Energy Substitutability in Canadian Manufacturing

Econometric Estimation with Bootstrap Confidence Intervals[#]

Yazid Dissou[*] and Reza Ghazal[**]

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[*] Department of Economics, University of Ottawa, Pavillon Desmarais, 55 Laurier Avenue East, Ottawa, Ontario, Canada K1N 6N5. Email:ydissou@uottawa.ca.
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[**] College of Insurance, Allameh Tabatabai University, Iran. Email: hazhar_ghazal@yahoo.com.

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Abstract.

This study provides estimates of the price and Morishima substitution elasticities between energy and non-energy inputs in two Canadian energy-intensive manufacturing industries: Primary Metal and Cement. The elasticities are estimated using annual industry-level KLEM data (1961-2003) and relying on two flexible functional forms: the Translog and the Symmetric Generalized McFadden (SGM) cost functions. In addition to the point estimates, the confidence intervals of the elasticities are computed using Studentized bootstrap resampling techniques. For both industries, the estimation results suggest that capital, labour, material and energy are pairwise substitutes and that energy is the most substitutable input. However, the low magnitudes of the estimated elasticities do not seem to offer great flexibility to these industries to adapt to high increases in energy prices.

Keywords: Energy; Elasticity of substitution; Translog Cost Function; Symmetric Generalized McFadden (SGM) Cost Function; Double Bootstrap.

JEL: C30, Q4

1. Introduction

This study provides econometric estimates of substitution elasticities between energy and non-energy inputs, as well as their confidence intervals for selected Canadian manufacturing industries. Successive oil crises and the growing awareness of societies and governments about environmental pollution and the depletion of non-renewable energy resources have led to economists' sustained interest on the importance of energy; particularly the possibility of substituting capital, labour and other inputs for energy.

The ease of change in input combinations induced by variations in input prices is governed by, among other factors, the curvature of the isoquant, which is measured locally by the elasticity of substitution. If non-energy inputs are substitutes for energy, higher energy prices will induce cost-minimizing firms to decrease energy use to attenuate the increase in production cost and to mitigate the fall in output. It follows that the extent to which energy can be substituted for by other production factors will have significant industrial effects. Information on energy substitutability is thus of paramount importance for, on the one hand, predicting the outcome of any policy or shock that affects energy prices and for, on the other hand, evaluating alternative environmental policies.

While a mere knowledge of the type of relationship (complementarity or substitutability) between energy and other inputs can be sufficient for some analyses, the precise values of these parameters are required in other kinds of investigation. Indeed, the influential critique of Lucas (1976) regarding the inadequacy of using traditional econometric models for the purposes of policy evaluation has led to a substantial shift toward the development of structural models to evaluate policy reform proposals and economic shocks. A distinctive feature of these structural models is their strong micro-foundations, whereby the behaviour of private economic agents is explicitly modeled through a detailed specification of preferences and technologies.

Computable general equilibrium (CGE) models, which constitute a particular type of structural model, have now become an important tool for analyzing policy shocks related to the energy sector. These models have been widely employed to analyze energy policies in different regions of the world.[1] They rely heavily on the values of substitution elasticities between pairs of inputs to characterize firm technology. Yet, the values of these critical parameters are not estimated within these models; they are rather taken from other studies. Given the sectoral nature of these models, the number of required elasticities is large and reliable estimates do not always exist for the economy and sectors under study. CGE modellers are often compelled to borrow from a handful of estimates available in the literature to calibrate their models. The paucity of econometric estimates of elasticities used in CGE models has led some authors to question their empirical foundations (see Hansen and Heckman, 1996 and McKitrick, 1998.)

Several attempts were made in the past few decades to estimate the elasticities of substitution between energy and other inputs for various industries in different regions of the world. Studies by Berndt and Wood (1975), Berndt and Jorgenson (1973) for the U.S. economy and by Fuss (1977) for the Canadian economy are milestones in this area. Despite the significant number of studies, there is still no clear consensus over the signs and the magnitudes of these parameters.[2] Econometric estimates suggest both complementarity and substitutability between energy and non-energy inputs. Results from Berndt and Wood (1975), and Griffin and Gregory (1976) on the U.S. economy are often contrasted in the

1 See Bhattacharyya (1996) and Devarajan and Robinson (2005) for surveys.

2 Thompson and Taylor (1995) and Thompson (2006) survey the empirical studies on this subject.

literature to illustrate how much estimates of the elasticity of substitution between energy and other factors can vary. Berndt and Wood (1975) find that energy is a substitute for capital but a complement of labour, while Griffin and Gregory (1976) find that energy is a substitute for both capital and labour. Denny *et* al. (1978) find that energy is a complement to capital in Canadian manufacturing industries, while results in Gervais *et* al. (2008) suggest that capital and energy are substitutes in the Canadian Food industry. The importance of these differences in the nature of substitutability between energy and capital, for example, cannot be ignored as they have different implications, as far as energy policy is concerned.

The objective of this study is to contribute to this literature by providing econometric estimates of the substitution and price elasticities between energy and the other production factors in some Canadian manufacturing industries. More recent estimates of elasticities of substitution between energy and other inputs are much needed in Canada, an energy-exporting country, as well as a traditional manufacturing-goods exporter, where a heated policy debate is still ongoing over the appropriate energy policy to address climate change. In contrast to other studies that use traditional functional forms like the CES (constant elasticity of substitution) function, our econometric estimation relies on flexible cost functions that have the advantage of not imposing any prior restrictions on the values of the elasticities (Diewert, 1971.) Because econometric estimates of elasticities can vary with the functional form used, we opt to use two well-known cost functions: the Translog cost function and the symmetric generalized McFadden (SGM) cost function. An increasing number of studies are now using the SGM cost function to evaluate the characteristics of firm technology. Kumbhakar (1994), Lawrence (1989), Peters and Surry (2000), Rask (1995), Sauer (2006), and Stewart and Jones (2008) are few examples, among many others.

While the Translog cost function is the most popular among the functional forms, it does not necessarily respect globally the theoretical curvature properties that a well-behaved cost function should have. Diewert and Wales (1987) show that these properties cannot be imposed globally without destroying the flexibility properties of the cost function. They propose the SGM cost function, which does not have that deficiency; this functional form is now considered the state-of-the-art specification in the analysis of firm technology because of its theoretical consistency.

Another methodological issue addressed in this study pertains to the confidence intervals for substitution elasticities. Most general equilibrium models used for the evaluation of energy policies are not stochastic; they rely on sensitivity analyses of the extraneous elasticity parameters used to check the robustness of their results. The theoretical distribution of the elasticity parameters obtained using flexible forms are often not known, since they are nonlinear combinations of estimated parameters obtained from regression analyses. In this study, in addition to obtaining point estimates of the elasticities, we provide confidence intervals of these parameters by relying on the resampling bootstrap technique that is more appropriate for constructing confidence intervals when the distribution of the statistics is not known (Eakin *et* al., 1990). The results of this study will be useful for Canadian CGE modellers, providing them with appropriate information to perform sensitivity analyses of their findings to parameter uncertainty. We are not aware of any study on energy substitutability with an SGM specification that provides bootstrap confidence intervals.

The remainder of the paper is organised as follows. The next section presents the specification of the models that we employ and their econometric estimation strategy; the third discusses the data and the results and the last section concludes.

2. The model

We assume the existence, at the industry level, of a twice-continuously differentiable production function that combines capital (*K*), labour (*L*), energy (*E*) and material (*M*) to produce a single gross output (*Y*).[3] A theoretical representation of the production of gross output that allows for non-neutral technical change can be stated as follows:

$$Y = f(K, L, E, M, t) \qquad (1)$$

where *f* is a twice continuously differentiable production function and *t* is an index of technical progress represented by the time trend. We suppose that the technology is homothetic and is characterized in particular by constant returns to scale.

Using duality theory, the technology can be represented by a twice-continuously differentiable cost function that has input prices (w_j), gross output (*Y*) and the time trend (*t*) as arguments. The cost function is the solution to the following problem:

$$C = C\ (W, Y, t) = \min_X \{W^{'}X : f(X, t) \geq Y, \quad X > 0\} \qquad (2)$$

where *W* is the vector of input prices and *X* is the vector of input quantities.

This cost function summarizes all relevant characteristics of the underlying technology if it is linear homogeneous and non-decreasing in prices, concave in prices and nonnegative. It can be represented by a flexible functional form, which is considered an approximation of the true unknown cost function. The flexibility property of these functions stems from the fact that they have a sufficient number of parameters to approximate an arbitrary twice-continuously differentiable function. More precisely, a functional form is considered flexible if its shape is only restricted by theoretical considerations, i.e., the regularity properties (Diewert, 1971). The use of flexible functional forms to estimate technology parameters is appealing since, in contrast to traditional functional forms like CES (Constant Elasticity of Substitution) and C-D (Cobb-Douglas), they do not impose a priori restrictions on elasticity values.

While several flexible functional forms have been proposed in the literature to represent well-behaved cost functions, we consider two functional forms: the Translog cost function (TCF) suggested by Christensen, Jorgenson and Lau (1971, 1973) and the SGM cost function. The TCF is very popular among researchers as it stands to be the most widely used second order flexible functional form that can assess the behavioural characteristics of firm technologies.[4]

The property of concavity in prices that any well-behaved cost function must respect cannot be imposed during estimation of the TCF without destroying its flexibility properties. Several studies have reported that estimated TCFs fail to satisfy that property globally. [5] The concavity property of a cost function is very important for at least two reasons. First, when the cost function is not concave in prices, the input demand determined through the first-order conditions might not be the cost-minimizing one. Second, the absence of concavity could lead to a non-continuous input demand function. This is important because, from a general equilibrium perspective, the continuity of the excess demand function is critical for the existence of Walrasian equilibrium.

[3] For the sake of notational simplicity, industry and time subscripts are omitted.

[4] See Apostolakis (1990) and Thompson and Taylor (1995) for some interesting reviews of studies using the TCF.

[5] See for example Ryan and Wales (2000).

To address the deficiencies of the TCF, we use another functional form, the SGM. As discussed in Diewert and Wales (1987), the parameters of the latter function can be estimated while globally imposing concavity in input prices without destroying its flexibility properties.

2.1 The Translog cost function

Letting C denote total expenditures on inputs, the TCF can be represented as follows:[6]

$$\ln C = \beta_0 + \sum_i \beta_i \ln w_i + \beta_y \ln Y + \beta_t t + \frac{1}{2}\sum_i \beta_{ii} (\ln w_i)^2$$
$$+ \frac{1}{2}\sum_{i\neq j}\sum_j \beta_{ij} \ln w_i \ln w_j + \sum_i \beta_{it} t \ln w_i \qquad i, j = K, L, E, M \qquad (3)$$

where β_0, β_i, β_y, β_{ij} and β_{it} are parameters to be estimated. Imposing linear homogeneity and symmetry restrictions leads to the following relationships between the parameters:

$$\sum_i \beta_i = 1, \quad \sum_j \beta_{ij} = 0, \quad \sum_i \beta_{it} = 0, \quad \beta_{ij} = \beta_{ji}. \qquad (4)$$

Using Shephard's lemma, the share, S_i, of input i in total cost is:

$$S_i = \beta_i + \beta_{ii} \ln w_i + \sum_{j\neq i} \beta_{ij} \ln w_j + \beta_{it} t \qquad (5)$$

$$i, j = K, L, E, M$$

As the sum of the input shares must be equal to one (adding-up property), the following restriction, which already holds through the linear homogeneity restriction, must be satisfied: $\sum_i \beta_i = 1$.

The econometric approach used consists of adding a random term u_i to each share equation and in estimating the parameters of three of the four share equations, while imposing the above-mentioned restrictions. The error terms u_i are assumed to have zero mean and constant variance, but they are contemporaneously correlated across equations. The equation for material inputs is removed from the econometric estimation to avoid singularity because of the adding-up property. The parameters of the last equation are recovered using the linear homogeneity and symmetry restrictions.

[6] For notational simplicity, we ignore the industry subscript in our notation.

$$S_K = \beta_K + \beta_{KK} \ln\left[\frac{w_K}{w_M}\right] + \beta_{KL} \ln\left[\frac{w_L}{w_M}\right] + \beta_{KE} \ln\left[\frac{w_E}{w_M}\right] + \beta_{Kt} t + u_K \quad (6a)$$

$$S_L = \beta_L + \beta_{KL} \ln\left[\frac{w_K}{w_M}\right] + \beta_{LL} \ln\left[\frac{w_L}{w_M}\right] + \beta_{LE} \ln\left[\frac{w_E}{w_M}\right] + \beta_{Lt} t + u_L \quad (6b)$$

$$S_E = \beta_E + \beta_{KE} \ln\left[\frac{w_K}{w_M}\right] + \beta_{LE} \ln\left[\frac{w_L}{w_M}\right] + \beta_{EE} \ln\left[\frac{w_E}{w_M}\right] + \beta_{Et} t + u_E \quad (6c)$$

Using the estimated parameters and the fitted values of the input shares, the Allen partial elasticities of substitution (AES), $\hat{\sigma}_{ij}^A$, could be estimated as follows.

$$\hat{\sigma}_{ij}^A = \frac{\hat{\beta}_{ij} + \hat{S}_i \hat{S}_j}{\hat{S}_i \hat{S}_j} \quad for\ i \neq j \qquad (7a)$$

$$\hat{\sigma}_{ii}^A = \frac{\hat{\beta}_{ii} + \hat{S}_i^{\,2} - \hat{S}_i}{\hat{S}_i^{\,2}} \qquad (7b)$$

$$i, j = K, L, E, M$$

Positive values for these elasticities suggest that the inputs are substitutes, while negative values suggest that they are complements. Estimates of cross-price elasticities, $\hat{\varepsilon}_{ij}$, are obtained from estimates of the Allen partial elasticities of substitution and of the fitted values of the input shares expressed below:

$$\hat{\varepsilon}_{ij} = \hat{S}_j \hat{\sigma}_{ij}^A \quad i, j = K, L, E, M \qquad (8a)$$

While the partial elasticity of substitution is widely used to classify pairs of inputs as substitutes or complements, Blackorby and Russell (1989) criticize its use for this purpose. They argue that the AES cannot be considered as an indicator of ease of substitution in the spirit of the marginal rate of substitution. Rather, they suggest using the Morishima elasticity of substitution (MES), $\hat{\sigma}_{ij}^M$, which truly reflects the characteristics of the Hicksian notion of elasticity of substitution for the case of two inputs. They show that the MES is a natural generalization of the Hicks concept of elasticity of substitution in the case of more than two inputs. The MES indicates the percentage change in proportional factor inputs that is brought about by a change in relative prices, while keeping output and all prices, but one constant. Its expression is:

$$\hat{\sigma}_{ij}^M = \varepsilon_{ij} - \varepsilon_{jj} \qquad (8b)$$

However, in contrast to the AES, the MES is not symmetric. Moreover, the Morishima measure tends to treat inputs as substitutes, while the AES tends to treat them as complements. If two inputs are Allen substitutes, it must be the case that they are Morishima substitutes; however, the converse is not true. We report only estimates of the MES.

2.2 The symmetric generalized McFadden cost function (SGM)

The linear homogeneous and homothetic version of the SGM cost function initially proposed is defined as follows:

$$C(Y,W) = \left(g(W) + \sum_i b_{ii} w_i + b_{it} w_i t \right) Y \qquad (9a)$$

$$with \quad g(W) \equiv \frac{W'SW}{2\theta'W} \qquad (9b)$$

$$i, j = K, L, E, M$$

where S is a 4x4 symmetric negative semi-definite matrix of parameters s_{ij}, and $\theta \left(\theta > 0 \right)$ is a 4x1 vector of nonnegative constants that are not all equal to zero and that can be freely chosen by the researcher. As in Diewert and Wales (1987), we set the elements of the vector θ equal to the sample average values of the inputs. The parameters, b_{it} and s_{ij} are the parameters to be estimated.

Some additional restrictions are required in order to identify all parameters. As suggested by the authors of this functional form, the following restriction can be imposed at some chosen input prices w^* $(w^*>0)$: $\sum_j s_{ij} w^* = 0$. When the chosen input prices are set equal to one, the preceding restriction can be written as $\sum_j s_{ij} = 0$. In other words, all rows of the S matrix must sum up to zero. With this in perspective, we rescale all prices so that the input prices of the first year are equal to one.

By differentiating the cost function with respect to input prices, and using Shephard's lemma, it is possible to obtain the conditional factor demands. Dividing each factor demand by the level of output to reduce potential heteroskedasticity, we have the following expressions for the system of input demands:

$$\frac{X_i}{Y} = \frac{\sum_j s_{ij} w_j}{\theta'W} - \frac{\theta_i}{2} \frac{W'SW}{\left(\theta'W \right)^2} + b_{ii} + tb_{it} \quad i = K, L, E, M \qquad (10)$$

When the identification restriction is imposed on the matrix S, the input demand system becomes:

$$
\begin{aligned}
\frac{X_K}{Y} = {} & s_{KK}\left[(P_K - P_M) - \frac{\theta_K}{2}(P_K - P_M)^2\right] + s_{KL}\left[(P_L - P_M) - \theta_K (P_K - P_M)(P_L - P_M)\right] \\
& + s_{KE}\left[(P_E - P_M) - \theta_K (P_K - P_M)(P_E - P_M)\right] + s_{LL}\left[-\frac{\theta_K}{2}(P_L - P_M)^2\right] \\
& + s_{LE}\left[-\theta_K (P_L - P_M)(P_E - P_M)\right] + s_{EE}\left[-\frac{\theta_K}{2}(P_E - P_M)^2\right] \\
& + b_{KK} + t b_{Kt} + u_K \qquad (11a)
\end{aligned}
$$

$$
\begin{aligned}
\frac{X_L}{Y} = {} & s_{KK}\left[-\frac{\theta_L}{2}(P_K - P_M)^2\right] + s_{KL}\left[(P_K - P_M) - \theta_L (P_K - P_M)(P_L - P_M)\right] \\
& + s_{KE}\left[-\theta_L (P_K - P_M)(P_E - P_M)\right] + s_{LL}\left[(P_L - P_M) - \frac{\theta_L}{2}(P_L - P_M)^2\right] \\
& + s_{LE}\left[(P_E - P_M) - \theta_L (P_E - P_M)(P_L - P_M)\right] + s_{EE}\left[-\frac{\theta_L}{2}(P_E - P_M)^2\right] \\
& + b_L + t b_{Lt} + u_L \qquad (11b)
\end{aligned}
$$

$$
\begin{aligned}
\frac{X_E}{Y} = {} & s_{KK}\left[-\frac{\theta_E}{2}(P_K - P_M)^2\right] + s_{KL}\left[-\theta_E (P_K - P_M)(P_L - P_M)\right] \\
& + s_{KE}\left[(P_K - P_M) - \theta_E (P_K - P_M)(P_E - P_M)\right] + s_{LL}\left[-\frac{\theta_E}{2}(P_L - P_M)^2\right] \\
& + s_{LE}\left[(P_L - P_M) - \theta_E (P_L - P_M)(P_E - P_M)\right] + s_{EE}\left[(P_E - P_M) - \frac{\theta_E}{2}(P_E - P_M)^2\right] \\
& + b_{EE} + t b_{Et} + u_E \qquad (11c)
\end{aligned}
$$

$$
\begin{aligned}
\frac{X_M}{Y} = {} & s_{KK}\left[-(P_K - P_M) - \frac{\theta_M}{2}(P_K - P_M)^2\right] + s_{KL}\left[-(P_L - P_M) - \theta_M (P_K - P_M)(P_L - P_M)\right] \\
& + s_{KE}\left[-(P_E - P_M) - \theta_M (P_K - P_M)(P_E - P_M)\right] + s_{LL}\left[-(P_L - P_M) - \frac{\theta_M}{2}(P_L - P_M)^2\right] \\
& + s_{LE}\left[-(P_L - P_M) - (P_E - P_M) - \theta_M (P_L - P_M)(P_E - P_M)\right] \\
& + s_{EE}\left[-(P_E - P_M) - \frac{\theta_M}{2}(P_E - P_M)^2\right] + b_{MM} + t b_{Mt} + u_M \qquad (11d)
\end{aligned}
$$

where the u_i are the error terms and the independent variables P_i are the normalized input prices such that: $P_i = \dfrac{w_i}{\sum_j \theta_j w_j}$ (i, j=K, L, E, M). Recall that the parameters to be estimated are s_{ij}, b_{ii} and b_{it}, and note that the expressions in brackets are nonlinear combinations of input prices, which are independent variables.[7] One can easily see that the demand system is linear in parameters. It is also worth mentioning that the parameters s_{iM} (i=K, L, E, M) do not appear in the list of

[7] Note that with the SGM specification, all four equations are used for estimation.

estimated parameters because of the imposition of identification restriction. Their values can be recovered by using those estimated directly from the system while taking into consideration the identification restriction.

If the estimated matrix, $\hat{S}$, does not satisfy the concavity criteria, Diewert and Wales (1987) show that it is possible to impose globally negative semi-definiteness without destroying the flexibility property of the cost function. Relying on the method suggested by Wiley *et* al., (1973), they reparametrize the *S* matrix through Cholesky decomposition by replacing it with *-AA'*, where *A* is a lower triangular matrix:

$$\mathrm{A} = [a_{ij}]\, i, j = K, L, E, M \quad a_{ij} = 0 \quad for\ i < j$$

The following relationships can then be established between the parameters s_{ij} and a_{ij}:

$$s_{KK} = -a_{kk}^2 \qquad (12a)$$

$$s_{KL} = -a_{KK} a_{KL} \qquad (12b)$$

$$s_{KE} = -a_{KK} a_{KE} \qquad (12c)$$

$$s_{LL} = -\left(a_{KL}^2 + a_{LL}^2\right) \qquad (12d)$$

$$s_{LE} = -\left(a_{KL} a_{KE} + a_{LL} a_{LE}\right) \qquad (12e)$$

$$s_{EE} = -\left(a_{KE}^2 + a_{LE}^2 + a_{EE}^2\right) \qquad (12f)$$

As a result, replacing the parameters s_{ij} in the system of equations (11a-d) by the expressions (12a-f) and estimating the parameters a_{ij} will ensure that the estimated cost function is globally concave. Still, a consequence of this adjustment is that the system is no longer linear in the parameters a_{ij}. Finally, the own- and cross-price elasticities between inputs in the SGM cost function have the following expressions:

$$\hat{\varepsilon}_{ii} = \left[\frac{\hat{s}_{ii}\sum_u \theta_u w_u - 2\theta_i \sum_u \hat{s}_{iu} w_u + 2\theta_i^2 \hat{g}(W)}{\left[\sum_u \theta_u w_u\right]^2}\right]\frac{w_i Y}{X_i} \qquad (13a)$$

$$\hat{\varepsilon}_{ij} = \left[\frac{\hat{s}_{ij}\sum_u \theta_u w_u - \theta_i \sum_u \hat{s}_{ju} w_u - \theta_j \sum_u \hat{s}_{iu} w_u + 2\theta_i \theta_j \hat{g}(W)}{\left[\sum_u \theta_u w_u\right]^2}\right]\frac{w_j Y}{X_i} \qquad (13b)$$

The Morishima elasticities can then be computed from the price elasticities using (8b).

2.3 Confidence intervals

As previously stated, the elasticities of interest are not directly estimated from the econometric models. Rather, these elasticities are nonlinear functions of estimated coefficients and of fitted values of input cost shares. As a result, the analytical derivation of their confidence intervals is non-tractable as their theoretical distributions are complex. The reason for this is that a nonlinear combination of normally distributed random variables is itself not necessarily normally distributed. Furthermore, even when the asymptotic distribution of an estimated parameter is well known, the confidence interval built on this distribution can be misleading in small samples.

Using the technique suggested in Efron (1982), Efron and Tibshirani (1993) show that the simple bootstrap method can produce reliable confidence intervals even when the distribution is not known. An increasing body of literature seems to suggest that bootstrap techniques provide better inferences than traditional asymptotic tests, especially in small samples. Horowitz (1994) and Davidson and MacKinnon (1999) are a few examples among others. The bootstrap technique has been used by several authors to provide confidence intervals for parameters that are nonlinear functions of estimated coefficients from econometric models (see Eakin *et* al., 1990, Hall and Horowitz, 1996, and Li and Maddala, 1999, among several others, for interesting examples.)

While there are several methods to compute confidence intervals, we elect to use the very popular percentile-t or Studentized bootstrap method suggested by Hall (1992) as it produces intervals that have better properties than the simple bootstrap method[8]. Another advantage of that that method is that it is very intuitive and easy to understand. The basic idea behind the construction of a percentile-t bootstrap confidence interval is the following. Let us denote by Ω the unknown parameter to be estimated and by, $\hat{\Omega}$ and s_Ω, respectively, its estimate and the standard error of the estimate. Following the percentile-t method, the confidence interval of the parameter $\hat{\Omega}$ at the (1-α) confidence level is as follows:

$$\left[\hat{\Omega} - s_\Omega . t_h^* \, , \hat{\Omega} - s_\Omega . t_l^*\right] \qquad (14)$$

t_l^* and t_h^* are respectively the ($\alpha/2$) and (1-$\alpha/2$) quantiles of the empirical distribution of the percentile-t statistics t_j^*, which is constructed as shown in Equation (15) below:

$$t_j^* = \frac{\hat{\Omega}_j^* - \hat{\Omega}}{s_j^*} \qquad (15)$$

where $\hat{\Omega}_j^*$ is the estimate of the parameter Ω in the j[th] bootstrap replication, and s_j^* is its standard error. In the present study, the standard error, s_Ω, of $\hat{\Omega}$ and those, s_j^*, of the j[th] bootstrap estimates $\hat{\Omega}_j^*$ cannot be calculated. Indeed, as discussed earlier, the parameters $\hat{\Omega}$ of interest, i.e., the elasticities of substitution, are nonlinear functions of the regression parameter estimates. We resort to a second-level bootstrap in order to compute all the required standard errors. We approximate the standard error, s_Ω, by the sample standard deviation of the J estimates $\hat{\Omega}_j^*$ obtained in the first level of bootstrap.

For each of the J first-level bootstrap estimates $\hat{\Omega}_j^*$, we perform another series of second level bootstraps to compute K estimates of the parameter, $\hat{\Omega}_{jk}^*$, whose standard deviation are used to approximate the standard errors s_j^* of $\hat{\Omega}_j^*$. More details on the procedures used to compute the confidence intervals are provided in the Appendix.

[8] We are grateful to an anonymous referee who suggested the use of that method. See also Mackinnon (2002) for an interesting presentation on the bootstrap-t confidence interval.

3. **Data, results and discussions**

3.1 Data

Our data come the annual Canadian KLEMS data set developed by the "Productivity Program Database of Statistics Canada" for the period 1961-2003. Our sample consists of two 4-digit manufacturing industries that are "Primary Metal" NAICS (3310) and "Cement" in the NAICS (3273) - at the L-level of aggregation[9]. These two industries have been chosen mainly due to their energy-intensive characteristic. The KLEMS data set includes information on chained-Fisher quantity indices and price indices for capital, labour, energy, material and service inputs collected on annual basis. It also contains annual data on the quantity index of output, as well as their nominal values on an annual basis. Capital input is represented by the services provided by the stock of capital instead of the stock of capital itself as used in other studies[10]. In this study, material input is represented by a Fischer-chained index of the material input and services input contained in the original database. For the sake of notational simplicity, we use the expression "material input" to refer to the composite of material and services inputs that we still denote by M.

Tables 1 and 2 provide a summary of descriptive statistics for selected variables in both industries during the study period. These statistics include the mean, standard deviation, minimum and maximum values of the price and quantity indices and cost shares of the four inputs. In both industries, material inputs account for, on average, the largest expenditure share in production in both industries (more than 60%) while energy has the lowest expenditure share (less than 8%).

3.2 Results and discussions

All estimation is performed using the SHAZAM econometric package (version 10).[11] The three factor share equations derived from the Translog specification (Equations 6a to 6c) are estimated using the iterative seemingly unrelated regression (SUR). The four equations of input-to-output ratios obtained in the SGM specification (Equations 11a to 11d) are estimated with nonlinear iterative SUR techniques using the Davidon-Fletcher-Powell algorithm. The initial values of the coefficients a_{ij} in the nonlinear regression are found using the following strategy. First, we estimate the parameters s_{ij} in the non-restricted (for concavity) system of equations; then we use the relationships between s_{ij} and a_{ij} in the Cholesky factorization to find those initial values. The systems converged from the supplied starting values within 115 iterations in both industries. The same initial values are used in the bootstrap estimations.

Tables 3-8 report the estimated coefficients from the regressions and the point estimates of elasticities as well as their confidence intervals for both industries. Estimated parameters derived from flexible functional cost functions do not have any intuitive economic interpretation in the sense that they do not convey any special information on the elasticities in which we are interested. We will rather focus on their statistical significance, instead of their signs and magnitudes. The results in Tables 3-4 suggest that most estimated parameters of the cost function are significant at the 5 percent level of significance in both specifications and in both industries. In particular, the time trend coefficient is significant at the 5

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[9] NAICS: North American Industry Classification System. See Baldwin *et* al. (2007) for details on the methodology used to produce the data set.
[10] Baldwin and Gu (2007) explain the estimation methods for capital services.
[11] All reported elasticities are estimated at the middle year of the sample period. The estimated values for the remaining years are displayed in tables and graphs.

percent level. Moreover, the relatively high values obtained for R^2 in both specifications show that the models fit the data well.

To check for the concavity property of the estimated Translog cost function, we compute the eigenvalues of the estimated Hessian matrix at the middle year of the sample period. They fail to meet the criteria for the matrix to be negative semi-definite, meaning that the estimated Translog cost function is not concave in prices at the middle year of the sample period.

In contrast, the estimated SGM cost function satisfies the concavity property at each data point, since the estimated $\hat{S}$ matrix is negative semi-definite[12]. We will therefore devote most of our discussions to the results with the SGM specification that are our preferred. Tables 5 and 6 report the price elasticities and Morishima elasticities of substitution evaluated at the middle year of the sample period. The empirical estimates obtained using Translog and SGM specifications are mostly similar, however, there are some sharp differences in few cases.

Before discussing our results in detail, it is worth clarifying the nature of our elasticities. Are these short- or long-run elasticities? Even though we use a long-run cost function, viewed from a microeconomic perspective whereby the capital stock is variable, we estimate short-run elasticities from an econometric perspective. Indeed, on the one hand, we use annual time-series data that are sensitive to short-run fluctuations and, on the other hand, our econometric specification does not account for intertemporal dynamic factor adjustments that would make it possible to disentangle between short- and long-run price effects, as suggested by Griffin and Gregory (1976). In this respect, the elasticities provided in this study should be considered short-run elasticities.[13]

Regarding the price elasticities in Tables 7 and 8, all estimated own-price elasticities are of the right sign, i.e., negative. Moreover, they are all less than unity in absolute value, meaning that the derived demand for these inputs is inelastic in both industries. This is an indication of the potential vulnerability of these industries to an increase in factor prices.

However, energy appears to be the most elastic factor among the four inputs in both industries as it has the highest own price elasticity in absolute terms. These results suggest that both industries have a larger ability to cope with an increase in the price of energy than with the prices of other factors. It is worth noticing that the estimated elasticities from Translog specification are in most cases larger in magnitude than the ones estimated from the SGM model. There is no theoretical justification for this; we conjecture that the failure of the estimated Translog cost function to satisfy the concavity property could be one of the reasons explaining these differences.

The point estimates of the Morishima elasticities of substitution are positive for all pairs of inputs for both specifications. This seems to indicate that most of these inputs are substitutes in both industries. However, the estimates are less than one in both industries and for all pairs of factors.

The point estimates of the substitution elasticities between energy and other inputs also deserve some attention. Referring to the SGM specification, the results in Tables 5 and 6 indicate that energy is the most substitutable in the Metal industry since the ratios of other inputs to energy are most sensitive to the change in energy prices. For example, using the results in the SGM specification for Metal industry and keeping the level of output constant, the ratio of capital to energy will increase

[12] None of its eigenvalues is strictly positive.

[13] In contrast, using time-series data, a dynamic econometric specification that accounts for cointegration among variables in an error-correction setting could make it possible to estimate long-run elasticities. See Silk and Joutz (1997) and Chritopolous (2000), among others, for details on this approach. We are grateful to an anonymous referee for reminding us to clarify these issues.

by 0.54 percent if the price of energy increases by one percent. Similarly, a one-percent increase in the price of energy will increase the ratio of labor to energy by 0.54 percent in the same industry.

Thus, if we abstract from the differences in the point estimates obtained using the two specifications, the figures in Table 6 suggest that capital is substitutable for energy in both industries. As the Morishima elasticity is asymmetric, the input whose price change alters the price ratio matters for the change in the ratio of input quantities. For example, focusing on the results for the SGM specification, a one-percent increase in the price of energy would increase the ratio of capital to energy by 0.54 percent in the Metal industry. The same one-percent increase in the price of capital would only induce a 0.17 percent rise in the ratio of energy to capital in the same industry.

The advantages of substitutability between energy and other production factors are of a paramount importance for energy-intensive industries, especially in the current context of rising energy prices. For, if the substitution between the other factors and energy are positive, this will enhance the ability of firms to cope with increased energy prices. As a result, this will prevent large fall in output and employment and possibly spur growth through increase in capital stock following an increase in energy prices. This knowledge is useful for policymakers in the design of their energy policies or of any other policies that might affect the price of energy goods. For example, reducing the price of capital services, by granting firms investment tax credits, could be an interesting policy response to higher energy prices.

Our result on the substitutability between capital and energy is different from the one in the seminal study of Denny *et* al. (1978) who find that energy is a complement to capital in Canadian manufacturing industries. This difference is probably due to the level of aggregation and the sample period. Denny *et* al. (1978) consider data spanning from the period 1947 to 1970 for the entire Canadian manufacturing industry, while we use data from two subsets of the same manufacturing industry for the period 1961 to 2003. The difference between our results and theirs holds even when we use comparable study periods. Indeed, as depicted in Figures 1 and 2, our results suggest that capital and energy are still substitutes between 1961 and 1970, which is the common period between our study and theirs.

The results obtained by Andrikopoulos et al. (1989) in their estimation of elasticities of substitution between pairs of factors for a Canadian provincial (Ontario) primary metal industry for the period 1962-82 deserve some attention, as their industry coverage includes one of our specific industries (primary metal).[14] They find that capital is a substitute to both energy and labor in the primary metal industry, which is consistent with our findings. As far as the elasticity between labor and energy are concerned, their results suggest that these factors are complements while our study suggests that they are substitutes.[15]

In comparing our results with those of the other researches conducted on different manufacturing industries in Canada or in other countries, the following studies are worth mentioning. Gervais *et* al. (2008) find that energy is a substitute to all other production factors in their study on the Canadian food-processing industries for the period 1990-1999.[16] This finding is consistent with our results. In the same vein, Taher and McMillan (1984), using data on seven two-digit Canadian manufacturing industries for the period 1961-76, find that capital and energy are

[14] They use a Translog cost function and unfortunately, they report on Allen substitution elasticities instead of the Morishima elasticities.
[15] It is worth mentioning that their estimation of the Translog cost function fails as well to satisfy the concavity property since they report a positive value for an own factor-price elasticity.
[16] It is interesting to mention that Gervais et al. (2008) make their inference using the Morishima elasticity of substitution.

substitutes in respectively, food, wood, paper and non-metallic industries. However, they find that capital and energy are complements in respectively, metal, non-metallic and petroleum industries.

As referred to, earlier in this paper, Berndt and Wood (1975), find that energy is a substitute for capital but a complement of labour, using the U.S. manufacturing sector data spanning the period 1947-71. Along the same lines, results from Hisnanick and Kyre (1995), based on their study of US manufacturing for the period 1958-85 suggest that capital and non-electric energy are substitutes, while labor and non-electric energy are complements. Finally, using data of the Greek manufacturing industry for the period 1970-90, Christopoulos (2000) find that energy is a substitute to each of all the other production factors.

We would like to call the reader's attention to some potential pitfalls in comparing our results to those of the above-mentioned studies. Beyond the divergence that might stem from differences in industry coverage and model specifications, we inferred on the substitutability between factors based on Morishima elasticity in our study, and by using the Allen elasticity in the others, (except in Gervais et al., 2008). It is well known that Allen elasticities tend easily to characterize factors as complements, while the opposite is true with the Morishima elasticities. Moreover, the comparison of our results with those in other studies is further complicated by the fact that most of them do not provide confidence intervals of their estimates as we do in the present study and discuss further below in this paper.

Elasticities over time

The reported elasticities in Tables 5-8 are calculated at the middle year of the sample period. These elasticities do vary over time and their evolution is shown in Tables 9-12 and Figures 1 to 4.[17] As depicted in these graphs and tables, the own-price elasticities of labor and energy have increased in absolute value since the early '80s in both industries. The own-price elasticity of capital increased in the Cement industry, and a clear pattern is evident for the same factor in the Metal industry. As far as energy is concerned, its own-price elasticity increased in absolute value in both industries.

However, in the Cement industry, there is a more pronounced increase in the absolute value of the own-price elasticity of energy after the second oil shock in 1979. The observed trend of that elasticity in both industries indicates that firms have learned over time to cope better with higher energy prices. Still, this behavioural response from the firm perspective does not match with recent empirical evidence obtained from the household perspective, as suggested in Hughes et al. (2006) for the U.S. These authors find that the own-price elasticity of gasoline has decreased in absolute values in the U.S.

Nevertheless, our results on the dynamic response of firms to change in energy prices over time is confirmed by several other studies, which find, for example, that the substitution elasticity between capital and energy increased in several industries and several countries after the second oil shock in 1979. Bernard et al. (2007), Ilmakunnas and Törmä (1989), and Koetse et al. (2008) are some examples among others. Indeed, there is a link between the Morishima elasticity and the own-price elasticity. Referring to the formula of the Morishima elasticity (Eq. 8.b) between capital and energy for example, the higher the absolute value of the own-price elasticity of energy, the higher is the value of the Morishima elasticity. As shown in Figures 3-4, it may be noted that the elasticity of substitution between capital and energy increased after 1980 as well, sharply in the Cement industry and at a moderate pace in the Metal industry.

[17] Due to space constraints and for better clarity, we elect to display only the graphs for the elasticities in SGM estimation, which respects globally the theoretical curvature properties expected from any regular cost function. Moreover, we display only the graphs of elasticities related to changes in energy prices.

As mentioned, before, the increase over time of the absolute value of the own-price elasticity of energy would make it easier for the firms to adjust to the rise in energy price in the future. Still the magnitude of the elasticity is still low (less than unity in absolute value).

Confidence intervals

Tables 5 to 8 report the 95-percent bootstrap-t confidence intervals for the price and substitution elasticities. Concerning the own-price elasticities, the reported confidence intervals confirm their negative sign and their small magnitude (less than 0.50 in absolute terms in most cases). This indicates that the demands for all inputs are inelastic in both industries.

In general, the computed confidence intervals of the Morishima elasticities tend to support our initial claim that most of the production factors are pairwise substitutes in both industries. In particular, considering both specifications, the lower bounds of the confidence intervals between, on the one hand, capital and energy, and, on the other hand, labour and energy, are positive. This corroborates our initial assertion of substitutability of energy by both capital and labour. Under these circumstances, the frequently cited complementarity between capital and energy is not supported by our results, for both industries. Still, the ease of this substitutability is not great, as none of the upper bound of the 95-percent confidence interval is higher than one. The highest upper bound of the Morishima confidence intervals is 0.69, observed in the Metal industry between capital and energy. This is an indication of the vulnerability of these industries to an increase in energy prices. As alluded to above, this vulnerability is more pronounced in the Cement industry than in the Metal industry, as the upper bound of the confidence interval between capital and energy is 0.52 in the former vs. 0.69 in the latter.

Besides, there are a few instances where the confidence intervals span positive and negative values. As shown in Table 6 for the SGM specification, the lower and upper bounds of the confidence interval of the substitution elasticity between capital and labour in the Cement industry are respectively -0.03 and 0.30, while the estimate is 0.14. In most of the cases where the confidence interval of the Morishima elasticity spans negative and positive values, the lower bound is too small in absolute value, i.e., very close to zero at the second decimal. The only exception relates to the Morishima elasticity between capital and material in both industries. For example, the lower and upper bounds of the elasticity of substitution between capital and material are, respectively, -0.18 and 0.12, in the Cement industry, while the estimate itself is close to zero, i.e., 0.05.

4. Concluding remarks

The economics of energy substitution has a vital importance in the design of energy and environmental policies. In this paper, we have estimated the price and Morishima substitution elasticities between energy and other production factors in two Canadian manufacturing industries, using annual industry-level data (1961-2003). The estimation has been based on two second-order flexible functional forms - the Translog and the SGM cost functions. The advantage of the SGM cost function is that concavity can be imposed globally without destroying its flexibility property. While this restriction ensures that the results derived from that specification satisfy economic theory, it introduces nonlinearity in the econometric estimation of the parameters.

In addition to providing the point estimates of these elasticities between pairs of inputs, we have also computed their confidence intervals using bootstrap-t resampling techniques. The reported confidence intervals would be useful for numerical modellers who would like to perform sensitivity analysis of their results to the values of elasticities of substitution. Although the estimated parameters obtained from the Translog specification failed ex-post to be globally concave, the computed elasticities using this functional form are in general qualitatively consistent with the ones obtained using the SGM specification.

The common observation emerging from the point estimates of elasticities of substitution for both industries, evaluated at the middle year of the sample period, is that all four inputs are pairwise substitutes, since all the estimated Morishima elasticities are positive. The magnitudes of the point estimates of these elasticities are lower than one. Still, in a small number of cases that are mostly related to the material input, the estimated confidence intervals span both positive and negative values. Besides, based on the 95-percent-level confidence intervals for these elasticities, we cannot reject the hypothesis that their magnitudes are lower than one. This suggests that substitution elasticities between inputs in the two industries are not as large as the findings from other studies seem to suggest.

Finally, energy seems to be the most substitutable factor in both industries. Our results indicate that the two industries are, to some extent, capable of coping with an increase in the price of energy more than they are with the prices of the other factors. However, the low magnitude of these elasticities does not seem to offer great flexibility for these industries to adapt to high increases in energy prices. The Cement industry appears to be the most vulnerable of the two industries to an increase in the price of energy.

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Appendix

Once the parameters of the system of equations are estimated, denote by $\hat{\Omega}$ the vector of elasticities of interest, by $\hat{Q}$ the vector of predicted dependent variables, and by $\hat{e}$, the sample of the residuals, which are rescaled by the factor $(n/(n-p))^{1/2}$, where n is the number of observations and p the number of regressors plus one. The rescaling of the residuals is performed to keep the pattern of disturbances across equations.

After rescaling the residuals, we form a new sample of residuals e^* by a random uniform draw with replacement of the residual vector $\hat{e}$.

Next, we obtain a new bootstrap vector of the dependent variable (Q^*) by adding the re-sampled vector of the residual, e^*, to the predicted vector of dependent variables, $\hat{Q}$: $Q^* = \hat{Q} + e^*$.

We estimate the system of equations once more with the bootstrap vector Q^* as dependent variables to form a bootstrap estimate of the elasticities. The procedure is repeated J times to obtain the bootstrap estimates of the elasticities $\hat{\Omega}^*_j$. We compute their standard deviation $s(\hat{\Omega}^*_j)$ to approximate s_Ω, the unknown standard error of $\hat{\Omega}$. In this procedure, we set the number, J, of replications in the first bootstrap to 1999. Several authors have suggested using a very large number (higher than 1000) of replications in the first-level bootstrap.

For each of the J bootstrap samples, the rescaled residuals, e^{**}, are computed and added to the vector of predicted variables $\hat{Q}^*$ to form a new vector of dependent variables, Q^{**}. The system of equations is subsequently estimated K times using the vector Q^{**} as dependent variables to compute the bootstrap estimates of the elasticities, $\hat{\Omega}^{**}_{jk}$. We compute the standard deviation, $s(\hat{\Omega}^{**}_{jk})$, of the K estimates of the elasticities for each jth first-level bootstrap and use it to approximate the unknown standard error, s^*_j, of the estimate $\hat{\Omega}^*_j$. The number, K, of replications in the second-level bootstrap is set to 250 as several authors have suggested that a number of replications larger than 100 is adequate for the estimation of the standard errors.

Besides, for each of the J replications, we compute the values of the percentile-t statistic t^*_j as:

$$t^*_j = (\hat{\Omega}^*_j - \hat{\Omega}) / s(\Omega^{**}_{jk}) .$$

These values are then are ordered from the smallest value to the largest. We find the ($\alpha/2$) and (1-$\alpha/2$) quantiles of the distribution, which are, respectively, the ($(J+1)\alpha/2$)th and ($(J+1)(1-\alpha/2)$)th values of the list to compute the (1-α)-level confidence interval as follows:

$$\left[\hat{\Omega} - s(\hat{\Omega}^*_j).t^*_{(J+1)(1-\frac{\alpha}{2})} , \hat{\Omega} - s(\hat{\Omega}^*_j).t^*_{(J+1)\frac{\alpha}{2}} \right]$$

Table 1: Summary statistics for the Metal industry:1961-2003

Variables	Mean	Standard deviation	Minimum	Maximum
Price index of capital	35.77	28.56	3.29	100
Price index of labour	52.29	34.15	10.13	104.36
Price index of energy	55.85	34.74	10.7	109.24
Price index of material inputs	60.11	30.34	18.6	101.11
Quantity index of capital	84.44	20.75	44.72	121.09
Quantity index of labour	101.51	10.97	71.49	122.07
Quantity index of energy	86.4	16.93	52.86	118.28
Quantity index of material inputs	60.97	20.66	27.06	100
Share of capital in total cost	9.03	2.97	1.06	14.14
Share of labour in total cost	20.16	2.52	15.76	26.06
Share of energy in total cost	7.81	1.57	5.17	10.77
Share of material inputs in total cost	63	1.84	59.25	65.63
Output	64.08	19.21	31.06	100

Table 2: Summary statistics for the Cement industry: 1961-2003

Variables	Mean	Standard deviation	Minimum	Maximum
Price index of capital	37.29	29.13	7.92	105.61
Price index of labour	51.3	30.81	10.3	100.71
Price index of energy	46.81	33.2	6.9	106.72
Price index of material inputs	57.2	31.25	16.37	100
Quantity index of capital	96.78	15.37	68.76	127.49
Quantity index of labour	82.92	11.11	56.36	110.29
Quantity index of energy	110.56	26.27	74.98	187.4
Quantity index of material inputs	59.43	16.16	28.65	105.96
Share of capital in total cost	17.54	3.17	9.51	22.57
Share of labour in total cost	24.38	1.54	21.59	28.17
Share of energy in total cost	6.91	1.18	5.34	9.26
Share of material inputs in total cost	51.17	2.39	46.82	56.93
Output index	65.99	15.2	32.91	103.81
Total cost index	2579	1783	335	6751

Table 3. Estimated coefficients of Translog input cost shares for the Metal and Cement industries

Coefficients	Metal industry		Cement Industry	
	Estimates	Standard errors	Estimates	Standard errors
Capital share equation				
w_K	0.0440	0.0024	0.0925	0.0057
w_L	-0.0215	0.0020	-0.0394	0.0036
w_E	-0.0057	0.0019	-0.0115	0.0038
T	0.0005	0.0001	-0.0011	0.0002
Constant	0.1029	0.0035	0.2341	0.0070
R^2	0.8851		0.8860	
Labour share equation				
w_K	-0.0215	0.0020	-0.0394	0.0036
w_L	0.1172	0.0133	0.1072	0.0137
w_E	0.0070	0.0055	-0.0309	0.0057
T	-0.0035	0.0003	-0.0001	0.0002
Constant	0.2838	0.0094	0.2292	0.0070
R^2	0.9228		0.8091	
Energy share equation				
w_K	-0.0057	0.0019	-0.0115	0.0038
w_L	0.0069	0.0055	-0.0309	0.0057
w_E	0.0522	0.0057	0.0444	0.0061
T	-0.0054	0.0002	-0.0008	0.0002
Constant	0.0972	0.0060	0.0903	0.0070
R^2	0.7776		0.6230	
Test of the overall significance	235.30		204.60	
P-value	0.0000		0.0000	

Table 4. Estimated coefficients of SGM input equations for the Metal and Cement industries

Coefficients	Metal industry		Cement industry	
	Coefficients	Standard errors	Coefficients	Standard errors
a_{KK}	6.899	0.701	8.343	0.900
a_{KL}	-3.237	1.183	-2.109	2.737
a_{KE}	-8.113	1.882	-10.431	1.558
a_{LL}	-9.366	1.015	-8.099	2.181
a_{LE}	8.755	0.971	3.321	5.237
a_{EE}	0.000	3.593	0.000	7.388
b_{Kt}	-0.008	0.170	-0.024	0.002
b_{KK}	1.426	0.384	1.943	0.043
b_{Lt}	-0.029	0.158	-0.011	0.002
b_{LL}	2.378	0.376	1.554	0.029
b_{Et}	-0.012	0.242	-0.034	0.002
b_{EE}	1.760	0.607	2.592	0.045
b_{Mt}	0.001	0.890	0.000	0.001
b_{MM}	0.877	0.122	0.789	0.032
R^2 values				
Capital equation	0.796		0.8165	
Labour equation	0.9135		0.7367	
Energy equation	0.4251		0.9241	
Material equation	0.6169		0.1156	
Residual variances				
Capital equation	0.0151		0.0178	
Labour equation	0.0146		0.0072	
Energy equation	0.0385		0.0203	
Material equation	0.0014		0.0071	
Log likelihood	219.7		163.1	

Table 5: Point estimates and bootstrap-t confidence intervals for Morishima elasticities of substitution for the Metal industry
(Middle year of the sample period)
SGM and Translog specifications

	SGM			Translog		
	Point estimates	95 % bootstrap-t confidence interval		Point estimates	95 % bootstrap-t confidence interval	
		Lower bound	Upper bound		Lower bound	Upper bound
KL	0.19	0.12	0.24	0.14	-0.01	0.30
KE	0.54	0.42	0.69	0.36	0.26	0.47
KM	0.00	-0.10	0.01	0.52	0.36	0.68
LK	0.09	0.07	0.11	0.34	0.26	0.42
LE	0.54	0.42	0.68	0.47	0.35	0.59
LM	0.10	0.01	0.16	0.24	0.00	0.49
EK	0.17	0.13	0.21	0.39	0.29	0.48
EL	0.39	0.29	0.48	0.49	0.27	0.73
EM	0.17	0.08	0.22	0.16	-0.12	0.44
MK	0.00	-0.03	0.01	0.42	0.33	0.50
ML	0.21	0.10	0.29	0.25	0.04	0.48
ME	0.52	0.40	0.66	0.35	0.20	0.49

Table 6: Point estimates and bootstrap-t confidence intervals for Morishima elasticities of substitution for the Cement industry
(Middle year of the sample period)
SGM and Translog specifications

	SGM			Translog		
	Point estimates	95 % bootstrap-t confidence interval		Point estimates	95 % bootstrap-t confidence interval	
		Lower bound	Upper bound		Lower bound	Upper bound
KL	0.14	-0.03	0.30	0.29	0.16	0.42
KE	0.37	0.24	0.52	0.39	0.28	0.53
KM	0.05	-0.18	0.12	0.55	0.38	0.74
LK	0.12	0.05	0.17	0.16	0.04	0.29
LE	0.26	0.05	0.47	0.36	0.18	0.53
LM	0.19	-0.08	0.39	0.71	0.53	0.88
EK	0.20	0.16	0.25	0.18	0.07	0.28
EL	0.20	0.00	0.38	0.22	-0.02	0.45
EM	0.17	-0.06	0.25	0.84	0.59	1.09
MK	0.00	-0.09	0.04	0.24	0.09	0.38
ML	0.27	0.00	0.59	0.51	0.34	0.67
ME	0.30	0.05	0.48	0.48	0.31	0.65

Table 7: Point estimates and bootstrap-t confidence intervals for price elasticities for the Metal industry
(Middle year of the sample period)
SGM and Translog specifications

	SGM			Translog		
	Point estimates	95 % bootstrap-t confidence interval		Point estimates	95 % bootstrap-t confidence interval	
		Lower bound	Upper bound		Lower bound	Upper bound
KK	-0.09	-0.11	-0.07	-0.37	-0.44	-0.29
KL	-0.01	-0.04	0.03	-0.07	-0.13	-0.02
KE	0.19	0.14	0.25	0.02	-0.03	0.07
KM	-0.09	-0.13	-0.07	0.41	0.31	0.51
LK	0.00	-0.01	0.01	-0.03	-0.05	-0.01
LL	-0.19	-0.23	-0.14	-0.21	-0.38	-0.05
LE	0.19	0.15	0.24	0.13	0.06	0.19
LM	0.01	-0.03	0.03	0.13	-0.04	0.30
EK	0.08	0.06	0.11	0.02	-0.02	0.06
EL	0.20	0.15	0.26	0.28	0.14	0.42
EE	-0.35	-0.45	-0.27	-0.34	-0.46	-0.22
EM	0.07	0.05	0.10	0.05	-0.17	0.27
MK	-0.09	-0.13	-0.07	0.05	0.04	0.07
ML	0.01	-0.06	0.08	0.04	-0.01	0.10
ME	0.17	0.11	0.23	0.01	-0.03	0.04
MM	-0.09	-0.13	-0.02	-0.11	-0.19	-0.03

Table 8: Point estimates and bootstrap-t confidence intervals for price elasticities for the Cement industry
(Middle year of the sample period)
SGM and Translog specifications

	SGM			Translog		
	Point estimates	95 % bootstrap-t confidence interval		Point estimates	95 % bootstrap-t confidence interval	
		Lower bound	Upper bound		Lower bound	Upper bound
KK	-0.12	-0.15	-0.09	-0.18	-0.29	-0.07
KL	0.00	-0.06	0.05	-0.03	-0.10	0.03
KE	0.20	0.16	0.27	0.00	-0.06	0.06
KM	-0.08	-0.13	-0.05	0.22	0.10	0.35
LK	0.00	-0.05	0.04	-0.02	-0.05	0.01
LL	-0.15	-0.28	-0.01	-0.33	-0.44	-0.20
LE	0.09	-0.03	0.21	-0.04	-0.09	0.02
LM	0.06	-0.03	0.16	0.38	0.27	0.49
EK	0.08	0.06	0.12	0.00	-0.09	0.10
EL	0.05	-0.01	0.12	-0.11	-0.27	0.06
EE	-0.17	-0.27	-0.07	-0.39	-0.55	-0.25
EM	0.03	-0.01	0.06	0.51	0.31	0.72
MK	-0.12	-0.21	-0.08	0.06	0.02	0.09
ML	0.12	-0.06	0.34	0.19	0.13	0.24
ME	0.13	-0.03	0.23	0.08	0.05	0.11
MM	-0.13	-0.22	0.07	-0.33	-0.40	-0.26

Table: 9 **Morishima elasticities of substitution in the Metal industry in different years SGM specification**

	1961	1966	1971	1976	1981	1986	2001	2002	2003
KL	0.17	0.19	0.22	0.19	0.19	0.22	0.33	0.34	0.34
KE	0.36	0.35	0.35	0.48	0.54	0.54	0.55	0.52	0.56
KM	0.00	0.00	0.00	0.01	0.00	0.00	-0.01	-0.02	-0.02
LK	0.13	0.14	0.00	0.07	0.09	0.10	0.03	0.22	0.25
LE	0.32	0.30	0.33	0.49	0.54	0.57	0.62	0.56	0.63
LM	0.09	0.09	0.11	0.13	0.10	0.09	0.09	0.08	0.08
EK	0.20	0.21	0.17	0.12	0.17	0.17	0.24	0.29	0.27
EL	0.22	0.22	0.27	0.39	0.39	0.45	0.51	0.46	0.52
EM	0.12	0.11	0.13	0.18	0.17	0.13	0.11	0.09	0.10
MK	0.00	0.00	-0.13	-0.01	0.00	0.01	0.03	0.04	0.03
ML	0.19	0.21	0.24	0.22	0.21	0.24	0.34	0.34	0.35
ME	0.35	0.33	0.34	0.47	0.52	0.51	0.49	0.46	0.50

Table: 10 **Morishima elasticities of substitution in the Cement industry in different years SGM specification**

	1961	1966	1971	1976	1981	1986	2001	2002	2003
KL	0.16	0.17	0.20	0.18	0.14	0.15	0.18	0.18	0.17
KE	0.26	0.26	0.27	0.33	0.37	0.44	0.62	0.64	0.66
KM	0.09	0.07	0.07	0.06	0.05	0.03	0.00	0.00	0.00
LK	0.14	0.17	0.00	0.17	0.12	0.20	0.13	0.37	0.38
LE	0.14	0.14	0.15	0.20	0.26	0.27	0.37	0.39	0.41
LM	0.23	0.20	0.22	0.20	0.19	0.15	0.13	0.13	0.13
EK	0.20	0.23	0.06	0.25	0.20	0.33	0.53	0.52	0.53
EL	0.14	0.13	0.15	0.17	0.20	0.17	0.18	0.19	0.19
EM	0.18	0.14	0.15	0.15	0.17	0.12	0.10	0.11	0.11
MK	-0.02	0.00	-0.18	0.00	0.00	0.04	0.13	0.13	0.12
ML	0.30	0.30	0.34	0.31	0.27	0.25	0.25	0.26	0.26
ME	0.24	0.21	0.21	0.25	0.30	0.33	0.43	0.44	0.46

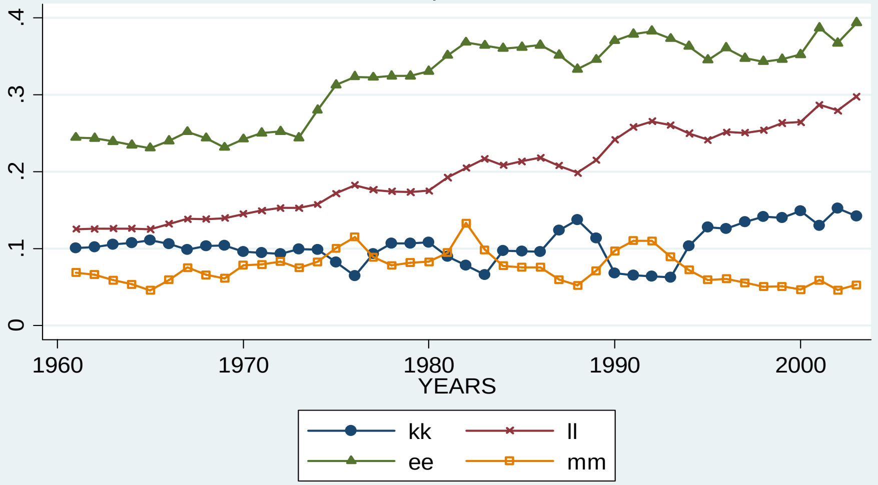
Table: 11 Own-price elasticities in the Metal industry in different years
SGM specification

	1961	1966	1971	1976	1981	1986	2001	2002	2003
KK	-0.10	-0.11	-0.09	-0.06	-0.09	-0.10	-0.13	-0.15	-0.14
LL	-0.13	-0.13	-0.15	-0.18	-0.19	-0.22	-0.29	-0.28	-0.30
EE	-0.24	-0.24	-0.25	-0.32	-0.35	-0.36	-0.39	-0.37	-0.39
MM	-0.07	-0.06	-0.08	-0.12	-0.09	-0.08	-0.06	-0.05	-0.05

Table: 12 Own-price elasticities in the Cement industry in different years
SGM specification

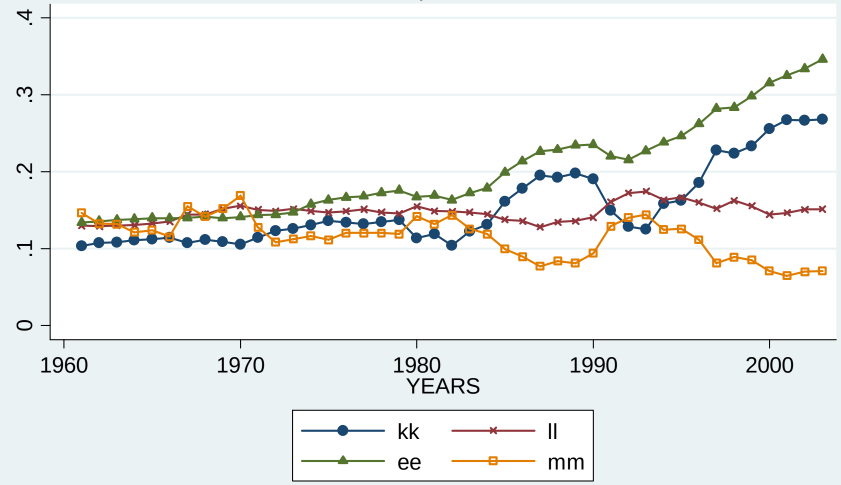
	1961	1966	1971	1976	1981	1986	2001	2002	2003
KK	-0.10	-0.11	-0.11	-0.13	-0.12	-0.18	-0.27	-0.27	-0.27
LL	-0.13	-0.14	-0.15	-0.15	-0.15	-0.14	-0.15	-0.15	-0.15
EE	-0.13	-0.14	-0.14	-0.17	-0.17	-0.21	-0.33	-0.33	-0.35
MM	-0.15	-0.12	-0.13	-0.12	-0.13	-0.09	-0.07	-0.07	-0.07

Fig 1: Evolution of own-price elasticities in the Metal Industry
SGM specification



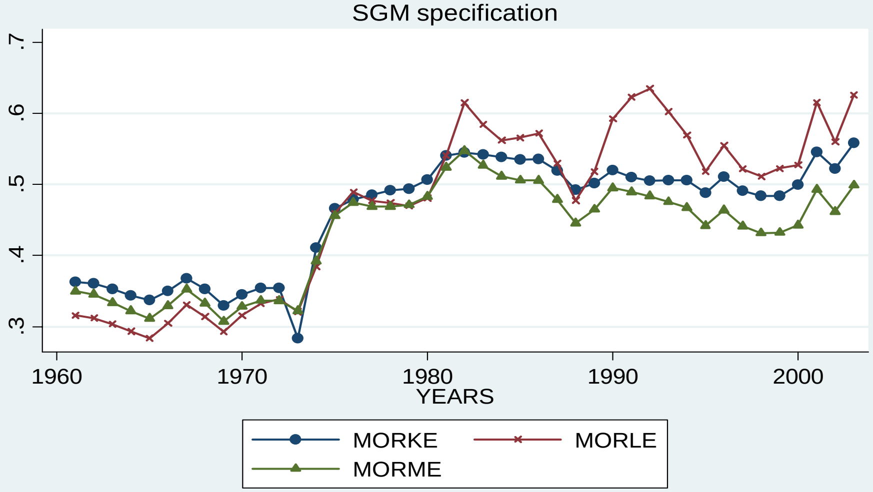
Source: Authors' calculations

Fig 2: Evolution of own-price elasticities in the Cement Industry
SGM specification



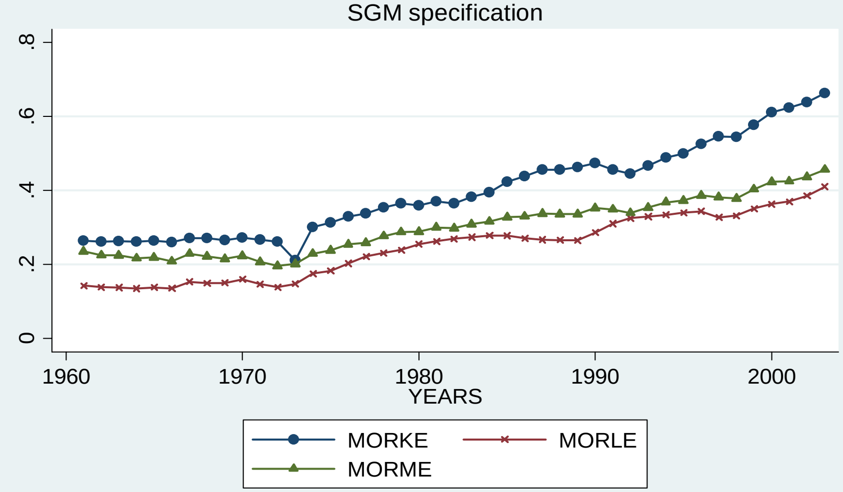
Source: Authors' calculations

Fig 3: Evolution of Morishima elasticities in the Metal Industry
SGM specification



Source: Authors' calculations

Fig 4: Evolution of Morishima elasticities in the Cement Industry
SGM specification



Source: Authors' calculations