Resource and Energy Economics 59 (2020) 101130

Contents lists available at ScienceDirect

Resource and Energy Economics

journal homepage: www.elsevier.com/locate/ree

Energy import costs in a flexible input-output price model

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ARTICLE INFO

Article history:
Received 8 April 2019
Received in revised form 31 October 2019
Accepted 2 November 2019
Available online 11 November 2019

JEL classification:
C67
D57
Q41
Q43

Keywords:
Energy import prices
Price impacts
Input-output model
Primary inputs
Substitution possibilities

ABSTRACT

A fundamental assumption of the input-output (IO) model is a fixed relationship between interindustry flows. In the price version of the model, the assumption of fixed-coefficients prevents the optimal mix of inputs being adjusted when relative prices change. The aim of this paper is to evaluate the role of energy import prices in the IO price model without the usual non-substitution technology inherent to the input-output structure. The analysis includes alternative substitution possibilities for the elements that comprise the sectoral costs, which are empirically implemented from an IO dataset. The various substitution scenarios are defined by three different cost structures: the Leontief, Cobb-Douglas and Constant Elasticity of Substitution (CES) functions. The empirical application to the Catalan economy illustrates the relevance of the flexibility option used for explaining the quantitative influence of energy import prices on domestic prices. Adapting the traditional input-output model to include factor substitution makes it possible to overcome the rigidity in transmitting price impacts, and illustrates a range of possible effects.

1. Introduction

Energy is of crucial importance for economic growth and human welfare. As societies become more developed, not only does the production system need more energy but individuals also demand more energy. This explains the uninterrupted incremental trend in energy consumption over the last century.[1]

For economies that have few energy sources, importing energy makes it possible to maintain a consumption level in accordance with productive and social requirements. Nonetheless, dependence on external energy sources can place the internal economy in a vulnerable situation, depending on both the conjuncture and the strategic decisions of the energy exporting economies. In the seventies, the oil crisis made it evident that domestic prices could be extremely sensitive to energy import prices in countries with low energy resources,[2] since internal uses of energy were highly inelastic to prices. This seemed to be especially true in the short-to-medium term.

The input-output (IO) price model has been used extensively to assess the impact on sectoral prices of an increase in the elements that comprise the sectoral costs. In particular, the impacts on domestic prices caused by exogenous shocks in

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[1] According to the International Energy Agency (IEA, 2019), during the period 1971-2016 the total energy consumption in the OECD countries rose by 43% (from 2,563 Mtoe in 1971 to 3,669 Mtoe in 2016) and world total primary energy supply increased by around 2.2 times during the same period.

[2] From 1970 to 2018, the annual average price of barrel crude oil (adjusted to inflation) increased by 260% (InflationData, 2019).

https://doi.org/10.1016/j.reseneeco.2019.101130

energy costs have generated many input-output contributions.[3] IO models are relatively easy to use and interpret, and can be adapted to assess economic and environmental issues in small scale economies. However, a fundamental limitation of the Leontief model for analysing price effects is the assumption that input requirements are fixed. This does not take into account that sectors can adapt their cost structure when relative prices of primary inputs change. This weakness is usually defended with the idea that the Leontief price version provides an upper bound of the possible price impacts of an exogenous cost increase, which could be consistent with producers' behaviour in the short-term.

Broadly speaking, two extreme approaches have been used to overcome the rigidity inherent to the Leontief price framework. One approach consists of modifying part of the input-output structure to encompass a degree of flexibility. In general, this type of approach modifies certain structural coefficients and exogenously introduces them into the model. An example is the contribution by Truchon (1984), who presented a method for inducing changes in selected coefficients of the price model in response to changes in prices, by exogenously specifying the values of some elasticities. In parallel, Duchin and Lange (1995) proposed an endogenization procedure for the substitution possibilities within an input-output price model, exogenously defining technological alternatives to ensure that firms could use current technologies. Kratena (2005) combined econometric factor demand functions and price equations with a conventional input-output price model to capture both the influence of output prices on input prices, and the feedback of factor demand changes on technical coefficients.

The other approach to include flexibility in the cost structure is the computable general equilibrium (CGE) framework, which completely endogenously defines the choice of all inputs and other primary factors as well as the final demand of institutional agents. In CGE, all the elements that comprise the production functions can potentially vary according to changes accrued in relative prices. However, an ad hoc criterium is adopted in the general equilibrium setting to determine the way in which the input structure adapts because the production functions in CGE modelling can respond to various mathematical relationships.[4] At the empirical level, the general equilibrium models require the input-output relationships to be extended to include the income and demand relationships of all the economic agents (production sectors, consumers, public administration, and foreign agents). Both the technical refinements and the (higher) empirical requirements make the general equilibrium analysis an alternative to the input-output framework.

In summary, in the first approach the input-output structure is partially adapted to encompass more flexibility while in the second approach the input-output structure is completely substituted by a CGE model. It is possible to combine these two extreme approaches (i.e. IO and CGE models) by making all the model's coefficients completely endogenous and also limiting the analysis to an input-output price structure. Although it is useful to combine the input-output simplicity and the CGE flexibility, there are few contributions in this line. To the best of this author's knowledge, Sancho (1992) provides the only example of this approach, where he defines a completely flexible structure in the sectoral price mechanism. In this paper, the input-output dataset is used to calibrate three alternative cost structures (Leontief, Cobb-Douglas and Constant Elasticity of Substitution-CES).[5] The Leontief cost function defines the standard (rigid) input-output model, the Cobb-Douglas function represents an adjustment parameter approach, and the CES function represents a flexible parameter approach. Specifically, Sancho's proposal consisted of a novel method for simulating the cost-push price effects caused by exogenous changes in the sectoral wage rate when various degrees of factor substitution are considered. The results provided interval estimates of price impacts instead of the IO standard point estimates, thus broadening the possible price effects after exogenous wage rises. From an empirical point of view, one advantage of this proposal is that all the cost functions are directly and completely calibrated from the input-output database, so that all coefficients in the price structure are fully adjusted.

Within this perspective of price modelling, this study uses the approach developed by Sancho (1992) and explores the role of imports within the complex process of price transmission. As a starting point, the input-output price structure is used to subsequently define various degrees of substitution between primary productive factors. The additional substitution scenarios implemented in this paper are in line with the empirical estimates of trade elasticities available for some large and rich economies. These empirical findings show high (negative) values for import price elasticities, reflecting low consumers' fidelity to foreign goods and high domestic willingness to substitute domestic and foreign commodities (Imbs and Méjean, 2010).

In particular, the price model is applied to evaluate by how much the cost-shocks in the energy import prices alter the domestic prices depending on the substitution scenario considered. All the exogenous elements of the model are calibrated by using an input-output dataset. The simulation analysis consists of exogenously increasing the price of energy imports in Catalonia, a highly open Spanish region with high scarcity of energy sources. This turns the Catalan economy into an interesting case-study, which can suggest the type of impacts that may occur in other similar regions and economies facing energy

[3] For instance, Catsambas (1982) used an input-output price model to analyse the US petroleum taxation on the internal prices, Hughes (1986) quantified the price impacts of fuel taxes on the Thailand price levels, Bazzazan and Batey (2003) extended the input-output price model with the household sector and analysed energy price rises in Iran, Llop and Pié (2008) quantified the influence of energy policies on domestic prices and domestic incomes of Catalonia, Choi et al. (2010) analysed the impact of a carbon tax on the prices and physical flows of the US by integrating the IO price model and the price elasticity of demand, Choi et al. (2016) estimated the economy wide impacts of energy policies by using monetary and physical changes in sequential IO models for the US, and Chik et al. (2017) evaluated the influence of petroleum prices on Malaysian sectoral prices.

[4] See Shoven and Whalley (1992) and Cardenete et al. (2017) for a description of all the components in applied general equilibrium.

[5] Similarly, there are other alternative approaches within this research area that define substitution possibilities in the (dual) quantity-focused input-output model (see, for instance, Tokutsu (1994), Zhao et al. (2006), Gordon et al. (2009), and Klijs (2015)).

shortages and being dependent on energy imports. The results point out the importance of the substitution mechanisms for determining the quantitative impact of the imported energy sources on the domestic cost indices.

The rest of the paper is organized as follows. Section 2 describes the price model by showing three possible cost functions (Leontief, Cobb-Douglas and CES). Section 3 shows the impacts of increasing the price of energy imports on the Catalan sectoral costs. Finally, the last section makes some concluding remarks.

2. Input-output price model and substitution possibilities

2.1. Fixed coefficient technology

The starting point for measuring the influence of import prices on regional prices is the standard price-version of the input-output model. The Leontief framework does not allow any substitutions among the elements that comprise sectoral costs. By assuming a constant structure of sectoral payments, the basic relationship of the Leontief model in matrix notation can be written as:[6]

$$\begin{aligned} p &= A'p + Bq \\ &= [I - A']^{-1} Bq \end{aligned} \tag{1}$$

In this expression, p is the $n \times 1$ vector of sectoral prices, A' is the $n \times n$ transpose matrix of input-output coefficients, q is the $m \times 1$ vector of primary input prices, and B is the $n \times m$ matrix of coefficients for primary factors. Bearing in mind that in matrix terms the inverse of a transpose matrix is equal to the transpose of the inverse, it follows that $[I - A']^{-1}$ coincides with the transpose of the Leontief matrix: $[I - A]^{-1'}$.

Because the structure of the coefficients in matrix A (or, equivalently, $A^{'}$) is completely fixed, the price transmission impacts reflected in the model above do not allow the proportion of primary inputs to be adjusted. In other words, the standard Leontief model assumes that producers do not react to changes in relative prices by substituting certain primary inputs for others, and thus there is no process for modifying the optimal mix of factors.

2.2. Flexible coefficient technology

The production technology is not necessarily linear since some degree of substitutability among production factors can exist within the production system. When we accept that firms have the option of altering the optimal mix of primary inputs after cost shocks are received, we should move from the linear relationships to a definition of non-linearities able to capture factor substitution possibilities.

If primary factors can be substituted by each other, then matrix B in expression (1) is not necessarily constant and its values are sensitive to the price of primary factors (q). According to Sancho (1992), expression (1) can be transformed to:

$$p = \left[I - A^{'}\right]^{-1} B(q) q \tag{2}$$

showing that primary coefficients are dependent on the corresponding prices of primary factors ($B(q)$).

For empirical purposes, we need to define the connection between the primary input coefficients and the corresponding prices for these inputs. Without losing generality, in what follows primary inputs are limited to two different categories: value added and imports.[7] Then, production prices in sector i ($i = 1, 2, \cdots, n$) respond to the following expression:

$$p_i = \sum_{j=1}^{n} p_j a_{ji} + \sum_{m=1}^{2} b_{im}(q) q_m. \tag{3}$$

By assuming a fixed combination of primary factors and intermediate inputs to obtain the sectoral output, and defining a variable combination of the two elements that comprise primary inputs (i.e. value added and imports), expression (3) can be written as follows:[8]

$$p_i = \sum_{j=1}^{n} p_j a_{ji} + \sum_{m=1}^{2} v_i c_m(1/q),$$

that, in matrix notation, is:

$$p = \left[I - A^{'}\right]^{-1} \hat{V} c(1/q) \tag{4}$$

[6] See, for instance, Miller and Blair (2009) for a detailed description of this model.

[7] Differently to Sancho (1992), who considered labour and capital to analyse the price impacts of exogenous changes in wage, this paper considers value added and imports to analyse the price effects of the cost-shocks in imported energy.

[8] See Sancho (1992) for details.

In this expression, $\hat{V}$ is the $n \times n$ diagonal matrix of the coefficients v_i of primary factors, denoting the minimum amount of primary factors required to produce one unit of output in sector i, and $c(1/q)$ is the $n \times 1$ vector containing the elements of the unitary costs of primary inputs in each sector. Note that expression (4) is the result of an optimisation problem, since sectors minimise the cost of producing primary inputs subject to the existing technological relationship between primary inputs and their output. This output is interpreted as the composition of primary inputs required to obtain sectoral output.

Once the coefficients for primary inputs have been endogenously defined, the following step is to empirically implement the relationship in expression (4). This can be done by defining a specific functional form for the primary factor coefficients v_i. In what follows, let us assume that value added and imports are combined through a Cobb-Douglas aggregator:

$$v_i = \beta_i b_{1i}^{\propto_i} b_{2i}^{1-\propto_i} \quad (5)$$

where β_i is the scale parameter, $\propto_i$ is the share parameter and b_{1i} and b_{2i} are, respectively, the factor coefficients of value added and imports in sector i. The cost minimization problem in i $(i = 1, 2, \cdots, n)$ implies:

$$\min \; q_1 b_{1i} + q_2 b_{2i}$$

$$\text{subject to} \;\; v_i = \beta_i b_{1i}^{\propto_i} b_{2i}^{1-\propto_i}$$

From first-order conditions, the resulting Cobb-Douglas cost functions respond to:

$$c_i(v_i/q) = A_i q_1^{\alpha_i} q_2^{1-\alpha_i} v_i \quad (6)$$

being $c_i(1/q) = A_i q_1^{\alpha_i} q_2^{1-\alpha_i}$ the unitary cost of producing one unit of primary factors in sector i.

The empirical calculation of the exogenous parameters in expression (4) comprises the calibration of α_i and β_i. From cost minimisation, bearing in mind the tangency condition between the isoquants and isocosts it follows that:

$$\frac{q_1 b_{1i}}{q_2 b_{2i}} = \frac{\alpha_i}{1-\alpha_i}.$$

This expression can be easily modified by multiplying and dividing the left-hand side by sectoral gross output (X_i):

$$\frac{X_i q_1 b_{1i}}{X_i q_2 b_{2i}} = \frac{\alpha_i}{1-\alpha_i},$$

where the numerator on the left-hand side is the sector's total value added, and the denominator is the sector's total imports. Consequently, the share parameters α_i can be directly calculated by using the corresponding data for value added and imports available in the input-output table. Finally, β_i is obtained from expression (5) as follows:

$$\beta_i = \frac{v_i}{b_{1i}^{\alpha_i} b_{2i}^{1-\alpha_i}},$$

where the values for α_i and the coefficients b_{1i}, b_{2i}, and v_i can be directly calibrated from the input-output database. Once all parameters in expression (6) are known, it is possible to use the Cobb-Douglas cost function for simulation analyses of price impacts

Suppose now that expression (4) is defined by combining value added and imports following a constant elasticity of substitution function:

$$v_i = \mu_i[(a_{1i} b_{1i})^{\rho} + (a_{2i} b_{2i})^{\rho}]^{\frac{1}{\rho}} \quad (7)$$

where μ_i is the scale parameter, a_{1i} and a_{2i} are productivity parameters, and b_{1i} and b_{2i} are the factor coefficients of value added and imports, respectively, in sector i. In expression (7), the exponent is equal to $\rho = \frac{1+\sigma}{\sigma}$, being σ the elasticity of substitution between value added and imports.

Unlike the Cobb-Douglas cost function, which only has two coefficients to be determined, in the CES function there are four exogenous variables. To reduce one degree of freedom, we can use the following combinations of parameters: $\mu_i a_{1i}$ and $\mu_i a_{2i}$.[9] Moreover, as the elasticity of substitution σ cannot be directly obtained from calibration, it is necessary to make external econometric estimations for σ. Alternatively, some ad hoc values can be used to define an interval of various possible values.

The cost minimization problem in sector i $(i = 1, 2, \cdots, n)$, conditional to a given value for σ, can now be written as:

$$\min \;\; q_1 b_{1i} + q_2 b_{2i}$$

$$\text{subject to} \;\; v_i^{\rho} = \mu_i^{\rho} \left[(a_{1i} b_{1i})^{\rho} + (a_{2i} b_{2i})^{\rho}\right]$$

[9] Sancho (1992).

From first-order conditions, the resulting cost function for the CES structure is:

$$c_i\left(v_i/q\right) = \left[\left(\frac{q_1}{\mu_i a_{1i}}\right)^{\tau} + \left(\frac{q_2}{\mu_i a_{2i}}\right)^{\tau}\right]^{\frac{1}{\tau}} v_i \tag{8}$$

being $\tau = \frac{\rho}{\rho-1}$. By applying Shepard's lemma, the conditional demand for primary factor m ($m = 1,\ 2$) is equal to:

$$\frac{dc_i\left(v_i/q\right)}{dq_{mi}} = b_{mi} = c_i\left(v_i/q\right)\frac{\left(\frac{q_k}{\mu_i a_{mi}}\right)^{\tau-1}\frac{1}{\mu_i a_{mi}}}{\left(\frac{q_1}{\mu_i a_{1i}}\right)^{\tau} + \left(\frac{q_2}{\mu_i a_{2i}}\right)^{\tau}} \tag{9}$$

For calibration purposes, let us define the cost share of primary factors (s_{mi}) in relation to the unitary cost of value added for each sector i:

$$s_{mi} = \frac{q_k b_{mi}}{c_i(v_i/q)} \tag{10}$$

Substituting expression (9) into expression (10), it follows that:

$$s_{mi}^{\frac{1}{\tau}} = \frac{q_m}{\mu_i a_{mi}}\frac{1}{c_i(1/q_i)} \tag{11}$$

Using expression (11) for the two primary inputs and dividing one by the other:

$$\frac{\mu_i a_{1i}}{\mu_i a_{2i}} = \frac{q_1}{q_2}\left(\frac{s_{2i}}{s_{1i}}\right)^{\frac{1}{\tau}} \tag{12}$$

Subsequently, we can assume that prices are unitary in the benchmark equilibrium ($q_1 = q_2 = 1$). In addition, from the input-output data, the observable cost shares are defined as:

$$s_{mi} = \frac{q_m b_{mi} X_i}{c_i(v_i X_i/q)} \tag{13}$$

where the numerator is total value added or total imports, and the denominator is the total primary factors in sector i. Homogeneity of the CES function implies that $c_i(v_i X_i/q) = c_i(v_i/q)X_i$ and thus Eqs. (13) and (10) are exactly the same. We can therefore calculate the cost shares from input-output data and exogenously establish the value for the elasticity of substitution σ to obtain the ratios $\frac{\mu_i a_{1i}}{\mu_i a_{2i}}$.

By taking into account that the choice of units implies $c_i(v_i/q) = v_i$ and benchmark prices are unitary, expression (8) for the CES cost function becomes:

$$(\mu_i a_{1i})^{-\tau} + (\mu_i a_{2i})^{-\tau} = 1 \tag{14}$$

Eqs. (12) and (14) allow the complete determination of the exogenous variables in the CES function once parameter τ (or, alternatively, σ) has been specified exogenously.

Expressions (6) and (8) complement the (rigid) input-output price structure (expression (1)), since the new cost functions capture general equilibrium price impacts when substitution possibilities among primary factors are allowed.

The calibration procedure for the three cost functions (i.e. Leontief, Cobb-Douglas and CES) assumes unitary prices so that all the parameters exactly replicate the input-output data in the benchmark equilibrium. From this base scenario, the simulation analysis provides changes in absolute variations of sectoral prices that can be interpreted directly as percentage variations with respect to the benchmark unitary prices.

3. Empirical results for Catalonia

The preceding price framework was applied to Catalonia by using an input-output table with 2011 data. This dataset, published by the regional statistics office (IDESCAT, 2019), originally shows 82 sectors of production including three energy activities. In the IO table finally used, production sectors were aggregated in 17 differentiated accounts: Agriculture, three energy activities (Extraction of minerals and petroleum, Electrical energy, and Gas and water), five industrial activities (Food production, Machinery, Automobiles, and Other industries), Construction, and finally, seven service activities (Commerce, Transportation, Finance, Education, Health and social services, Public administration and Other services).

The input-output database can be used to calibrate all the parameters related to the alternative cost structures defined. The exception is the elasticity of substitution for the CES function (σ), which has been assumed to be equal to −1.5 and −2. These two values were chosen to complete the range of price impacts in the scenarios of substitution considered, and

Table 1
Price impacts of a 10 % price rise in imported petroleum.

SECTORS	LEONTIEF ($\sigma = 0$)	COBB-DOUGLAS ($\sigma = -1$)	CES ($\sigma = -1.5$)	CES ($\sigma = -2$)
1. Agriculture	1.0012	1.0011	1.0009	1.0008
2. Extraction of minerals, petroleum	1.0853	1.0799	1.0631	1.0602
3. Electrical energy	1.0067	1.0063	1.0049	1.0047
4. Gas and water	1.0372	1.0349	1.0275	1.0263
5. Food production	1.0012	1.0011	1.0009	1.0008
6. Chemistry	1.0057	1.0053	1.0042	1.0040
7. Machinery	1.0015	1.0014	1.0011	1.0011
8. Automobiles	1.0010	1.0009	1.0007	1.0007
9. Other industry	1.0014	1.0013	1.0011	1.0010
10. Construction	1.0015	1.0014	1.0011	1.0010
11. Commerce	1.0013	1.0012	1.0010	1.0009
12. Transportation	1.0064	1.0060	1.0048	1.0045
13. Finance	1.0004	1.0003	1.0003	1.0003
14. Education	1.0003	1.0002	1.0002	1.0002
15. Health and social services	1.0008	1.0007	1.0006	1.0006
16. Public administration	1.0007	1.0007	1.0005	1.0005
17. Other services	1.0005	1.0005	1.0004	1.0003
AGGREGATED EFFECTS	LEONTIEF ($\sigma = 0$)	COBB-DOUGLAS ($\sigma = -1$)	CES ($\sigma = -1.5$)	CES ($\sigma = -2$)
Consumption Prices	1.0039	1.0036	1.0029	1.0027
Production Prices	1.0047	1.0044	1.0035	1.0033
Change in Income (%)	0.5829	0.5461	0.4311	0.4112

oscillates between $\sigma = 0$ (Leontief function), $\sigma = -1$ (Cobb-Douglas function), $\sigma = -1.5$ (CES function), and $\sigma = -2$ (CES function).[10]

The simulation analysis is based on an exogenous increase of 10 % in the price of energy imports. The results obtained with the import cost-push are contrasted to the initial computation of the model in which all the sectoral prices are unitary. The difference between the new prices and the unitary ones provides the percentage of price rise in the new situation.

3.1. Increase in the price of imported petroleum

Table 1 shows the price impacts when the price rise in imported petroleum (Sector 2) is applied in the cost function structures defined. The reaction of domestic prices to exogenous cost shocks in imported petroleum illustrates how the economy is affected by (uncontrolled) impacts on the price of this energy source. This makes it possible to estimate how the internal competitiveness is influenced by the costs of this highly imported energy good.[11] Specifically, Table 1 shows the price effects on production sectors when the price of petroleum imports increase by 10 %. The columns in Table 1 show the alternative cost substitution possibilities defined and calibrated through the input-output dataset.

The Leontief cost function shows a 0.12 % increase in the agricultural price (Sector 1) after a 10 % rise in the price of imported petroleum. Note that in this situation the highest price impact (8.53 %) would be triggered in Extraction of minerals and petroleum (Sector 2), as the price shock directly affects the import price of this activity. The price impact on Gas and water (Sector 4) of 3.72 % is also numerically significant, illustrating that this energy form is sensitive to the price of petroleum imports. The price of Electrical energy (Sector 3) and Transportation (Sector 12) also rise notably due to the price increases in imported petroleum (0.67 % and 0.64 %, respectively). Nevertheless, the impact of the price increase on the rest of activities is lower.

When substitution possibilities are defined in the technology of sectors, the relative impacts on sectoral prices follow the same ranking as that of the Leontief function. However, Table 1 shows clearly lower quantitative magnitudes. Specifically, a 10 % price rise in imported petroleum leads to an increase in production costs of Extraction of minerals and petroleum (Sector 2) of 7.99 % with the Cobb-Douglas function, and 6.31 % ($\sigma = -1.5$) and 6.02 % ($\sigma = -2$) with the two CES functions. Similarly to the function without factor substitution, the sectoral effects mainly impact Extraction of minerals and petroleum (Sector2), Gas and water (Sector 3) and Transportation (Sector 12), although the impacts are lower than in the non-substitution function (i.e. Leontief function).

The last rows in Table 1 show the aggregated price indices resulting from the weighted average of the sectoral price multipliers. In particular, the sectoral shares of private consumption are the weights used to calculate the total price impacts, which lead to the consumption price index. The shares of production in each sector in relation to the total output lead to

[10] According to Imbs and Méjean (2010), the aggregate import price elasticity for the whole Spanish economy ranged from -1.948 to -2.074 during the period 1991-1996, and from -1.649 to -1.864 during the period 1996-2000. The elasticity values chosen in the CES functions are in line with these empirical values, which illustrate high domestic willingness to substitute domestic and foreign goods.

[11] According to the input-output table for Catalonia, in 2011 the petroleum imports represented around 68% of the total resources in this production sector.

Table 2
Price impacts of a 10 % price rise in imported electricity.

SECTORS	LEONTIEF ($\sigma = 0$)	COBB-DOUGLAS ($\sigma = -1$)	CES ($\sigma = -1.5$)	CES ($\sigma = -2$)
1. Agriculture	1.0003	1.0001	1.0001	1.0000
2. Extraction of minerals, petroleum	1.0002	1.0001	1.0000	1.0000
3. Electrical energy	1.0340	1.0135	1.0076	0.9973
4. Gas and water	1.0025	1.0010	1.0005	0.9998
5. Food production	1.0006	1.0002	1.0001	0.9999
6. Chemistry	1.0008	1.0003	1.0002	0.9999
7. Machinery	1.0006	1.0002	1.0001	1.0000
8. Automobiles	1.0004	1.0001	1.0001	0.9999
9. Other industry	1.0008	1.0003	1.0002	0.9999
10. Construction	1.0005	1.0002	1.0001	1.0000
11. Commerce	1.0009	1.0004	1.0002	0.9999
12. Transportation	1.0005	1.0002	1.0001	0.9999
13. Finance	1.0002	1.0001	1.0000	1.0000
14. Education	1.0002	1.0000	1.0000	0.9999
15. Health and social services	1.0005	1.0002	1.0001	1.0000
16. Public administration	1.0008	1.0003	1.0002	0.9999
17. Other services	1.0003	1.0001	1.0001	0.9999
AGGREGATED EFFECTS	LEONTIEF ($\sigma = 0$)	COBB-DOUGLAS ($\sigma = -1$)	CES ($\sigma = -1.5$)	CES ($\sigma = -2$)
Consumption Prices	1.0011	1.0004	1.0002	0.9999
Production Prices	1.0011	1.0004	1.0002	0.9999
Change in Income (%)	0.1305	0.0504	0.0278	−0.0124

the production price index. Although the comparison of the two price indices illustrates different quantitative magnitudes, the relative differences between the substitution possibilities are symmetrical. In particular, the consumption price index predicts lower price impacts than the production price index. In addition, the CES function shows lower impacts than the Cobb-Douglas function (around 25 %) in the two weighted effects, while the Leontief function shows the highest estimates for price impacts.

Finally, Table 1 contains the changes in regional income, which have been obtained as the difference in total spending (final demand valued at the initial –unitary- and final prices). From the last row of this table, income increases are quantitatively higher when inputs of production cannot be adapted.

3.2. Increase in the price of imported electricity

Table 2 shows the sectoral price impacts of a 10 % increase in the price of imported electricity. When the structure of sectoral costs is fixed (i.e. Leontief function), Electrical energy (Sector 3) receives a price shock of 3.4 %. The rest of the activities are hardly affected by the cost-shock in imported electricity and the only exception is the impact on the price of Gas and water (Sector 4), which would increase by 0.25 %.

When substitution possibilities are assumed, the sectoral price impacts are clearly reduced. The Cobb-Douglas column shows a price shock to Electrical energy (Sector 3) of 1.35 % after a 10 % rise in the price of imported electricity. The CES functions obtained a significant reduction in the observed impacts and in most cases the values do not vary from the benchmark (unitary) values, especially in the last column showing the highest elasticity of substitution.

The last rows in Table 2 show identical aggregated price impacts for both the consumption and production indices. As expected, when imports can be substituted, prices react less than in a fixed cost structure. Specifically, the interval estimates of price indices are between 0.11 % in the Leontief function, 0.04 % in the Cobb-Douglas function, and negligible impacts in the CES functions (specifically 0.02 % and −0.01 %). Finally, changes in regional income also depend on the function considered, with an increase of 0.13 % and 0.05 % in the Leontief and the Cobb-Douglas situation respectively, and an increase of 0.02 % and a decrease of 0.01 % in the two CES cost functions.

3.3. Increase in the price of imported gas

Table 3 shows the effect of a price shock on imported gas determined with the alternative substitution possibilities for primary inputs. The table shows that sectoral costs are only slighted affected by price increases in imported gas.[12] The only appreciable impact is in the Leontief function on the Gas and water costs (Sector 4). The Cobb-Douglas and the CES functions show almost negligible price impacts.

[12] According to the input-output database, in the regional economy the imported gas represents a small part of the total resources of this sector (of around 5 %) and this explains why its prices have a low influence on domestic costs.

Table 3
Price impacts of a 10 % price rise in imported gas.

SECTORS	LEONTIEF ($\sigma = 0$)	COBB-DOUGLAS ($\sigma = -1$)	CES ($\sigma = -1.5$)	CES ($\sigma = -2$)
1. Agriculture	1.0001	1.0000	0.9998	0.9998
2. Extraction of minerals, petroleum	1.0000	1.0000	0.9999	0.9998
3. Electrical energy	1.0000	1.0000	0.9645	0.9645
4. Gas and water	1.0058	0.9981	1.0108	1.0027
5. Food production	1.0001	1.0000	0.9995	0.9994
6. Chemistry	1.0002	0.9999	0.9995	0.9993
7. Machinery	1.0000	1.0000	0.9995	0.9994
8. Automobiles	1.0000	1.0000	0.9996	0.9995
9. Other industry	1.0001	0.9999	0.9993	0.9992
10. Construction	1.0000	1.0000	0.9996	0.9995
11. Commerce	1.0000	1.0000	0.9991	0.9991
12. Transportation	1.0000	1.0000	0.9996	0.9995
13. Finance	1.0000	1.0000	0.9997	0.9997
14. Education	0.9999	0.9999	0.9997	0.9996
15. Health and social services	1.0000	1.0000	0.9996	0.9995
16. Public administration	1.0000	1.0000	0.9993	0.9992
17. Other services	1.0000	1.0000	0.9996	0.9996
AGGREGATED EFFECTS	LEONTIEF ($\sigma = 0$)	COBB-DOUGLAS ($\sigma = -1$)	CES ($\sigma = -1.5$)	CES ($\sigma = -2$)
Consumption Prices	1.0001	0.9999	0.9990	0.9989
Production Prices	1.0001	0.9999	0.9991	0.9989
Change in Income (%)	0.0211	−0.0096	−0.0866	−0.1128

With the Leontief function the aggregated prices increased slightly (0.01 %) while with the Cobb-Douglas and CES functions impacts on regional prices were insignificant. The last row in Table 3 shows that the price increase of imported gas is linked to a decrease in income when substitution possibilities are defined.

Extending the input-output price model to include flexibility in the cost structure makes it possible to reinterpret the magnitudes of variation predicted by the standard IO model. In fact, the results obtained define a range of possible variations instead of the upper-bound of the possible impacts that the Leontief structure provides.

4. Conclusions

This paper examines the degree to which domestic prices are affected by the price of energy imports, considering alternative substitution possibilities among productive primary factors. Specifically, the price impacts were evaluated with three sectoral cost functions, which represent different factor substitution options (the Leontief, the Cobb-Douglas and the CES production technologies). These functions were applied to the Catalan economy using an input-output table for 2011.

The magnitude of the effect of imported energy prices on the domestic prices depends on both the energy resource and the substitution possibilities among the set of primary inputs. In particular, the imported petroleum prices have the highest influence on domestic prices, especially on the costs of Extraction of minerals and petroleum, Gas and water and Transportation. In contrast, electricity imports and gas imports only alter domestic prices slightly.

The different substitution options made it possible to consider a varying range of final impacts on prices. In the paper, the upper-biased Leontief estimates for calculating price effects were compared with Cobb-Douglas and CES cost relationships to provide a broader view of the possible consequences. Nonetheless, the empirical application showed that the differences between the cost functions are limited to quantitative impacts since the input substitution possibilities all obtained the same relative order for the effects.

Adapting the input-output model to capture alternative substitution possibilities between the elements of the production costs makes it possible to overcome the rigidity inherent to the standard IO price structure. The method used in this paper offers a more precise view of the impacts caused by changes in energy import costs. Moreover, the general equilibrium price structure of this paper is simple enough since all the model components are directly calibrated from the input-output dataset. Despite this simplicity, defining flexible price effects makes it possible to cover a larger set of economic issues and provides a clearer representation of the possible behaviours within the production system.

According to Sancho (1992), ‘Whether or not factor substitution takes place quickly enough to affect commodity prices is a question that can only be resolved empirically. Likewise, whether or not incorporating choice of techniques in input-output analysis will substantially affect price computations is also an empirical and country-specific question.’ For empirical estimates, during the period 1991–2000 aggregated imports in Spain were very responsive to a shift in international prices (Imbs and Méjean, 2010). This evidence suggests that the inherent rigidity of the input-output model could be inappropriate to assess trade issues for any of the Spanish regions such as Catalonia. Nevertheless, to the best of this author’s knowledge there are no recent estimates for Catalonia (or Spain) that help to determine which cost structure is more appropriate for assessing the price effects of imported energy. Once this information was available, the energy-induced inflation from abroad could be more precisely determined.

For practical purposes, the choice across functional forms should be based on econometric estimations of the degree of substitutability of energy imports with the other inputs of production. A possible way to empirically obtain the substitution elasticities is the specification of flexible cost functions through which one can estimate the confidence intervals for such elasticities.[13] The resulting values from this calculation could be directly used to choose across the alternative functions evaluated in this paper.

Declaration of Competing Interest

None.

Acknowledgements

The author acknowledges the financial support of the *Ministerio de Ciencia, Universidades e Innovación* (grant ECO2016-75204-P, AEI/FEDER-UE) and the *Universitat Rovira i Virgili* (grant PFR2019). The paper has benefited from the helpful comments by three anonymous referees and the editor of the journal.

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[13] See, for instance, Medina and Vega-Cervera (2001) for an evaluation of the energy (domestic and imported) and non-energy inputs substitution in Italy, Portugal and Spain based on an econometric estimation of cost functions.