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Electricity Consumption and Spillover Effects—A Dynamic Panel Data Approach

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The paper intends to analyze economic factors that influence electricity consumption in the OECD economies. A special interest in this context is given to spillover effects of trade on electricity consumption. For this purpose, a model is constructed that using a dynamic panel study approach. The model is estimated in a GMM framework in which a dynamic procedure is conducted along the balanced growth path for electricity consumption in each economy. In advance, the long run dynamic behavior of prices, GDP, and trade induced spillover variables is determined. In a further step, the short run dynamic mechanism is pursued by estimating the partial adjustment dynamic coefficient on the target level of electricity consumption. The analysis is conducted for industrial, as well as residential electricity consumption. Alternatively, the same procedure is estimated by the application of a fixed period model. The model provides a benchmark tool for electricity policy decisions and for electricity consumption projections.

Keywords: energy economics, spillover effects, electricity consumption, dynamic panel studies, partial adjustment

Introduction

The deregulation and liberalization in the energy markets in a wide range of countries in the last twenty years, such as in the USA and in Europe called forth new challenges for energy companies, distributors and consumers. The price building process follows a competitive market process in contrast to the monopolistic price setting of a public regulator. Deregulated prices are indicating a new basis for cost structures: Supply and demand curves of market participants determine the price equilibrium. Consequently, market participants allocate their investment or consumption decisions according to the new market equilibrium which proclaims new risk management and optimization tools. Further, global acting energy sales companies are getting involved in the previously non-contestable national energy markets inducing more market pressure. From the perspective of an energy company, new methods for risk management of the above described risk became necessary. In this context, the knowledge of energy market dynamics enables new market actors to profound their management decision on a robust basis.

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An important strand of the energy market related literature pursues the relationship of electricity consumption and economic growth. In this context, elasticities that describe the consumption behavior in different countries are investigated. A pioneering research is employed by Nordhaus (1975). He uses a pooled autoregressive distributed lag (ARDL) model to examine the relationship of electricity consumption and economic growth in the largest OECD countries. The estimation includes income and price elasticities for industrial and residential electricity demand observing the short-term, as well as the long-term. He finds lower short-term parameters. In all elasticity classifications except for short-term prices, residential elasticities are higher than the industrial counterparts. Industrial elasticities are below unity, indicating inelastic dynamics. The same scheme is valid for the residential sector, except for long term income elasticity. Liu (2004) finds results that are consistent with the previous research. In the industrial sector, income elasticity is about unity. In the residential sector, the demand is more elastic for prices.

Haas and Schipper (1998), Lanzi and Roson (2007) and Duerick (2009) find that income elasticities are higher than price elasticities in the residential sector. Lanzi and Roson (2007) model a fixed effect panel study including weather, price and income electricity, gas and oil products. They find long-run price and income elasticities around unity with expected sign.

Contradicting results is given by Duerick (2009). He finds larger negative short-term income elasticity for electricity demand that is significant for a 10% level. Long-term elasticities in sign and magnitude however, are in theoretical accordance with previous studies. Concerning the industrial sector, Adeyemi and Hunt (2007) estimated long-run income and price elasticity about 0.8 and -0.3, respectively. Ciarreta and Zarraga (2010) are conducting a GMM estimated panel cointegration approach. Their estimated results are comparable to the previous studies, and income as well as price elasticity is low with the predicted sign.

Other studies with similar methodology are focusing on a single country case, when analyzing electricity demand elasticities. All studies exhibit a higher long-run elasticity magnitude than short-run elasticities. However, Dubin and Mc Fadden (1984) and Holtedahl and Joutz (2004) supply some offensive results, such that, short-run price elasticities are larger than the long-run counterparts.

A wide range of studies observe a long-term income elasticity above unity, among them following authors can be mentioned, Holtedahl and Joutz (2004), Rapanos and Polemis (2006), Zachariadis and Pashaourtidou (2006). Studies indicating inelastic income behavior below unity are employed by authors such as Dubin and McFadden (1984), Halicioglu (2007), Dergiades and Tsoulfidis (2008), Narayan and Smyth (2005). All the cointegration analyses or ECM approaches yield income elasticity values above unity in the case of residential electricity demand and indicate the same pattern for short-run and long-run price elasticities.

Other methodologies for single country studies are applied as follows: Nakajima and Hamori (2010) uses a dynamic OLS approach, Sa'ad (2009) is applying a structural time series approach, Kamerschen and Porter (2004) are utilizing partial-adjustment approach and simultaneous equations approach, Dubin and McFadden (1984) conduct an instrumental variable approach by employing OLS.

In this research paper, we intend to analyze the role of trade spillover effects on electricity demand in the OECD countries. For this purpose, a model that uses a dynamic panel study approach is constructed. The model is estimated in a GMM framework in which a dynamic procedure is conducted along the balanced growth path for electricity consumption in each economy. In advance, the long run dynamics of prices, GDP, and trade induced spillover variables are determined. In a further step, the short run dynamic mechanism is pursued by estimating the partial adjustment dynamic coefficient on the target level of electricity consumption. The analysis is conducted for industrial, as well as residential electricity consumption. The remainder of the paper is organized as follows. Section 2 deals with methodological issues used in the econometric models. Section 3 presents the particular model specifications. Section 4 discusses the results. Section 5 gives a brief summary and concludes.

Econometric Methodology

Data and Spillover Variable Creation

The data sample spans the period from 2000 to 2006 and involves all OECD countries (updated for 2009). The data for industrial and residential electricity consumption and electricity prices are taken from the International Energy Agency's (IEA) electricity information and energy prices and taxes reports for each period. GDP values are expressed in constant 2,000 US$ and are obtained from World Bank's World Development Indicators (WDI) database.

The trade data surrounds imports and exports by commodity in value (2,000 US$) between each country and remaining other OECD countries. Two thousand five hundred and eighty two different products are classified according to the Standard International Trade Classification system (SITC) (revision 2). SITC does not contain the most recent products in markets but provides the most consistent time series over a longer period.

The industry specific spillover variable is created as follows:

$$X_{2t} = \sum_i \sum_j \frac{(x_{ij} \bullet GDP_j)}{GDP} \tag{1}$$

where, *i* denotes the countries and *j* each specific industry. The industry specified trade value of a country is weighted by the GDP of the partner country for the recent period. This procedure is repeated for all OECD countries successively. The same index building procedure is followed for imports of each country.

$$M_{2t} = \sum_i \sum_j \frac{(m_{ij} \bullet GDP_j)}{GDP} \tag{2}$$

Dynamic Panel Data Analysis

Consider an example with standard log linear autoregressive specification of the described electricity model:

$$\ln E^*_t = \alpha_0 + \mu_{t-1} \sum E_t + \alpha_1 \sum \ln P_t + \alpha_2 \sum \ln y_t + \alpha_3 \sum \ln X_{2t} + \varepsilon_t \tag{3}$$

Elasticities and specific regression error terms can be correlated. In this case, the usage of an OLS-estimator will generate inconsistent results due to hetero-skedasticity or serial correlation in the error terms. First differences are taken in order to eliminate unobserved firm-specific effects and use lagged instruments to correct for simultaneity. However, unsatisfactory estimation can be resulting. This problem of weak estimation is related to weak correlation between the explanatory variables and the lagged levels of these variables (assuming that explanatory variables are persistent over time). This fact induces weak instruments in the context of the first-differenced GMM estimator (Arellano & Bond, 1991). A solution is provided by including more moment conditions under stationarity restrictions on the initial condition process.

Blundell and Bond (1998) propose to use of a system estimator that exploits moments through combining a level equation, which is using lagged first differences as instruments. Their proposed framework uses lagged first-differenced endogenous variables as instruments for equations at levels in addition to the usual lagged level variables. Thus, temporal and cross sectional variation in the data can be exploited and unobserved cross-country heterogeneity can be controlled.

GMM estimation. The Generalized Moments Methods (GMM) is a semi-parametrically efficient estimation method. The GMM methodology starts from a set of overidentified population of moment conditions and seeks to find an estimator that minimizes a quadratic norm of the sample moment vector. The resulting estimation has been shown to be consistent and asymptotically normal under many conditions.

Main underlying GMM assumptions to be mentioned are that variations of initial conditions from their long-run values should be uncorrelated with their long run values. Furthermore, current or lagged changes in explanatory variables should not be correlated with individual effects.

Under these considerations the first differences of equation (3) are taken, which yields:

$$\Delta \ln E_t = \beta\Delta_1 \ln P_t + \beta_2\Delta \ln y_t + \beta_3\Delta \ln X_{2t} + \gamma\Delta \ln E_{t-1} + \Delta u_t \tag{4}$$

The choice of consistent instruments set the condition of correlation with $\Delta \ln E_{t-1}$, however not with the error terms Δu_t. Appropriate candidates are lagged values of the endogenous regressors (Arellano & Bond, 1991) that satisfy the moment conditions $E\{\Delta x_{it}\Delta u_{it}\} = 0$ for each *t*.

The models' instrument matrix can be described as (Verbeek, 2004, p. 365):

$$Z_i = \begin{pmatrix} [y_{i0}, \Delta \ln P_{i2}, \Delta \ln y_{i2}, \Delta \ln X_{2i2}] & 0 & \cdots & 0 \\ 0 & [y_{i0,} y_{i1}, \Delta \ln P_{i3}, \Delta \ln y_{i3}, \Delta \ln X_{2i3}] & & 0 \\ . & & & \\ . & & \cdots & 0 \\ . & & & \\ 0 & \cdots & 0 & [y_{i0,}, ..., y_{iT-2}, \Delta \ln P_{iT}, \Delta \ln y_{iT}, \Delta \ln X_{2iT}] \end{pmatrix}$$

The most efficient estimator is determined by the optimal weighting matrix.

$$W_n^{pot} = \left(\frac{1}{N} \sum_{i=!}^{N} Z_i^{'} \Delta\hat{\varepsilon}_i \Delta\hat{\varepsilon}^{'}{}_i Z_i \right)^{-1} \tag{5}$$

Under the assumption that autocorrelation is absent the validity of the moments conditions is guaranteed. The optimal weighting matrix can be calculated by imposing the following restrictions on the error terms:

$$E\{\Delta\varepsilon_i \Delta\varepsilon_i^{'}\} = \sigma_\varepsilon^2 G = \sigma_\varepsilon^2 \begin{pmatrix} 2 & -1 & 0 & \cdots \\ -1 & 2 & . & 0 \\ 0 & . & . & -1 \\ . & 0 & -1 & 2 \end{pmatrix} \tag{6}$$

The consistency of instruments depends on their relevance and their validity. The relevance is determined by the correlation with endogenous variables, whereas the validity of instruments depends on the orthogonality to the error terms. In order to apply the GMM estimator it is essential to test the absence of serial correlation in the differenced residuals. This test is known as the Arellano-Bond m2 test for second order serial correlation of differenced residuals. We implement this test as conventional AR(2) regression on the differenced residuals, which asymptotically provides the same results:

$$u_t = \rho u_{t-1} + \rho^2 u_{t-2} + \varepsilon_t \tag{7}$$

The correct specification is tested by the Sargan test of over-identifying restrictions. The obtained statistic value is named as the *J*-statistic, which asymptotically follows the chi-square distribution. Under the null hypothesis of validity of instruments, we reject this hypothesis if the obtained *p*-value is below the chosen significance level.

Empirical Specification

Due to frequently missing values in almost all trade data and due to the flexibility of a GMM framework, the application of unbalanced panel data analysis has been preferred. The partial adjustment model describes the desired level of the electricity consumption $E^{*}{}_{t}$:

$$\ln E^{*}{}_{t} = \alpha_0 + \alpha_1 \ln P_t + \alpha_2 \ln y_t + \alpha_3 \ln X_{2t} \quad (8)$$

$$\ln E_t^{*} = \alpha_0 + \alpha_1 \ln P_t + \alpha_2 \ln y_t + \alpha_3 \ln M_{2t} \quad (9)$$

Equation (8) contains the export induced trade spillover variable and equation (9) the import induced one. These equations represent the desired demand function for electricity. The desired demand function is supposed to behave in a similar way to the current demand.

The short run adjustment process of electricity consumption is generated through a partial adjustment mechanism (PAM) model. The adjustment equation is given as follows:

$$\ln E_t - \ln E_{t-1} = \lambda(\ln E_t^{*} - \ln E_{t-1}) \quad (10)$$

where, λ describes the short-run elasticity that can be regarded as the speed of adjustment for reaching the desired level of consumption. The actual change during one time period is described by $\ln E_t - \ln E_{t-1}$, and $(\ln E_t^{*} - \ln E_{t-1})$ reflects the desired change. The long-run adjustment mechanism can be computed by setting equal the desired demand and the actual demand. Therefore, equation (10) is rearranged as:

$$\frac{\ln E_t - \ln E_{t-1}}{\lambda} + \ln E_{t-1} = \ln E_t^{*}$$

Substituting equation (8) or equation (9) for $\ln E_t^{*}$ yields:

$$\frac{\ln E_t - \ln E_{t-1}}{\lambda} + \ln E_{t-1} = \ln E^{*}{}_{t} = \alpha_0 + \alpha_1 \ln P_t + \alpha_2 \ln y_t + \alpha_3 \ln X_{2t} + \varepsilon_t$$

Rearranging gives:

$$\ln E_t - \ln E_{t-1} + \lambda \ln E_{t-1} = \lambda\alpha_0 + \lambda\alpha_1 \ln P_t + \lambda\alpha_2 \ln y_t + \lambda\alpha_3 \ln X_{2t} + \lambda\varepsilon_t$$

$$\ln E_t - (1-\lambda) \ln E_{t-1} = \lambda\alpha_0 + \lambda\alpha_1 \ln P_t + \lambda\alpha_2 \ln y_t + \lambda\alpha_3 \ln X_{2t} + \lambda\varepsilon_t$$

$$\ln E_t = \lambda\alpha_0 + \lambda\alpha_1 \ln P_t + \lambda\alpha_2 \ln y_t + \lambda\alpha_3 \ln X_{2t} + (1-\lambda)\ln E_{t-1} + \lambda\varepsilon_t \quad (11)$$

The new parameters and the new error term are obtained in the following way (Liu, 2004, p. 5):

$$\beta_0 = \lambda\alpha_0,\ \beta_1 = \lambda\alpha_1,\ \beta_2 = \lambda\alpha_2,\ \beta_3 = \lambda\alpha_3,\ \gamma = 1-\lambda \text{ and } u_t = \lambda\varepsilon_t$$

Substituting the new parameters into equation (11) gives:

$$\ln E_t = \beta_0 + \beta_1 \ln P_t + \beta_2 \ln y_t + \beta_3 \ln X_{2t} + \gamma \ln E_{t-1} + u_t \quad (12)$$

Now, the short-run and interim effects of a change in the real price can be easily obtained by taking the derivations of each variable for the period of interest (Liu, 2004, p. 6):

Current period: $\frac{\partial y_t}{\partial P_t} = \beta_1$; two periods later: $\frac{\partial y_{t+2}}{\partial P_t} = \gamma^2 \beta_1$.

Finally, the geometric lag order structure gives following expression for the long-run elasticities:

$$\beta_1 + \gamma\beta_1 + \gamma^2\beta_1 = \frac{\beta_1}{(1-\gamma)} \quad (13)$$

Empirical Results

The estimation results of the models together with standard statistics are reported in Table 1 for import and in Table 2 for export, respectively. In the illustration of the results, we focus on the results of Model I which prevails an overall higher significance in the relevant statistics, and seems to be more consistent with the previous energy literature.

Table 1
Estimation Results Including Import Spillover Index

Variable	Industrial		Residential	
	Model Ⅰ	Model Ⅱ dummy	Model Ⅰ	Model Ⅱ dummy
Consumption (-1)	0.299 (3.64)	0.033 (0.199)	0.011 (15.77)	0.035 (2.17)
Price	-0.025794 (-7.38)	-0.016 (0.058)	-0.0013 (-0.087)	-0.196 (-3.66)
GDP	0.29 (4.04)	2.17 (0.69)	0.68 (13.39)	0.66 (4.69)
Import	0.018 (6.057)	0.096 (0.016)	0.0067 (1.43)	0.0022 (0.22)
Period dummy 2002	-	-0.096 (0.021)	-	0.017 (1.34)
Period dummy 2003	-	-0.14 (0.047)	-	0.061 (2.92)
Period dummy 2004	-	-0.21 (0.068)	-	0.081 (3.063)
Period dummy 2005	-	-0.29 (0.099)	-	0.089 (3.11)
Period dummy 2006	-	-0.32 (0.12)	-	0.10 (3.30)
S. E. of regression	0.051	0.066	0.051	0.052
SSR	0.21	0.34	0.34	0.33
J-statistic	12.84	14.79	21.17	14.61
Instrument rank	18	19	18	27

Note. GMM estimation with first differenced cross-sections and fixed periods.

In a general evaluation, it can be observed that the signs of coefficients are consistent with previous research on electricity or energy demand. In the case of residential electricity demand in Table 1 and in Table 2, price has a slight negative coefficient with weak significance. The coefficient for GDP is illustrated as positive with high significance. The residential import and export coefficients are small and exhibit only weak significance. The coefficients for the industrial import estimation in Table 1 are all significant with expected signs. The counterparts in Table 2 follow the same pattern, except for the consumption parameter which indicates only weak significance.

The computed elasticities for the estimated models are presented in Table 3 and Table 4. Initially, it should be maintained that in all cases elasticities in the long-run are larger than in the short-run. Concerning the industrial sector, import elasticity (see Table 3) has a slightly higher positive effect on electricity consumption than industrial export (see Table 4). Residential income elasticity is more sensitive than industrial income elasticity (see Table 3 and Table 4). Price elasticities are negative and exceptionally low for all residential specifications, and industrial price elasticities are only somewhat higher about -0.05 percent, but still negative. For all sectorial classifications, income elasticity are positive and higher than price elasticity in magnitude, but still below unity, indicating an inelastic demand function. The adjustment parameter is about unity for residential import and export specifications, about 0.70 for industrial import and 0.86 for industrial export, respectively. In this context, unity indicates an adjustment process of the parameters within one single period which means a very rapid speed of adjustment to the long-run equilibrium.

Table 2

Estimation Results Including Export Spillover Index

Variable	Industrial		Residential	
	Model Ⅰ	Model Ⅱ dummy	Model Ⅰ	Model Ⅱ dummy
Consumption (-1)	0.14 (1.36)	0.29 (4.0798)	0.011 (15.96)	0.019 (1.49)
Price	-0.046 (-3.38)	-0.0083 (-0.24)	-0.0077 (-0.49)	-0.22 (-4.13)
GDP	0.47 (6.42)	1.074 (9.18)	0.69 (14.42)	0.66 (4.93)
Export	0.011 (3.298)	0.021 (-2.61)	0.0069 (1.58)	-0.0074 (-0.89)
Period dummy 2002	-	-0.031 (0.021)	-	0.031 (2.58)
Period dummy 2003	-	-0.046 (-2.34)	-	0.083 (3.9797)
Period dummy 2004	-	-0.078 (-2.95)	-	0.11 (3.77)
Period dummy 2005	-	-0.10 (-3.015)	-	0.12 (3.49)
Period dummy 2006	-	-0.13 (-3.36)	-	0.13 (3.46)
S. E. of regression	0.050	0.053	0.0514	0.052
SSR	0.29	0.301	0.335	0.328
J-statistic	14.77	22.42	21.49	16.0014
Instrument rank	18	25	18	27

Note. GMM estimation with first differenced cross-sections and fixed periods.

Table 3

Elasticities Including Import Spillover Index for Model I

	Residential		Industrial	
	Short run elasticity	Long run elasticity	Short run elasticity	Long run elasticity
Price	-0.0013 (insignificant)	-0.0013	-0.025	-0.036
Income	0.67	0.68	0.29	0.42
Import	0.0067	0.0067	0.017	0.025
γ	0.98		0.70	

Note. Model I, GMM estimation with first differenced cross-sections.

Table 4

Elasticities Including Export Spillover Index for Model I

	Residential		Industrial	
	Short run elasticity	Long run elasticity	Short run elasticity	Long run elasticity
Price	-0.0076 (sign.at 10% level)	-0.0077	-0.045566	-0.053
Income	0.69	0.70	0.470165	0.55
Export	0.0069	0.00695	0.011	0.013
γ	0.99		0.86	

Note. Model I, GMM estimation with first differenced cross-sections.

The examined results are consistent with findings in different studies: industrial income elasticity is comparable to Nordhaus (1975), industrial price elasticity is similar to Liu (2004) and residential income elasticity supports findings in Kamerschen and Porter (2004). Similarly to Haas and Schipper (1998), Lanzi and Roson (2007) and Duerick (2009), our research results suggest that income elasticities are higher than price elasticities in the residential sector.

Conclusion

This study examines electricity consumption in industrial and residential sector for 30 OECD countries from 2000 to 2006. The methodology we used in the study consists of a GMM estimated dynamic panel data approach applied on unbalanced data. In a further step, a partial adjustment model is pursued to determine the short-run elasticities. In addition to previous studies on energy demand, we contribute findings for an industry specified trade induced spillover variable to the discussion on electricity demand elasticities. The findings of the study are in general consistent in sign and magnitude with the results in the energy demand literature; except for price elasticity in the residential sector which is exceptionally low.

The trade spillover variable elasticity exhibits a slight positive effect concerning imports, as well as exports. The positive import elasticity of electricity demand indicates necessities for intermediate products during the industrial production process. An increase in exports induces enhanced further production. The trade spillover effects in the residential sector on the other hand, are quite low and partly insignificant.

For sure, taking additional data on electricity market would improve the efficiency of the model, when considering that we have supply and demand conditions in the electricity markets evolving over time. In addition, some different methodologies like simultaneous equations model (SEM) can be applied.

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