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Natural gas demand in the European household sector

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Abstract

This paper analyzes the residential natural gas demand per capita in 12 European countries using a dynamic loglinear demand model, which allows for country-specific elasticity estimates in the short- and long-run. The explanatory variables included lagged demand per capita, heating degree days index, real prices of natural gas, light fuel oil, electricity, and real private income per capita. The short-run own-price and income elasticity tend to be very inelastic, but with greater long-run responsiveness. By splitting the data set in two time periods, an increase in the own-price elasticities were detected for the European residential natural gas demand market as a whole. We have provided support for employing a heterogeneous estimator such as the shrinkage estimator. But the empirical results also motivates a further scrutiny of its properties.

Keywords: residential, elasticities, shrinkage estimation

1 Introduction

Despite the large changes in the European natural gas marked due to deregulation and development of the natural gas grid, there have not been any econometric studies of residential natural gas demand for the last years. An up to date study of the European residential natural gas demand should be useful. The modelling of natural gas demand in national markets is important for a number of reasons. These models give researchers and other market observers information about the structure and composition of demand. Furthermore, the results of these models inform users about the magnitude of future demand and its sensitivity to key determinants such as energy prices and income. A central part of our study is an econometric analysis of residential natural gas demand utilizing a panel of 12 European countries.

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The development of total residential energy demand (split into groups of energy carriers) in the European Union (EU) over the period from 1960 to 2002 is presented in figure 1. The total residential consumption of natural gas, electricity and petroleum products have grown over the period, while the consumption of coal has been reduced. From 1978 to 2002 the annual average change in natural gas, electricity, petroleum products and coal demand were 133.5%, 74.3%, −35.2% and −85.2%, respectively.

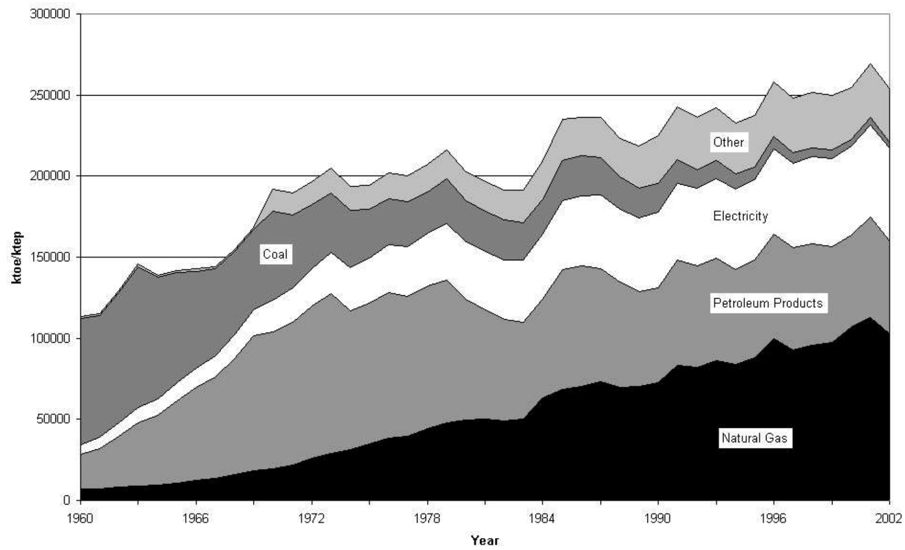

Figure 1: Total residential energy consumption (excluding fuels used for transport) in the EU for the period 1960-2002. *Source: The IEA.*

There is some studies of European residential natural gas demand done previous to the period of deregulation. Pindyck (1979) studied the structure of residential demand for different fuels (including natural gas) using pooled panel data for 9 OECD countries over the period 1955 - 1972. Griffin (1979) estimated a pooled and a country-specific dynamic model for 18 OECD countries over the period 1955 - 1972. Estrada and Fugleberg (1989) analyzed the own-price and cross-price elasticities of residential natural gas demand in France and West Germany using a translog function over the period 1960 - 1983.

However, there are a number of surveys in the literature dedicated energy demand modelling in general (Bohi, 1981; Bohi and Zimmerman, 1984; Al-Sahkawi, 1989; Atkinson and Manning, 1995; Madlener, 1996) and a less is known about natural gas and little after deregulation. However, there have been some studies of residential natural gas demand on US state level data (e.g. Maddala et al. (1997)). Energy elasticities have been estimated by various methods and model approximations, and have tended to differ substantially. To date, most econometric studies of energy demand report that the short-run price and income elasticities tend to be very inelastic, but with much greater long-run responsiveness, and such studies has mainly focused on residential electricity demand.

Our modelling of aggregate residential natural gas demand built on the work of Houthakker and Taylor (1970) and is a straightforward formulation based on standard income and price variables. Heating degree days index are included to account for climate effects, for instance, cold temperatures drive increased natural gas consumption for space heating. The variables were modelled by a loglinear geometric distributed-lag model as formulated by Koyck (1954) and others. The dynamic structure capture the evolution of energy use over time, and makes it possible separate the short- and long-run effects on demand. This functional form has found general acceptance in residential energy demand studies and will not be discussed here.

Potential structural differences between the countries and certain features of the panel data make it desirable to obtain country-specific estimates. However, such an approach presents some challenges, since energy demand data is usually available as annual country or state data, with a limited number of observations of each time series. Few degrees of freedom is a recurrent problem in demand analysis and is closely related to the debate of whether to use homogeneous or heterogeneous model parameters over the cross-section (Maddala, 1991; Maddala et al., 1997; Pesaran and Smith, 1995; Baltagi and Griffin, 1997; Baltagi et al., 2000). Pooling the data retain more degrees of freedom, but lead to a loss of information by imposing homogeneity across sections.

We employ competing econometric estimators to estimate the elasticities of natural gas demand. These estimators vary in their degree of parameter heterogeneity, with pooled estimators at the one extreme and individual country estimators at the other. Intermediate estimators in terms of heterogeneity are standard panel data estimators (i.e. fixed and random effects estimators), and the more novel iterative Maddala et al. (1997) shrinkage estimator. The shrinkage estimator enables us to pursue an estimation strategy that discriminates between countries with structural differences in natural gas demand. The estimator "shrinks" country-specific parameters of the individual countries toward a common probability distribution, but where the individual country estimates remain heterogeneous after shrinkage. The iterative shrinkage estimator has become popular in heterogeneous estimation on panel data models since it appear to provide more plausible elasticity estimates (Baltagi et al., 2003; Baltagi and Griffin, 1997; Maddala et al., 1997).

2 Model specification and estimators

We posit that residential natural gas energy consumption per capita can be approximated by an autoregressive loglinear model of the form

$$\begin{aligned} y_{t,i}^{NG} &= \beta_i^0 + \beta_i^y y_{t-1,i}^{NG} + \beta_i^{NG} p_{t,i}^{NG} + \beta_i^{LFO} p_{t,i}^{LFO} \\ &\quad + \beta_i^{EL} p_{t,i}^{EL} + \beta_i^m m_{t,i} + \beta_i^z z_{t,i} + \varepsilon_{t,i}, \end{aligned} \tag{1}$$

for all $t = 1, 2, \ldots, T_i$ (year subscript) and $i = 1, 2, \ldots, 12$ (country subscript), respectively, where $y_{t,i}^{NG}$ = ln(residential natural gas consumption per capita), $p_{t,i}^{NG}$ = ln(real residential natural gas price), $p_{t,i}^{LFO}$ = ln(real residential light fuel oil price), $p_{t,i}^{EL}$ = ln(real residential electrical price), $m_{t,i}$ = ln(real personal income per capita), $z_{t,i}$ = ln(heating degree days index), and $\varepsilon_{t,i} \sim \mathscr{N}(0, \psi_i^2)$ is some error term ($\psi_i^2 > 0$). The annual residential prices and quantities were obtained from IEA (2004) and the private income and consumer price index from IMF (2003). Annual weather data (heating degree days index) by country were taken from Klein Tank et al. (2002). The prices (total end-use prices inclusive taxes) and private consumption were deflated using the consumer price index (basis year = 1999) from the IFS, and provided in Euro per toe tonnes of oil equivalent (€/toe) and thousand Euro per capita (k€/cap), respectively. The natural gas demand was provided in tonnes of oil equivalent per thousands of capita (toe/kcap). The heating degree days index is unit-free.

Since equation (1) neglects the demand relations for other goods, one will generally neglect restrictions between all or some of the parameters in the demand structure. To relax this assumption, demand equations analogous to equation (1) for light fuel oil and electricity demand were included and connected in a seemingly unrelated regression (SUR) model.

3 Empirical results

This section presents residential natural gas own-price, cross-price and income elasticity estimates in the short- and long-run, using different estimators on a annual panel data from 12 European countries covering the period from 1978 to 2002.[2] Estimation of separate demand models for each country gives the greatest degree of flexibility, but earlier studies have demonstrated that such regression models often provide implausible estimates, for example, positive own-price elasticities (Atkinson and Manning, 1995). Here, seventeen different estimators are compared, ten on the pooled data set: ordinary least squares (OLS), Prais and Winsten (1954) generally least squares (GLS) estimator with a first-order autoregressive error term (GLS-AR1), fixed effects estimator (FE), fixed effects estimator with a first-order autoregressive error term (FE-AR1), random effects GLS estimator (RE), random effects GLS estimator with a first-order autoregressive error term (RE-AR1), Hildreth and Houck (1968) random-coefficients GLS estimator (RCM), two-stage least squares regression estimator with the first-lag of demand as instrumental variable (2SLS), fixed effects 2SLS estimator (2SLS-FE), and iterated Zellner (1962) seemingly unrelated regression estimator (SUR). The SUR model include demand relationships for electricity and light fuel oil specified analogous to equation (1).[3] Finally, there are

[2]The panel data is unbalanced due to missing data.

[3]Demand data for light fuel oil was not available. A summation of gas/diesel oil and heavy fuel oil were used as an proxy.

seven heterogeneous estimators: individual OLS, GLS-AR1, 2SLS and SUR on each country, and the iterative Maddala et al. (1997) shrinkage estimator using individual OLS, GLS-AR1 and 2SLS estimates as initial values.

One obvious basis for comparison among the different estimators is difference in the plausibility of the parameter estimates vis-a-vis the existing literature. Both a priori experience as well as earlier energy demand studies provide evidence as to a range of plausible price and income elasticities. Residential energy consumption is characterized by very limited technological substitution possibilities between different energy carriers in the short-run, after investments in heating infrastructure bas been undertaken. In the longer run it is costly to switch between energy carriers due to high investment costs in heating infrastructure. Thus, one should expect a priori low own-price and cross-price elasticities. We will see that this is confirmed by our empirical results.

Table 1 summarizes the parameter estimates from the natural gas demand model in equation (1) using different estimators. The country-specific parameter estimates from the heterogeneous estimators were included only by the maximum, average and minimum values of the parameters. Since equation (1) is a dynamic log-linear model, the coefficients correspond to the short-run elasticities. Overall, the explanatory power is provided primarily by the lagged consumption term, the heating degree days index and the contemporary natural gas price. The very high coefficients of the lagged dependent variable may be imply long lags in adjustments.

Table 2 contains the price and income elasticities of natural gas demand in the short- and long-run based on the parameter estimates in table 1. The t-statistics were obtained using the delta method and the elasticity estimates from the heterogeneous estimators were included by the maximum, average and minimum values of the elasticities. To save space, the heterogeneous country specific elasticity estimates were only included for the OLS, GLS-AR1, Shrinkage (OLS) and Shrinkage (GLS-AR1) estimators, see tables 3, 4, 5 and 6 in the appendix. In absolute terms, all the price and income elasticities were larger in the long-run than the short-run for both the homogeneous and heterogeneous estimators, which harmonize with the a priori expectations. The difference between short- and long-run estimates suggests that the residential consumers demanding natural gas have more possibilities to respond to price and income changes in the longer run.

3.1 Comparison of homogeneous and heterogeneous estimates

The income and price elasticity estimates vary quite a bit over the ten homogeneous estimation methods. For example, the long-run own-price elasticity range from -1.541 to 1.844 and the long-run income elasticity range from 1.649 to 2.251. The fixed effects type estimators stand out among these estimators, as only, the fixed effects estimators provide own-price natural gas elasticity estimates significantly different from zero at the 1% level with the a priori expected correct negative sign, and they may provide more sensible estimates of income elasticities than most other homogeneous estimators. For example, the homogeneous long-run own-price elasticities were in the range from -1.541 to -0.873 with country-specific fixed effects dummies and in the range from -0.318 to 1.844 without.

The heterogeneous estimators reveal the wide variability of individual country estimates. The country-specific elasticity estimates were found to have substantial variation across countries, and they had often implausible signs and values. For example, the country-specific OLS long-run own-price elasticity ranged from -3.171 to 1.179 and the long-run income elasticity ranged from -5.096 to 7.442. Such variation and plausibleness of the estimates are similar to what is found in other energy demand studies using individual country-specific estimators. However, such variation is particulary distressing when it is recognized that all the 12 countries are European OECD countries and should share considerable commonalities. In contrast, the shrinkage estimator provide a more narrow range of country-specific estimates and seems to perform better than the other heterogeneous estimators (to be discussed below).

The country-specific GLS-AR1 estimator accounts for the dynamic structure in the model and provided 31 of 96 elasticities significantly different from zero at a 5% level. To comparison, 27 of 96 elasticities were found significantly different from zero at a 5% level using the OLS estimator. The long-run GLS-AR1 own-price elasticities were in the range -3.225 to 0.787 and the long-run income elasticities were in the range -4.884 to 6.360. Overall, the GLS-AR1 estimator seems to have a better model fit than the country specific OLS, but both estimators provided elasticities with substantial variation across countries.

The gains from correcting for possible endogeneity in the lagged dependent variable was disappointing, as the 2SLS performed worse than the counterpart assuming all variables are exogenous. Only 22 of 96 the 2SLS elasticities were found significantly different from zero at a 5% level. We believe it is simply a matter of the poor information content of the instruments selected.

Including demand relationships for light fuel oil and electricity demand in a SUR model did not gain the country-specific natural gas demand parameter estimates. The country-specific SUR estimator provided only 23 of 96 natural gas demand elasticities significantly different from zero at a 5% level and the estimates were relatively unchanged relative to a single equation OLS estimation. A possible explanation for why SUR estimation did not perform better than a single equation OLS estimation, is that the demand equations for light fuel oil and electricity had very poor model fit.

As previously mentioned, the shrinkage estimator seems to perform better than the other heterogeneous estimators. The short- and long-run demand elasticities based on shrinkage parameter estimates generally have more plausible signs and values, and larger t-values, than competing estimators. The shrinkage provided long-run own-price elasticity estimates in the range from -0.757 to 0.765 for the shrinkage (OLS), from -0.507 to 0.403 for the shrinkage (2SLS), and from -0.743 to 0.236 for the shrinkage (GLS-AR1). The long-run income elasticity estimates were in the range from -0.363 to 7.703 for the shrinkage (OLS), from -0.366 to 7.029 for the shrinkage (2SLS), and from -0.317 to 6.111 for the shrinkage (GLS-AR1). Overall, the shrinkage based on the individual GLS-AR1 estimates seem to be superior to the shrinkage (OLS) and shrinkage

(2SLS).

Although the shrinkage estimator allows for slope coefficient heterogeneity, it imposes some additional structure on the coefficients compared to separate regressions on each country, which is the assumption of a common normal probability distribution, involving a common mean and covariance matrix of the parameters (Maddala et al., 1997). The present t-statistics of the shrinkage elasticities in tables 5 and 6 are computed using the delta method based on this covariance matrix. Notice that the number of significant elasticities is relatively high for the shrinkage estimators compared to the other heterogeneous estimators. For example, the shrinkage (GLS-AR1) provided 80 of 96 elasticities significantly different from zero at a 5% level. This relatively high number of significant elasticities is probably upward biased (Laird and Louis, 1987; Carlin and Gelfand, 1991).

3.2 A more detailed study of the elasticities

Finally, we compare the two types of estimators that performed best, the fixed effects estimators and the shrinkage estimators. Together, we believe that these two types of estimators provide an indication of what may be a plausible value range for natural gas demand elasticities. In most cases, they both performed well in terms of statistical significance.

When we examine the natural gas own-price elasticity estimates, we find that shrinkage based short- and long-run elasticities are generally smaller in absolute terms than the fixed effects. Shrinkage based short-run own-price elasticities are typically in the range -0.1 to 0, while fixed effects own-price elasticity estimates lie between -0.3 and -0.2. In the longer run shrinkage own-price elasticities typically lie between -0.6 and 0, while fixed effects own-price elasticities are in the range -1.5 to -0.9.

Considering previous studies of residential natural gas demand on European country data; Pindyck (1979) reported a long-run own-price elasticity for the pooled sample of -1.7 for 9 OECD countries using annual data over the period 1960 - 1974. Griffin (1979) estimated a pooled and a country-specific dynamic model for 18 OECD countries using annual data over the period 1955 - 1972. The pooled model provided a short-run elasticity of -0.95 and a long-run of -2.61. However, his country-specific results were mixed; from a very high -23.7 for Sweden to -1.67 for Netherlands. Our pooled long-run own-price elasticity estimates are lower in absolute term than the pooled estimates of Pindyck (1979) and Griffin (1979), but the differences may be caused by different period of analysis and grouping of countries.

The natural gas demand study of Maddala et al. (1997) on US state panel data over the period 1970 - 1990 provided long-run own-price elasticity estimates of -0.381 and income elasticity estimates of 0.104 for a fixed effects model. Their country-specific shrinkage estimates of the long-run own-price and income elasticities were in the range from -0.660 to 0.085 and in the range from -0.486 to 0.473. Our fixed effects estimates of the European consumers' long-run own-price elasticities were in the range from -1.541 to -0.873, while the long-run income elasticities were in in the range from 1.951 to 2.145. Our shrinkage (GLS-AR1) provided long-run own-price elasticity estimates in the range from -0.743 to 0.236 and long-run income elasticity in the range from -0.317 to 6.111. The differences suggest that European consumers' natural gas demand is more price and income elastic than for the consumers in the US.

Estrada and Fugleberg (1989) analyzed the own-price and cross-price elasticities of residential natural gas demand in France and West Germany using a translog function over the period 1960 - 1983, and argued that the absolute values of the elasticities are generally higher for West Germany than for France. They reported own-price elasticities in the range from -0.61 to -0.76 for France and from -0.75 to -0.82 for West Germany. Our shrinkage (GLS-AR1) estimator provided long-run own-price elasticity of -0.160 for France and of -0.274 for Germany, which support the study of Estrada and Fugleberg (1989) of a higher absolute value of the elasticity for Germany than for France, but at a more inelastic level. Unfortunately, the other heterogeneous estimators had difficulties to obtain reliable statements of the difference between France and Germany. For example, a Wald test at a 5% significance level did not suggest structural difference in the long-run own-price elasticity between France and Germany when using the OLS and GLS-AR1 estimator.

Considering income, the homogeneous fixed effects estimators all provided positive income elasticities, which typically lie between 0.3 and 0.7 in the short-run and between 1.9 and 2.1 in the long-run. The country-specific shrinkage (GLS-AR1) income elasticities typically lie between 0.5 and 1.2 in the short-run and between 1.3 and 6.1 in the long-run. On US state panel data, Maddala et al. (1997) provided long-run income elasticities of 0.104 using homogeneous fixed-effects and in the range from -0.486 to 0.473 using shrinkage. This may suggests that residential European consumers of natural gas is more income elastic than the consumers in the US, or that our income elasticities are upward biased. Since income per capita has been increasing over the period, the income elasticities may include effects of omitted increasing variables in our model, for instance, the increasing availability of natural gas through the natural gas grid.

The cross-price elasticities were typical very inelastic and indicated very low cross-price responsibleness to the energy carrier substitutes for natural gas demand. The fixed effects estimators provided positive light fuel oil cross-price elasticities, which were in the range from 0.088 to 0.118 in the short-run and from 0.330 to 0.577 in the long-run, while the electricity cross-price elasticities were approximately zero and not significant different from zero at a 5% level. The heterogeneous country-specific cross-price elasticities had typical mixed signs and values close to zero. Shrinkage provided long-run light fuel oil cross-price elasticities in the range from -0.132 to 0.159 and long-run electricity cross-price elasticities in the range from -1.430 to 0.226.

The low cross-price elasticities were priori expected, and mixed signs and values close to zero is also provided by earlier energy demand studies. For example, Maddala et al. (1997) provided shrinkage electricity cross-price elasticities in the range from -0.091 to 0.083 in the short-run and from -0.233 to 0.151 in the long-run on US state panel data. Their homogeneous fixed effects estimator provided short- and long-run elasticities of 0.016 and 0.044.

3.3 Time shift in the elasticities

Constant elasticities over time may not be a tenable assumption. We investigated whether it was possible to detect a shift in the elasticities by splitting the data set in two time periods according to a split off year. Here we restrict ourselves to homogeneous estimators since the time series were relatively short after splitting and too short for individual country-specific regressions. The homogeneous fixed effects estimators were estimated separately on each part using 1987 as split-off year. The results are provided in table 7.

All the homogeneous fixed effects estimators indicate that there have been an increase in the absolute long-run own-price elasticity for the period after 1987 relatively to the previous period. For example, the FE-AR1 had an estimate of -0.586 for the period before 1987 and of -0.997 for the period after. A Wald test for structural change in the long-run own-price elasticity for the period after 1987 relatively to the previous period, provided F-statistic of 19.43; the corresponding critical value at a 5% level is 3.88, which suggest a statistical difference. Thus, the consumers may have become more price elastic. One possible explanation is that the consumers have invested in more flexible equipment and have increased possibility to switch between different energy carriers due to changing prices. This was supported by our long-run cross-price elasticities, which had an relative increase in absolute term from the first period to the second. However, the change in long-run income elasticities were mixed and it was not possible to draw unambiguous conclusions.

4 Summary and conclusions

This paper has analyzed the residential natural gas demand per capita in 12 European countries during the period from 1978 to 2002 using a dynamic log-linear demand model, which allows for country-specific elasticity estimates in the short- and long-run. The explanatory variables included lagged demand per capita, heating degree days index, real prices of natural gas, light fuel oil, electricity, and real private income per capita. We have provided support for employing a heterogeneous estimator such as the shrinkage estimator. But the empirical results it has provided also motivates a further scrutiny of its properties.

Seventeen different econometric estimators were employed to obtain natural gas demand elasticity estimates. The estimators varied in their degree of parameter heterogeneity, with pooled homogeneous estimators (OLS, GLS-AR1, 2SLS) and several variants of standard panel data estimators at the one extreme, and individual country estimators at the other. Intermediate estimators in terms of heterogeneity are standard panel data estimators, i.e. fixed effects and random effects estimators, and the more novel shrinkage estimator.

The fixed effects estimators stand out among the homogeneous estimators, as only fixed effects estimators provide significant own-price natural gas elasticity estimates with the a priori expected correct negative sign. They also provide more sensible estimates of short- and long-run income elasticities than most other estimators. The estimators gave very high coefficients of the lagged dependent variable implying long lags in adjustments.

With an exception for the shrinkage estimator, our country-specific estimates were hard to interpret and had several wrong signs. Estimation of separate demand models for each country gives the greatest degree of flexibility, but earlier studies have demonstrated that such regression models often provide implausible estimates. The most striking conclusion is that shrinkage performs better than the other heterogeneous estimators. short- and long-run demand elasticities based on shrinkage estimates generally have more plausible signs and values, much smaller spread, and larger t-values, than competing heterogeneous estimators.

We also investigated the assumption of constant elasticity over time by splitting the data set in two time periods, 1978 - 1986 and 1987 - 2002, and estimate separate models for these two time periods. For the residential natural gas demand market as a whole, the homogeneous fixed-effect estimators indicated an increase in the own-price and cross-price elasticities, while the development of the income elasticity had no clear trend.

Finally, we compare the two types of estimators that had the best performance, the fixed effects estimators and the shrinkage estimators. Both perform well in terms of statistical significance in most cases. The short-run own-price and income elasticity tend to be very inelastic, but with greater long-run responsiveness. When we examine the natural gas own-price elasticity estimates, we find that shrinkage based elasticities are generally smaller in absolute terms. Shrinkage based short-run own-price elasticities are typically in the range -0.1 to 0, while fixed effects elasticity estimates lie between -0.3 and -0.2. In the longer run the shrinkage own-price elasticities typically lie between -0.6 and 0, while fixed effects elasticities are in the range from -1.5 to -0.9. Further, the income elasticities provided by shrinkage were typically in the range from 0.4 to 1.3 in the short-run and from 0.9 to 6.1 in the long-run, while the income elasticities provided by fixed effects were typically in the range from 0.3 to 0.7 in the short-run and from 1.9 to 2.2 in the long-run. The cross-price elasticities provided by fixed-effects and shrinkage were typical very inelastic and indicated very low cross-price responsibleness to the energy carrier substitutes for natural gas demand. The shrinkage country-specific cross-price elasticities had mixed signs and values close to zero. The low cross-price elasticities were priori expected, and mixed signs and values close to zero is also provided by earlier energy demand studies.

Appendix: Tables

Table 1: Parameter estimates from the different estimators used on the natural gas demand model.[a]

Estimator		β^y	β^{NG}	β^{LFO}	β^{EL}	β^m	β^z	β^0
Pooled OLS		0.987*	0.023	-0.019	0.018	0.028	0.203*	-1.064*
		(147.034)	(0.710)	(-0.752)	(0.426)	(0.839)	(2.233)	(-2.477)
Pooled GLS-AR1		0.982*	0.001	-0.019	0.040	0.034	0.308*	-1.558*
		(119.679)	(0.014)	(-0.619)	(0.797)	(0.817)	(3.157)	(-3.342)
FE		0.843*	-0.242*	0.091*	-0.010	0.329*	0.387*	-0.760
		(36.561)	(-4.638)	(2.440)	(-0.120)	(3.779)	(3.885)	(-0.891)
FE-AR1		0.754*	-0.264*	0.100*	-0.032	0.521*	0.424*	-0.743
		(26.173)	(-4.429)	(2.395)	(-0.330)	(4.913)	(4.270)	(-0.955)
RE		0.987*	0.023	-0.019	0.018	0.028	0.203*	-1.064*
		(147.034)	(0.710)	(-0.752)	(0.426)	(0.839)	(2.233)	(-2.477)
RE-AR1		0.983*	0.003	-0.019	0.037	0.033	0.298*	-1.510*
		(122.276)	(0.080)	(-0.633)	(0.762)	(0.817)	(3.073)	(-3.265)
RCM		0.613*	-0.123	0.038	-0.091	0.638*	0.505*	-0.690
		(10.052)	(-1.218)	(0.391)	(-0.561)	(2.257)	(6.479)	(-0.549)
2SLS		0.808*	0.061	-0.133*	0.057	0.345*	0.761*	-3.386*
		(13.891)	(0.960)	(-2.173)	(0.687)	(2.963)	(3.024)	(-3.016)
2SLS-FE		0.641*	-0.313*	0.118*	-0.019	0.700*	0.378*	-0.338
		(7.115)	(-4.642)	(2.878)	(-0.212)	(3.980)	(3.568)	(-0.355)
SUR-FE		0.845*	-0.237*	0.088*	-0.004	0.332*	0.403*	-0.845
		(38.608)	(-4.628)	(2.407)	(-0.050)	(3.890)	(4.087)	(-1.032)
	min	0.245	-0.635	-0.617	-1.254	-0.853	0.286	-6.979
OLS	avg	0.541	-0.154	0.043	-0.149	0.613	0.548	0.005
(by country)	max	0.845	0.277	0.524	0.484	1.981	0.820	6.614
	min	-0.016	-1.572	-0.402	-2.314	-3.498	0.223	-7.106
GLS-AR1	avg	0.503	-0.250	0.098	-0.342	0.319	0.609	2.045
(by country)	max	0.838	0.263	0.791	0.525	1.899	1.900	21.215
	min	0.095	-1.205	-0.653	-1.366	-1.805	0.286	-5.235
2SLS	avg	0.443	-0.182	0.115	-0.196	0.629	0.589	0.190
(by country)	max	0.792	0.316	1.137	0.318	1.781	1.451	5.700
	min	0.231	-0.461	-0.614	-0.765	-0.920	0.195	-6.480
SUR	avg	0.605	-0.118	0.091	-0.085	0.508	0.506	-0.797
(by country)	max	0.978	0.188	1.242	0.443	1.632	0.825	3.165
	min	0.314	-0.156	-0.072	-0.074	-0.249	0.239	-3.345
Shrinkage	avg	0.666	-0.030	0.002	-0.025	0.808	0.442	-1.863
(OLS)	max	0.851	0.184	0.042	0.072	1.440	0.794	1.433
	min	0.327	-0.144	-0.031	-0.268	-0.213	0.246	-2.674
Shrinkage	avg	0.651	-0.074	0.004	-0.071	0.793	0.425	-1.045
(GLS-AR1)	max	0.812	0.056	0.030	0.152	1.298	0.743	1.017
	min	0.225	-0.176	-0.046	-0.151	-0.283	0.230	-3.841
Shrinkage	avg	0.569	-0.050	-0.009	-0.032	1.038	0.446	-1.733
(2SLS)	max	0.766	0.129	0.018	0.150	1.705	0.796	1.854

[a]Figures put in parenthesis denote the t-statistics and the symbol * denotes statistically significant different from zero at the 5% level.

Table 2: Elasticity estimates of natural gas demand in the short-run (SR) and long-run (LR).[a]

Estimator		**Natural Gas** SR	**Natural Gas** LR	**L. Fuel Oil** SR	**L. Fuel Oil** LR	**Electricity** SR	**Electricity** LR	**Income** SR	**Income** LR
OLS		0.023	1.844	-0.019	-1.532	0.018	1.404	0.028	2.251
		(0.710)	(0.664)	(-0.752)	(-0.736)	(0.426)	(0.421)	(0.839)	(0.887)
GLS-AR1		0.001	0.031	-0.019	-1.056	0.040	2.216	0.034	1.889
		(0.014)	(0.014)	(-0.619)	(-0.617)	(0.797)	(0.760)	(0.817)	(0.869)
FE		-0.242*	-1.541*	0.091*	0.577*	-0.010	-0.063	0.329*	2.094*
		(-4.638)	(-4.259)	(2.440)	(2.328)	(-0.120)	(-0.120)	(3.779)	(4.242)
FE-AR1		-0.264*	-1.072*	0.100*	0.408*	-0.032	-0.128	0.521*	2.113*
		(-4.429)	(-4.265)	(2.395)	(2.336)	(-0.330)	(-0.330)	(4.913)	(5.406)
RE		0.023	1.844	-0.019	-1.532	0.018	1.404	0.028	2.251
		(0.710)	(0.664)	(-0.752)	(-0.736)	(0.426)	(0.421)	(0.839)	(0.887)
RE-AR1		0.003	0.179	-0.019	-1.099	0.037	2.153	0.033	1.915
		(0.080)	(0.080)	(-0.633)	(-0.631)	(0.762)	(0.729)	(0.817)	(0.869)
RCM		-0.123	-0.318	0.038	0.098	-0.091	-0.236	0.638*	1.649*
		(-1.218)	(-1.175)	(0.391)	(0.388)	(-0.561)	(-0.564)	(2.257)	(2.260)
2SLS		0.061	0.321	-0.133*	-0.694*	0.057	0.297	0.345*	1.803*
		(0.960)	(0.946)	(-2.173)	(-2.701)	(0.687)	(0.707)	(2.963)	(5.560)
2SLS-FE		-0.313*	-0.873*	0.118*	0.330*	-0.019	-0.054	0.700*	1.951*
		(-4.642)	(-4.593)	(2.878)	(2.557)	(-0.212)	(-0.210)	(3.980)	(7.653)
SUR-FE		-0.237*	-1.531*	0.088*	0.569*	-0.004	-0.026	0.332*	2.145*
		(-4.628)	(-4.263)	(2.407)	(2.300)	(-0.050)	(-0.050)	(3.890)	(4.326)
	min	-0.635	-3.171	-0.617	-1.254	-1.254	-2.619	-0.853	-5.096
OLS	avg	-0.154	-0.442	0.043	0.192	-0.149	-0.196	0.613	1.422
(by country)	max	0.277	1.179	0.524	2.476	0.484	2.536	1.981	7.442
	min	-1.572	-3.225	-0.402	-1.195	-2.314	-2.498	-3.498	-4.884
GLS-AR1	avg	-0.250	-0.546	0.098	0.201	-0.342	-0.398	0.319	1.137
(by country)	max	0.263	0.787	0.791	2.595	0.525	2.420	1.899	6.360
	min	-1.205	-3.151	-0.653	-1.939	-1.366	-2.113	-1.805	-1.996
2SLS	avg	-0.182	-0.372	0.115	0.168	-0.196	-0.233	0.629	1.617
(by country)	max	0.316	0.949	1.137	2.894	0.318	1.229	1.781	6.688
	min	-1.572	-3.225	-0.653	-1.939	-2.314	-2.619	-3.498	-5.096
SUR	avg	-0.349	-0.888	0.115	0.460	-0.477	-0.208	0.119	1.410
(by country)	max	0.316	1.179	1.137	2.894	0.525	2.536	1.981	7.442
	min	-0.156	-0.757	-0.072	-0.300	-0.074	-0.411	-0.249	-0.363
Shrinkage	avg	-0.030	-0.099	0.002	0.006	-0.025	-0.132	0.808	3.324
(OLS)	max	0.184	0.765	0.042	0.222	0.072	0.106	1.440	7.703
	min	-0.144	-0.743	-0.031	-0.132	-0.268	-1.430	-0.213	-0.317
Shrinkage	avg	-0.074	-0.226	0.004	0.014	-0.071	-0.324	0.793	2.919
(GLS-AR1)	max	0.056	0.236	0.030	0.159	0.152	0.226	1.298	6.111
	min	-0.176	-0.507	-0.046	-0.144	-0.151	-0.469	-0.283	-0.366
Shrinkage	avg	-0.050	-0.114	-0.009	-0.021	-0.032	-0.130	1.038	3.063
(2SLS)	max	0.129	0.403	0.018	0.073	0.150	0.194	1.705	7.029

[a]Figures put in parenthesis denote the t-statistics and the symbol * denotes statistically significant different from zero at the 5% level.

Table 3: Heterogeneous OLS elasticity estimates in the short-run (SR) and long-run (LR).[a]

	Natural Gas		L. Fuel Oil		Electricity		Income	
Estimator	SR	LR	SR	LR	SR	LR	SR	LR
Austria	0.027	0.043	-0.008	-0.012	0.484*	0.758*	1.981*	3.099*
	(0.223)	(0.230)	(-0.068)	(-0.068)	(2.344)	(2.249)	(3.622)	(10.094)
Belgium	0.141	0.218	0.060	0.093	-0.733	-1.137*	0.430	0.667
	(1.035)	(1.065)	(1.525)	(1.485)	(-2.051)	(-2.111)	(1.302)	(1.311)
Denmark	-0.506	-3.171	0.395	2.476	0.405	2.536	-0.813	-5.096
	(-0.853)	(-0.903)	(0.485)	(0.494)	(0.973)	(0.830)	(-1.233)	(-0.891)
Finland	-0.635	-1.403	0.393	0.867	-0.072	-0.158	-0.853	-1.882
	(-1.205)	(-1.276)	(0.592)	(0.602)	(-0.066)	(-0.066)	(-0.970)	(-1.112)
France	-0.152	-0.317	0.524*	1.095	-1.254*	-2.619*	0.594	1.241
	(-0.370)	(-0.329)	(2.545)	(1.395)	(-2.615)	(-2.787)	(0.837)	(1.119)
Germany	-0.087	-0.163	-0.044	-0.082	-0.035	-0.066	0.774*	1.442*
	(-0.764)	(-0.753)	(-0.735)	(-0.740)	(-0.166)	(-0.167)	(4.931)	(5.946)
Ireland	-0.158	-0.320	-0.617*	-1.254	-0.183	-0.371	1.099	2.233*
	(-0.545)	(-0.524)	(-2.131)	(-1.835)	(-0.452)	(-0.483)	(1.984)	(2.572)
Italy	0.277*	0.712*	-0.190	-0.487	0.012	0.030	1.078*	2.765*
	(2.080)	(2.584)	(-1.471)	(-1.522)	(0.072)	(0.072)	(2.173)	(6.504)
Netherlands	-0.256*	-0.340*	0.049	0.064	0.185	0.244	-0.206	-0.272
	(-3.770)	(-3.596)	(0.518)	(0.514)	(1.100)	(1.117)	(-1.635)	(-1.816)
Spain	0.183	1.179	-0.085	-0.546	-0.003	-0.016	1.154*	7.442*
	(0.921)	(0.876)	(-0.803)	(-0.737)	(-0.033)	(-0.034)	(3.009)	(3.826)
Switzerland	-0.622*	-1.614*	0.054	0.141	-0.639	-1.658*	1.790*	4.647*
	(-2.530)	(-3.039)	(0.855)	(0.768)	(-2.032)	(-2.263)	(2.273)	(4.256)
UK	-0.056	-0.133	-0.020	-0.046	0.042	0.100	0.330*	0.780*
	(-0.661)	(-0.635)	(-0.732)	(-0.765)	(0.407)	(0.408)	(3.242)	(4.931)
min	-0.635	-3.171	-0.617	-1.254	-1.254	-2.619	-0.853	-5.096
avg	-0.154	-0.442	0.043	0.192	-0.149	-0.196	0.613	1.422
max	0.277	1.179	0.524	2.476	0.484	2.536	1.981	7.442

[a]Figures put in parenthesis denote the t-statistics and the symbol * denotes statistically significant different from zero at the 5% level.

Table 4: Heterogeneous GLS-AR1 elasticity estimates in the short-run (SR) and long-run (LR).[a]

	Natural Gas		L. Fuel Oil		Electricity		Income	
Estimator	SR	LR	SR	LR	SR	LR	SR	LR
Austria	0.004	0.006	0.029	0.049	0.525*	0.891*	1.899*	3.221*
	(0.030)	(0.030)	(0.257)	(0.247)	(2.748)	(2.503)	(3.822)	(9.977)
Belgium	0.149	0.253	0.071*	0.121	-0.834*	-1.416*	0.257	0.436
	(1.300)	(1.341)	(2.114)	(2.052)	(-2.704)	(-2.767)	(0.894)	(0.904)
Denmark	-0.522	-3.225	0.420	2.595	0.392	2.420	-0.791	-4.884
	(-0.878)	(-0.929)	(0.512)	(0.523)	(0.941)	(0.809)	(-1.204)	(-0.882)
Finland	-1.572*	-1.548*	0.791	0.778	-2.314	-2.279	-3.498	-3.444
	(-3.351)	(-3.158)	(1.730)	(1.735)	(-1.499)	(-1.657)	(-1.747)	(-1.951)
France	-0.144	-0.277	0.535*	1.027	-1.300*	-2.498*	0.632	1.214
	(-0.347)	(-0.313)	(2.586)	(1.455)	(-2.588)	(-2.785)	(0.843)	(1.108)
Germany	-0.132	-0.193	-0.031	-0.045	-0.145	-0.213	0.872*	1.280*
	(-1.183)	(-1.181)	(-0.573)	(-0.571)	(-0.584)	(-0.592)	(4.808)	(5.801)
Ireland	-0.316	-0.939	-0.402	-1.195	-0.108	-0.320	0.566	1.680
	(-1.496)	(-1.281)	(-1.767)	(-1.626)	(-0.389)	(-0.412)	(1.432)	(1.802)
Italy	0.263*	0.787*	-0.216	-0.648	0.042	0.125	0.931*	2.790*
	(2.347)	(2.868)	(-2.072)	(-2.054)	(0.328)	(0.334)	(2.229)	(7.234)
Netherlands	-0.243*	-0.318*	0.027	0.036	0.212	0.277	-0.214	-0.280
	(-3.398)	(-3.220)	(0.286)	(0.285)	(1.209)	(1.222)	(-1.562)	(-1.729)
Spain	0.139	0.684	-0.088	-0.433	-0.028	-0.140	1.294*	6.360*
	(0.929)	(0.856)	(-0.996)	(-0.847)	(-0.277)	(-0.295)	(2.964)	(4.517)
Switzerland	-0.580*	-1.674*	0.058	0.167	-0.605*	-1.745*	1.551*	4.474*
	(-2.484)	(-2.961)	(0.950)	(0.840)	(-2.104)	(-2.334)	(2.068)	(3.917)
UK	-0.048	-0.113	-0.019	-0.045	0.054	0.127	0.334*	0.793*
	(-0.669)	(-0.639)	(-0.834)	(-0.877)	(0.595)	(0.600)	(3.305)	(5.408)
min	-1.572	-3.225	-0.402	-1.195	-2.314	-2.498	-3.498	-4.884
avg	-0.250	-0.546	0.098	0.201	-0.342	-0.398	0.319	1.137
max	0.263	0.787	0.791	2.595	0.525	2.420	1.899	6.360

[a]Figures put in parenthesis denote the t-statistics and the symbol * denotes statistically significant different from zero at the 5% level.

Table 5: Heterogeneous shrinkage (OLS) elasticity estimates in the short-run (SR) and long-run (LR).[a]

	Natural Gas		**L. Fuel Oil**		**Electricity**		**Income**	
Estimator	SR	LR	SR	LR	SR	LR	SR	LR
Austria	-0.105*	-0.343*	0.029*	0.094*	-0.021*	-0.069*	0.724*	2.364*
	(-4.446)	(-5.388)	(3.510)	(4.073)	(-3.527)	(-3.075)	(9.668)	(6.899)
Belgium	-0.054*	-0.130*	0.009	0.023	-0.004	-0.009	0.580*	1.408*
	(-2.778)	(-3.031)	(1.425)	(1.488)	(-0.646)	(-0.633)	(8.682)	(6.832)
Denmark	-0.062*	-0.209*	0.014	0.046	-0.029*	-0.097*	0.830*	2.800*
	(-2.123)	(-2.617)	(1.368)	(1.558)	(-2.883)	(-2.277)	(6.968)	(4.244)
Finland	-0.053	-0.344	0.012	0.078	-0.063*	-0.411*	1.179*	7.703*
	(-0.602)	(-0.625)	(0.389)	(0.399)	(-4.491)	(-3.242)	(6.020)	(3.983)
France	0.028	0.101	-0.018	-0.064	-0.045*	-0.160*	1.047*	3.756*
	(0.540)	(0.513)	(-0.987)	(-0.901)	(-3.398)	(-2.530)	(6.331)	(3.865)
Germany	-0.065*	-0.174*	0.014*	0.037*	-0.010*	-0.028*	0.643*	1.715*
	(-4.702)	(-5.209)	(2.908)	(3.094)	(-2.827)	(-2.656)	(13.992)	(10.620)
Ireland	-0.022	-0.079	-0.001	-0.001	-0.038*	-0.138*	0.950*	3.416*
	(-0.401)	(-0.408)	(-0.010)	(-0.010)	(-3.694)	(-3.096)	(6.845)	(5.050)
Italy	0.109*	0.312*	-0.047*	-0.134*	-0.039*	-0.112*	1.042*	2.978*
	(6.265)	(5.520)	(-7.785)	(-6.667)	(-9.589)	(-7.838)	(20.083)	(13.698)
Netherlands	-0.156*	-0.227*	0.042*	0.062*	0.072*	0.106*	-0.249*	-0.363*
	(-9.100)	(-10.951)	(7.215)	(8.329)	(13.541)	(18.613)	(-3.864)	(-4.189)
Spain	0.184*	0.765*	-0.072*	-0.300*	-0.074*	-0.308*	1.440*	6.000*
	(7.013)	(6.157)	(-7.873)	(-6.810)	(-16.350)	(-12.283)	(23.189)	(15.782)
Switzerland	-0.113*	-0.757*	0.033*	0.222*	-0.056*	-0.377*	1.072*	7.205*
	(-7.391)	(-24.758)	(6.411)	(19.690)	(-8.683)	(-4.034)	(14.394)	(4.947)
UK	-0.048*	-0.099*	0.007*	0.014*	0.011*	0.024*	0.434*	0.902*
	(-7.083)	(-7.599)	(2.860)	(2.940)	(5.257)	(5.624)	(16.847)	(13.950)
min	-0.156	-0.757	-0.072	-0.300	-0.074	-0.411	-0.249	-0.363
avg	-0.030	-0.099	0.002	0.006	-0.025	-0.132	0.808	3.324
max	0.184	0.765	0.042	0.222	0.072	0.106	1.440	7.703

[a]Figures put in parenthesis denote the t-statistics and the symbol * denotes statistically significant different from zero at the 5% level.

Table 6: Heterogeneous shrinkage (GLS-AR1) elasticity estimates in the short-run (SR) and long-run (LR).[a]

	Natural Gas		**L. Fuel Oil**		**Electricity**		**Income**	
Estimator	SR	LR	SR	LR	SR	LR	SR	LR
Austria	-0.144*	-0.420*	0.025*	0.074*	-0.137*	-0.398*	0.702*	2.043*
	(-7.600)	(-11.816)	(4.953)	(6.447)	(-30.539)	(-19.512)	(9.304)	(6.372)
Belgium	-0.092*	-0.218*	0.007	0.016	-0.021*	-0.049*	0.554*	1.306*
	(-6.153)	(-8.049)	(1.683)	(1.799)	(-6.343)	(-5.507)	(8.044)	(6.108)
Denmark	-0.055*	-0.178*	-0.001	-0.001	-0.087*	-0.280*	0.927*	2.983*
	(-2.716)	(-3.585)	(-0.063)	(-0.063)	(-11.215)	(-5.667)	(8.487)	(4.786)
Finland	-0.081	-0.386	0.011	0.054	-0.197*	-0.938*	1.169*	5.555*
	(-1.315)	(-1.445)	(0.627)	(0.654)	(-4.464)	(-4.365)	(7.878)	(4.129)
France	-0.047	-0.160	-0.002	-0.007	-0.093*	-0.315*	0.981*	3.317*
	(-1.270)	(-1.471)	(-0.213)	(-0.209)	(-10.101)	(-7.799)	(6.661)	(3.814)
Germany	-0.110*	-0.274*	0.013*	0.032*	-0.056*	-0.141*	0.592*	1.476*
	(-11.286)	(-15.246)	(4.940)	(5.567)	(-19.432)	(-16.124)	(14.099)	(10.443)
Ireland	-0.085*	-0.287*	0.009	0.031	-0.125*	-0.423*	0.921*	3.102*
	(-2.128)	(-2.455)	(0.812)	(0.855)	(-6.339)	(-8.701)	(8.053)	(5.221)
Italy	0.034*	0.104*	-0.028*	-0.086*	0.004	0.013	1.018*	3.123*
	(2.664)	(2.451)	(-8.040)	(-6.378)	(1.123)	(1.114)	(20.450)	(12.018)
Netherlands	-0.142*	-0.211*	0.012*	0.018*	0.152*	0.226*	-0.213*	-0.317*
	(-10.928)	(-15.245)	(3.722)	(4.115)	(25.250)	(46.281)	(-3.026)	(-3.299)
Spain	0.056*	0.236*	-0.031*	-0.132*	-0.053*	-0.223*	1.298*	5.455*
	(2.931)	(2.675)	(-5.678)	(-4.789)	(-5.229)	(-6.254)	(25.671)	(13.873)
Switzerland	-0.139*	-0.743*	0.030*	0.159*	-0.268*	-1.430*	1.146*	6.111*
	(-12.680)	(-27.479)	(11.344)	(25.778)	(-32.414)	(-7.461)	(16.215)	(6.021)
UK	-0.086*	-0.181*	0.003*	0.006*	0.031*	0.064*	0.415*	0.869*
	(-17.479)	(-21.441)	(2.137)	(2.184)	(8.292)	(9.012)	(16.242)	(13.185)
min	-0.144	-0.743	-0.031	-0.132	-0.268	-1.430	-0.213	-0.317
avg	-0.074	-0.226	0.004	0.014	-0.071	-0.324	0.793	2.919
max	0.056	0.236	0.030	0.159	0.152	0.226	1.298	6.111

[a]Figures put in parenthesis denote the t-statistics and the symbol * denotes statistically significant different from zero at the 5% level.

Table 7: Homogeneous elasticity estimates of natural gas demand in the short-run (SR) and long-run (LR) before and after 1987.[a]

	Natural Gas		**L. Fuel Oil**		**Electricity**		**Income**	
Estimator	SR	LR	SR	LR	SR	LR	SR	LR
Time period from 1978 to 1986								
FE	-0.354*	-1.265*	-0.058	-0.208	0.352	1.258	0.711	2.543
	(-2.570)	(-2.204)	(-0.619)	(-0.619)	(1.792)	(1.785)	(1.836)	(1.657)
FE-AR1	-0.302*	-0.586	-0.121	-0.235	0.230	0.447	0.663	1.287
	(-2.043)	(-1.925)	(-1.087)	(-1.103)	(0.984)	(0.988)	(1.374)	(1.315)
2SLS-FE	-0.253	-0.443	-0.174	-0.306	0.365	0.639	0.607	1.065
	(-1.712)	(-1.401)	(-1.289)	(-1.464)	(1.480)	(1.672)	(1.185)	(0.991)
SUR-FE	-0.292*	-0.990*	-0.133	-0.451	0.441*	1.496*	0.523	1.776
	(-2.209)	(-1.967)	(-1.386)	(-1.389)	(2.353)	(2.347)	(1.384)	(1.288)
Time period from 1987 to 2002								
FE	-0.339*	-1.450*	0.215*	0.920*	-0.235*	-1.006*	0.301*	1.289*
	(-3.699)	(-3.754)	(3.569)	(3.108)	(-2.407)	(-2.336)	(2.589)	(3.066)
FE-AR1	-0.334*	-0.997*	0.194*	0.580*	-0.299*	-0.891*	0.410*	1.223*
	(-2.937)	(-2.936)	(3.018)	(2.715)	(-2.316)	(-2.335)	(2.631)	(3.027)
2SLS-FE	-0.518*	-1.124*	0.213*	0.462*	-0.300*	-0.651*	0.704*	1.527*
	(-3.893)	(-4.971)	(3.181)	(2.459)	(-2.660)	(-2.590)	(3.030)	(6.341)
SUR-FE	-0.340*	-1.447*	0.215*	0.916*	-0.236*	-1.002*	0.304*	1.291*
	(-3.918)	(-3.973)	(3.756)	(3.303)	(-2.538)	(-2.469)	(2.775)	(3.254)

[a]Figures put in parenthesis denote the t-statistics and the symbol * denotes statistically significant different from zero at the 5% level.

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