and output variables, this study also considered additional explanatory variables that could affect potentially electricity demand of steel industry such as oil price, unemployment, consumer price index (CPI), heating degree day (HDD) and cooling degree day (CDD), but the estimation results showed that these variables have low explanatory powers, so they were omitted.

$$\mathrm{Ln}ED_t = \alpha_t + \beta_{1,t}\mathrm{Ln}P_t + \beta_{2,t}\mathrm{Ln}Y_t \tag{4}$$

$$\beta_{1,t+1} = \beta_{1,t} + v_t \tag{5}$$

$$\beta_{2,t+1} = \beta_{2,t} + w_t \tag{6}$$

$$\alpha_{t+1} = C_2\alpha_t + \sigma_t,\ \sigma \sim NID(0,\ \exp(C_1)) \tag{7}$$

$\beta_{1,t}$ and $\beta_{2,t}$ are time-varying parameters of price and income elasticities, respectively; α_t is a time-varying parameter of unobserved factors affecting the electricity demand; C_1 is a log of the variance of the error terms; C_2 is an estimated constant; v_t and w_t are Gaussian disturbances. Note that Eviews program, which was utilized for estimation of Kalman filter, allows ARMA (p, q) model specification for equation (7). However, based on the AIC, Schwarz, and Hannan-Quinn information criteria specification, ARMA (1, 0) for equation (7) was preferred as it has lower values of above-mentioned criteria.

After the estimation of the state space, we applied the Kalman filter by substitution of unknown parameters C_1 and C_2 in equation (7) with their estimated values from the state space, and re-estimated system of equations (4) − (7).

Notice that a Kalman filter is suitable for application to a stationary and non-stationary time series, but it is required to estimate the initial state vector and the variance of the errors. For the stationary time series the usual initialization uses the unconditional mean and variance of the initial states. However, for non-stationary time series the unconditional means and covariances change over time, and therefore it is required to set initial states. One of possible ways of initializing the Kalman filter letting the variance of the initial state be "large". Eviews program follows the method adopted by Koopman, Shephard and Doornik (1999) in setting initial state mean of zero, and variance matrix as follow:

$$P = P_* + kP_\infty,\ P_* = 0,\ K = 10^6,\ P_\infty = I \tag{8}$$

Where P_* is a symmetric (r × r) matrix, P_∞ is a diagonal identity (r × r) matrix. If any diagonal value of residual covariances matrix is larger than unity the constant k will be multiplied by the maximum diagonal value of residual covariances.

2. Data description

For the estimation of electricity demands in the energy-intensive steel industry, we use the monthly data from January 2005 to December 2017. The electricity expenditure and consumption data are collected for large and SMEs steel companies2). Companies are classified as large if their sales are above KRM 5 trillion, while if the sales between KRW 12 billion and KRW 5 trillion the company is classified as medium size, and if sales are KRW 1 − 12 billion that is a small business. The electricity consumption is expressed in terms of gigawatt-hours (GWh). The electricity price is derived by dividing the total electricity expenditure of each firm by electricity consumption, expressed in Korean won per kilowatt-hour (KRW/kWh). We use the industrial production index (excluding Agriculture, Forestry and Fishing) (hereafter IPI) as a proxy to output variable; of which value in the year 2015 is set as 100. The descriptive statistics of all variables are shown in Table 2.

〈Table 2〉 Descriptive summary of statistics

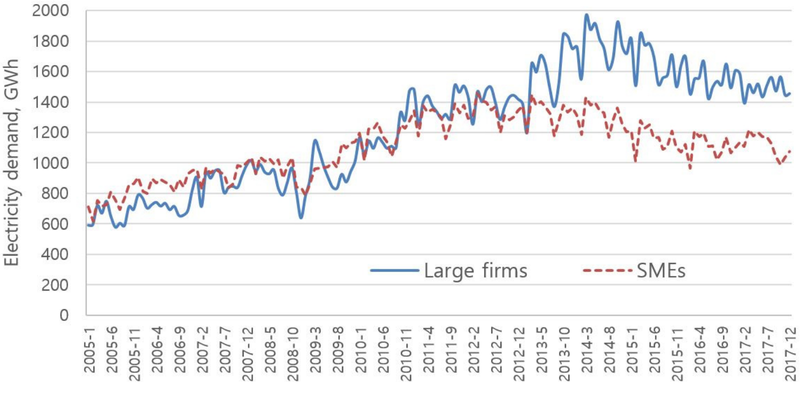
Variable definition	Unit	Mean	Std. Dev.	Min	Max
Electricity demand of large firms[1]	GWh	1240.9	382.67	576.35	1965.7
Electricity demand of SMEs[1]	GWh	1106.6	196.54	614.97	1458.1
Electricity price of large firms[1]	KRW/kWh	72.97	17.94	46.30	103.83
Electricity price of SMEs[1]	KRW/kWh	74.04	15.65	50.78	102.51
Industrial production index[2]	100	91.35	10.54	64.6	116.4

Sources: [1]Internal data from the Ministry of Trade, Industry and Energy; [2]Korean statistical information service: https://kosis.kr/

2) These data were provided by the corresponding staff in the Ministry of Trade, Industry and Energy (MOTIE), and not available for open access.

Figure 1 shows electricity demands for large and SMEs firms. As shown in the Figure 1, before 2011 the electricity demand of large firms was slightly lower than the SMEs, but since 2013 it surpassed the electricity demand of SMEs.

〈Figure 1〉 Electricity demand for large firms and SMEs



IV. Estimation Results

1. Hansen instability test

The Hansen instability test was used to determine whether the estimated parameters change over time (Table 3). The test L_C-statistics are 0.75 and 1.56 for large firms and SMEs models respectively. Since the p-values are smaller than the 5% level of significance, the null hypothesis that the parameters are stable is rejected. Thus, we can apply Kalman filter approach to analyze the dynamics of electricity demand.

〈Table 3〉 Hansen instability test

Model	LC statistics	P-value
Large firms	0.751071	0.0316
SMEs	1.557824	<0.01

Note: The null hypothesis of the test is that the parameters are stable

2. Kalman filter estimation.

Table 4 reports the Kalman filter estimation results of final state and average values for the estimated price and output elasticities, as well as estimated value of the final period of the time-varying intercept, which represents other unobservable factors that affect the electricity demand in steel industry. The average values of predicted price elasticity of electricity demand over the data period are -0.30 and -0.25 for large firms and SMEs respectively, which indicates that price elasticity of electricity demand for large firms and SMEs in Korea are similar each other and relatively inelastic. These results coincide with Wakashiro (2019) who estimated that price elasticity of electricity demand in iron, steel, non-ferrous metals and products is relatively inelastic (-0.251) relative to the other industries. Chang et. al (2014) also confirmed that the short-run price elasticity of electricity demand for Korean industrial sector was inelastic (-0.12). However, the estimation results showed that output elasticity of electricity demand is more elastic than price elasticity, and the average value of output elasticity for SMEs (0.68) is higher than for large firms (0.44). These results are close to Chang et. al (2014) who also concluded that the short-run output elasticity for Korean industrial sector is varying between 0.45 and 0.65.

〈Table 4〉 Kalman filter estimation results

Coefficients	Large firms		SMEs	
	Final state	Average	Final state	Average
LnP	-0.361*** (0.069)	-0.30	-0.310*** (0.047)	-0.25
LnY	0.366*** (0.121)	0.44	0.534*** (0.094)	0.68
Intercept	21.005*** (0.740)		19.851*** (0.558)	
Log likelihood	127.52		186.68	
AIC	-1.609		-2.123	
Schwarz criterion	-1.570		-2.084	
Hannan-Quinn criterion	-1.593		-2.107	
Number of observations	156		156	

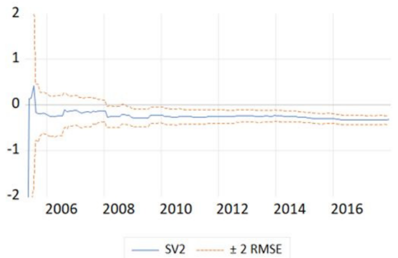
Note: The values in parentheses are standard errors. The symbols *, ** and *** indicate statistical significance at 10%, 5% and 1% levels, respectively.

Figure 2 shows time-varying price and output elasticities for SMEs and large size firms. As it is shown neither of estimated elasticity did not exceed 2RMSE. Moreover, the variation at the beginning of analyzed period is high due to the estimation procedure of Kalman filter. The Kalman filter is an algorithm for sequentially updating a linear projection for the system. Using the initial estimate, it almost does not matter what is initial estimate is, while through the iterative process the Kalman filter very quickly narrows down to the true value. Thus, we ignored these initial estimates in Figures 3 and 4.

〈Figure 2〉 Price and output time-varying elasticities for SMEs and large size firms

a. Price elasticity (large firms)

b. Output elasticity (large firms)



c. Price elasticity (SMEs)

d. Output elasticity (SMEs)

Figure 3 compares the evolutions of price elasticity of electricity demand for SMEs and large size firms. Because of high variation of the initial estimates this figure shows the time-varying price elasticities from 2006. The figure shows that the variation of price elasticity for large firms is higher than SMEs, moreover, it indicates that large firms are more price elastic than SMEs. The price elasticity of electricity demand for large firms after 2008 increased in absolute value and achieved the maximum absolute value between 2009 and 2010 (below -0.4). Those results coincidence with Burke (2017) who also suggested that the electricity demand became more price elastic after 2008 financial crisis. And beginning from 2012 the price elasticity for large firms is stabilized at about -0.35. The SMEs price elasticity of electricity demand between 2008 and 2014 was relatively stable (about -0.25) and then slightly increased in absolute value to about -0.32.

It is presumable that large firms might respond more flexibly for changes in electricity prices than the SMEs, so if Korean government should increase the industrial electricity prices to reduce electricity demands in association with climate mitigation policy, the SMEs in the steel industry would not decrease electricity demands in significant amount due to the inflexibility of substitution from electricity to the other inputs.

〈Figure 3〉 Price elasticities of electricity demand for large firms and SMEs in steel industry

Figure 4 shows trajectory of the output elasticity of electricity demand. Similar to the Figure 3 it also dropped the initial estimates of time-varying output elasticities. The magnitudes of the estimates are larger for SMEs than for large firms. One of the reasons why output elasticity for large firms is smaller than the SMEs might be explained based on the economies of scale. Economies of scale exist when increase in output is expected to result in a decrease in unit cost while keeping the input costs constant. Thus, if cost of typical unit decreases, it means that less inputs are used for production of that unit. As electricity is one of the main inputs in steel production, the increase in total output implies decrease in electricity consumption per unit of production due to the economy of scale. Moreover, Figure 4 shows that output elasticity of electricity demand for large size varies more than that for the SMEs. Specifically, output elasticity falls for large firms after 2008 financial crisis, but increases slightly after 2012. For the SMEs, output elasticity of electricity demand falls from 1.4 in 2006 to about 0.6 in 2010, and then was relatively stable. As it shown at Figure 5 the production of steel in Korea fell significantly between the end of 2008 and the beginning of 2009, the output elasticity for large firms at that period also fell considerably from about 0.6 to 0.2. After that, steel production in Korea increased substantially from 3155 thousand tons in February 2009 to 6087 thousand tons in October 2011. As a result, we observe an increase of output elasticity of large firms between 2009 and 2013.

〈Figure 4〉 Output elasticities of electricity demand for large firms and SMEs in steel industry

〈Figure 5〉 Total Production of Crude Steel in Korea

(Source: www.worldsteel.org)

V. Conclusion and Policy Implications

1. Conclusion

This paper estimates electricity demands for energy-intensive steel industry for SMEs and large size firms in Korea, employing monthly data from January 2005 to December 2017. To our best knowledge, this study is the first attempt to derive electricity demands by different firm sizes for the energy-intensive steel industry in South Korea. Moreover, we estimate price and output elasticities of electricity demands in large firms and SMEs by using the Kalman filter approach that allows for time-varying elasticities.

The estimation results show that price and output elasticities of electricity demand in the steel industry are varying over time. However, after recovering from financial crisis in 2008, price and output elasticities of electricity demand were relatively stable and below one in absolute value. Moreover, we found that price and output elasticities for large firms have higher variations than SMEs. By comparing the estimation results for different firm sizes, we found that large firms in the steel industry have generally higher price elasticity than the SMEs due to the higher flexibility of large firms for input substitution, but SMEs have generally higher output elasticity than the large firms, probably because of cost advantage of large-scale firms in association with economies of scale.

2. Policy Implications

Steel industry represents one of the most energy intensive sectors in Korea, so it is important how to mitigate carbon emissions in this sector in accordance with nationally determined contribution (NDC) for reduction of greenhouse gases emissions (GHGs). Besides, Korean government should submit a long term low greenhouse gas emission development strategies by the end of 2020 to the United Nations. According to the 2050 low carbon society vision forum, we need to mitigate GHGs emission between 40% and 75% by 2050 relative to 2017 GHGs emission level. Therefore, it is inevitable to increase industrial electricity prices to reduce electricity demands of energy intensive sectors.

Although this paper used the data for steel industry only, the policy implications that it provides could be applied to the other electricity-incentive industries. Based on the estimation results, policymakers have two choices in reducing industrial electricity demands: one is to introduce a carbon tariff on the sales of the energy-intensive industries. Such policy would increase sales price of the energy-intensive commodities and would lead to reduction of output demand in those sectors. However, for the steel industry the output elasticity of large firms was lower than for the SMEs, so the carbon tariff will affect the electricity demand of the SMEs more than that of the large firms. Thus, government should consider how to improve flexibility of the SMEs in response to reduction of electricity input for production.

The second option is to increase the industrial electricity price to directly reduce electricity demands by the energy intensive sectors, such as steel industry. Although Korea has implemented the tradable permit system for carbon emissions from 2015, the financial burden of KEPCO due to the implementation of the permit system has not been reflected in the electricity bill so far. Thus, the final electricity consumers such as energy intensive industries do not have incentives to reduce their electricity consumption. If the electricity bill reflects financial burden of the permit system, energy intensive companies would reduce their electricity consumption significantly. As the estimated price elasticity of electricity demand in the steel industry for the large firms is higher than the SMEs, electricity demand of large firms will decrease more than the SMEs.

At last, both two approaches (increase of output price or electricity tariff) will lead to considerable burden to the large as well as SMEs because electricity is one of the necessary inputs in the steel industry. Moreover, decrease of output in the steel industry can affect the other relevant sectors, and therefore, government should account how to minimize potential impacts on energy-intensive industries by considering supporting polices on transition to more efficient and green energy systems.

[References]

Amusa, H., K. Amusa, and R. Mabugu, "Aggregate demand for electricity in South Africa: an analysis using the bounds testing approach to cointegration," *Energy Policy*, Vol. 37, No. 10, 2009, pp. 4167~4175.

Arisoy, I. and I. Ozturk, "Estimating industrial and residential electricity demand in Turkey: a time varying parameter approach," *Energy 66*, 2014, pp. 959~964.

Burke, P. and A. Abayasekara, "The Price Elasticity of Electricity Demand in the United States: A Three-Dimensional Analysis," *SSRN Electronic Journal*, 2017.

Chang, B., S. J. Kang, and T. Y. Jung, "Price and Output Elasticities of Energy Demand for Industrial Sectors in OECD Countries," *Sustainability*, Vol. 11, No. 6, 2019, 1786p.

Chang, Y., C. S. Kim, J. I. Miller, J. Y. Park, and S. Park, "Time-varying Long-run Income and Output Elasticities of Electricity Demand with an Application to Korea," *Energy Economics*, Vol. 46, 2014, pp. 334~347.

Cialani, C. and R. Mortazavi, "Household and industrial electricity demand in Europe," *Energy Policy*, Vol. 122, 2018, pp. 592~600.

Csereklyei, Z., "Price and income elasticities of residential and industrial electricity demand in the European Union," *Energy Policy*, Vol. 137, 2020, 111079p.

Faisal, J. and A. Eatzaz, "Income and price elasticities of electricity demand: Aggregate and sector-wise analyses," *Energy Policy, Elsevier*, Vol. 39, No. 9, 2011, pp. 5519~5527.

Halicioglu, F., "Residential electricity demand dynamics in Turkey," *Energy Economics*, Vol. 29, 2007, pp. 199~210. Homepage of Ministry of SMEs and Stardups, accessed at 31th of May, 2019. https://www.mss.go.kr/site/smba/01/10106060000002016101111.jsp

Hamilton, J. D., *Time Series Analysis* (1st ed.). Princeton University Press, 1994.

Hansen, B. E., "Tests for parameter instability in regressions with I(1) processes," *Journal of Business and Economic Statistics*, Vol. 10, No. 3, 1992, pp. 321~335.

Inglesi-Lotz, R. and J.N. Blignaut, "Estimating the price elasticity of demand for electricity by sector in South Africa," *South African Journal of Economic and Management Sciences*, Vol. 14, No. 4, 2011, pp. 449~465.

Ishaque, H., "Revisiting income and price elasticities of electricity demand in Pakistan," *Economic Research-Ekonomska Istraživanja*, Vol. 31, No. 1, 2018, pp. 1137~1151.

Koopman, S. J., N. Shephard, and J. A. Doornik, "Statistical Algorithms for Models in State Space using SsfPack 2.2," *Econometrics Journal*, Vol. 2, No. 1, 1999, pp. 107~160.

Morisson, G. W. and D. H. Pike, "Kalman filter applied to statistical forecasting," *Management Science*, Vol. 23, No. 7, 1977, pp. 768~774.

Na, I. G. and J. H. Seo, "Elasticities in Electricity Demand for Industrial Sector," *Environmental and Resource Economics Review*, Vol. 9, Issue 2, 2000, pp. 333~347.

OECD, 2000, Korea - Regulatory Reform in Electricity. Available at: http://www.oecd.org/korea/2497412.pdf

Otsuka, A., "Demand for industrial and commercial electricity: evidence from Japan," *Journal of Economic Structures*, Vo. 4, No. 1, 2015, pp. 1~11.

Paul, A., E. Myers, and K. Palmer, *A partial adjustment model of U.S. electricity demand by region, season, and sector*, Resource for the Future Discussion Paper No. 08-50, 2009.

Thamae, R. I., L. Z. Thamae, and Th. M. Thamae, "Dynamics Of Electricity Demand In Lesotho: A Kalman Filter Approach," *Studies in Business and Economics, Lucian Blaga University of Sibiu, Faculty of Economic Sciences*, Vol. 10, No. 1, 2015, pp. 130~139, April.

Wakashiro, Y., “Estimating price elasticity of demand for electricity: The case of Japanese manufacturing industry,” *International Journal of Economic Policy Studies*, Vol. 13, No. 1, 2019, pp. 173~191.

Wang, N. and G. Mogi, “Industrial and residential electricity demand dynamics in Japan: How did price and income elasticities evolve from 1989 to 2014?” *Energy Policy*, Vol. 106, 2017, pp. 233~243.

Ziramba, E., “The demand for residential electricity in South Africa,” *Energy Policy*, Vol. 36, 2008, pp. 3460~3466.