An energy AGE model.
Forecasting energy demand in Spain.

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ABSTRACT

The paper develops an Applied General Equilibrium (AGE) model for the estimation of energy demand and applies it to the Spanish Economy. The price system is based in the classical (Sraffian) theory of prices of production. The quantity system is based on the Keynesian principle of effective demand supported by broad energy multipliers. Both systems have been adapted to the specificities of energy industries. The model is dynamic in nature since output and technology are evolving through time. Energy technical coefficients are declining at a specific rate that may be speeded up or slowed down after changes in prices of the different sources of energy. The "tendencies" and "elasticities" implied are computed by calibration and econometric methods.

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1. Introduction [1]

The purpose of this paper is to build an AGE (applied general equilibrium) model combining elements of the Classical-Sraffian tradition and the Keynesian one. The model will be applied for forecasting the demand for energy in the Spanish economy in different scenarios and after different shocks. The time span of our predictions will be one to five years. The questions to be answered are of the following type: What will the path of energy demand be if the economy enters into a recession (or into a boom)? What if the price of crude doubles? What if natural gas producers receive a huge subsidy while petrol refiners are heavily taxed? Although the purpose of this paper is restricted to forecasting energy demand, there are obvious extensions into the analysis of environment (emission of pollutants, exhaustion of natural resources and so on).

The structure of the paper is as follows. Section 2 analyzes the structure and technology implicit in an input-output table. Section 3 develops the quantity system and derives the energy multipliers. Section 4 develops the price system and adapts it to the specificities of energy industries. Section 5 integrates the quantity and price systems and explores its dynamics. In section 6 we fill the model with Spanish data and forecast energy demand in a couple of alternative scenarios. Conclusions appear in section 7.

Before entering into the mechanics of our energy AGE model, we should examine its alternatives[2]. Any overview of the literature should start with the International Energy Agency (IEA) model (IEA: 2006 a; 2006 b; 2007). IEA estimates worldwide demand for different types of energy in the very long run (up to 25 years). We are looking for a more concrete model that takes into

[1] Previous versions of this paper were presented by Oscar Dejuán at the Zaragoza Conference on Input-Output Economics (5-7 September 2007) and at the Eco-Mod Moscow Conference on “Energy and Environmental Modelling” (September 13-14, 2007). The proceedings of the last conference were edited by Ali Bayar (2008). The model was applied to forecast the demand for the six main products derived from petrol. The research was financed by Spanish CNE (Comisión Nacional de Energía). Other participants in the applied research, apart from the signatories of this paper, were M.A. Cadarso, C. Córcoles and E. Febrero. Our gratitude to them and to the CNE.

[2] Our survey on the literature does not exhaust the variety of models in use. Kydes, Shaw & McDonald (1995) provides additional models and references.

account the specific technology of different sectors and households, in order to make accurate predictions in a time span of one to five years. To gain accuracy, we should tie mathematically the variables in a true AGE model, showing the interrelationship between prices and quantities.

The use of econometric techniques to forecast energy demand has increased in parallel to the availability of data. Econometric models focus on elasticities, i.e. on the variation of energy demand after a small change in income and prices (everything in percentage terms). They have problems predicting the impact of big changes in prices, whose impact is usually registered after several months (or years) and is not reversible[3].

Input-output models are specialized in finding the direct and indirect links between industries by means of a variety of multipliers[4]. They can compute the demand for energy (or the pollution resulting from it) after the expansion of any industry. By means of social accounting matrices (SAM) they can even trace the path of income from the moment it is received by factors to the moment it is spent by households. These models, however, cannot analyze the impact on energy demand associated to changes in energy prices. Neither can they endogeneize technical progress.

Neoclassical CGE (Computable General Equilibrium), models are well equipped for the integration of the price and the quantity system[5]. EcoMod has developed specific software (GAMS) for that purpose. The possibility of substitution among factors of production and among consumption goods is a remarkable feature of the model. The strong and immediate influence of demand on prices, and of prices on the quantities demanded is another one.

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[3] Studies focusing on energy consumption by households: Galli, 1998; Gately & Huntington, 2002; Labandeira et al, 2006, Lenzen, 2006. Dynamic studies: Judson et al, 1999; Olatubi & Zhang, 2003, Roca & Alcántara, 2002.
[4] Some useful references may be: Alcantara & Padilla, 2003; Casler & Willbur, 1984; Dejuán, Cadarso & Córcoles, 1994; Duchin, 1998; Galli, 1998; Manresa, Sancho & Vegara, 1998; McKibbin & Wilcoxen, 1993; Miyazawa & Masegi, 1963; Pyatt and Round, 1985; Roca & Serrano, 2007; Sun, 1998; Vringer & Blok, 1995.
[5] An overview of the neoclassical CGE models can start with Kehoe & Kehoe (1994); Kehoe, Srinivasan & Whalley, eds (2004), Gibson & Seventer, 2000; Ginsburgh & Keyzer (2002). Neoclassical CGE models related to energy are: André, Cardenete & Velázquez (2005), Capros et al (1996), Ferguson et al (2005), Hanley et al (2006), Roson (2003), Welsch & Ehrenheim (2004).

Despite the great and ingenious versatility of GAMS we have decided to build a personal model closer to the Classical – Keynesian theory and to the real economy we intend exploring (Dejuán 2006 and 2007 justifies the option). The main features of our energy model are the following ones:

(1) It is an "energy model" nested in a general equilibrium context. Parameters of non-energy sectors are derived directly from the IOT. We take them as given data until a new table is released. By contrast, energy parameters are obtained checking a variety of sources and they are allowed to change endogenously. This "dual" treatment of energy and non-energy sectors is a crucial simplification to make our model manageable.

(2) It is a "hybrid model" that combines input-output techniques with econometric methods. From input-output tables (IOT) we obtain, via "calibration", technical coefficients, consumption patterns and import propensities. Econometrics informs how significant and robust these parameters are. It also helps finding out price elasticities and technological trends that cannot be derived from input-output tables.

(3) It is a dynamic and sequential model in the sense that some key variables convey an implicit rate of growth or decline. Autonomous demand grows at an exogenous rate. Technical progress brings about a continuous reduction of energy coefficients. This trend may be accelerated or delayed if there are significant movements in the relative prices of the different sources of energy. Changes occur sequentially and, by and large, they are irreversible.

(4) The quantity system is based on the Keynesian principle of effective demand and the multiplier mechanism (Keynes, 1936). It states that the level production at year *t* (and energy demand) is a multiple of the expected level of autonomous demand for the same period. By the same token, the growth of output and of energy demand will be related to the growth of autonomous demand.

(5) The price system is based on the Classical theory of prices of production. It has been updated by Sraffa (1960) and goes back to Ricardo (1817). It

contends that goods exit factories with a price label. The cost of production (which includes the "normal" rate of profit) determines this price and plays the role of a gravity centre for market prices. The special features of energy prices do not prevent their integration into a price of production model.

2. An input-output table and model useful for the analysis of energy.

The economy we are considering can be represented by a symmetric IOT, at basic prices. The last symmetric IOT released in Spain corresponds to the year 2000 and considers 73 industries. Each one is identified with the homogeneous commodity it produces. There is a make and use matrix for 2004 but we cannot rely in it since the production process is very important for our purposes.

Our "energy input-output" has 18 industries. Each of the 18 industries we consider shall be identified with the homogenous commodity it produces. The first four columns and rows correspond to the four energy sources we are considering:

1. Petrol (refining and distribution);
2. Gas (gasification and distribution);
3. Electricity (generation and distribution);
4. Coal (extraction and distribution).

The remaining industries of the Spanish input-output table appear highly aggregated. Nevertheless we keep separated the industries which consume more energy. They are the four producers of energy and the four transport services (by train, land, sea and air). Agriculture, Chemistry-Plastics and Restoration-Hotels do also stand out as big energy consumers.

Households consume plenty of energy. This fact justifies the endogeneization of households' consumption. It will become our "n" industry ("19" to be more precise). The 19 column gathers final induced consumption by households. We exclude final consumption by tourists that is clearly "autonomous", i.e. not dependent on current income generated in the country.

The 19 row gathers the part of value added that finance induced final consumption. Since the household sector does not generate value added, the 19 row adds up to the value of the 19 column. We know that there is a high and stable relationship between households' disposable income and final induced consumption. We have also realized that there a stable relationship between value added and final induced consumption. In Spain, during the last two decades, 64% of gross value added has been devoted to final consumption. (The R^2 of the regression is 0,9). This finding authorizes us to compute the 19 row by extracting in each industry the percentage necessary to finance final consumption by households.

Table 1: Spanish input-output table (2000)

Table 1.1 shows the structure of our energy input-output table. As its is well known, an IOT can be read horizontally (as in [2.1]) or vertically (as in [2.2] and [2.3]). The vertical reading explains the cost structure of each industry: cost of intermediate inputs and cost of primary inputs (factors of production who receive value added). A horizontal reading shows the allocation of each commodity among intermediate and final uses.

$$(Z - M) + (Y' - M_y) = Z_d + Y'_d = q \qquad [2.1]$$

$$Z + PI' = (Z_d + M) + PI' = q \qquad [2.2]$$

$$Z' + PI = q \qquad [2.3]$$

q is the vector of total output produced in the economy (domestic production). In [2.1] it appears as a column vector. In [2.2] and [2.3] it appears as a row vector.

Z is a square matrix with *n* columns (industries) and *n* rows (goods). It accounts for intermediate consumption by industries and induced final consumption by households. It describes sales of good i when we read horizontally; purchases by industry *j* when we read vertically.

$\boldsymbol{Z_d}$ results from subtracting imports of intermediate goods (*M*) from *Z*.

Z' is the proper interindustry table. It is derived from *Z,* after equating to zero the cells of the last row corresponding to the finance of induced consumption.

Y stands for final demand. It is a rectangular matrix with *n* rows and four columns: final consumption by households, government's final consumption, gross investment and exports)

Y' stands for final autonomous demand. It is a matrix similar to *Y* but in the first column we only include autonomous consumption by households. We can withdraw the column altogether and include final consumption by tourists in the export column.

$\boldsymbol{Y'_d}$ results from subtracting imports of final goods from *Y'.*

M is a *n·n* square matrix gathering the imports of each commodity by each industry.

$\boldsymbol{M_y}$ is a rectangular matrix of *n* rows (one for each commodity) and 3 columns (one for each element of final autonomous demand).

PI is a rectangular matrix of "primary inputs" or "non produced inputs". It has *n* columns and 6 rows. Row W stands for wages; B for profits; T1 for specific indirect taxes (net of subsidies) on energy sources; T2 for value added tax, other indirect taxes and other rents; COG for imports of crude oil and gas by industries 1 and 2.

PI' results from subtracting from *PI* the percentage of value added devoted to finance induced consumption.

Dividing these matrices and vectors by the corresponding value of sectoral output (*q*) we obtain the matrices and vectors expressing the average technology of each industry [6].

(a) *Matrix of (total) technical coefficients:*

$$A_t = Z \cdot (\hat{q})^{-1} \qquad [2.4]$$

[6] Some comments on notations are necessary at this point.
(a) Diagonal matrices are identified by angular brackets (<*q*>) or by a circumflex ($\hat{q}$). "I" is the identity matrix.
(b) Unless otherwise stated the order of the matrix is *n·n*, being *n* the number of industries. Households occupy the last position, i.e. the 19[tth].
(c) In other cases, the order of the matrix or vector appears inside a parenthesis with two figures separated by a dot; the first one refers to the number of rows; the second, to the number of columns.
(d) The single figure in a parenthesis refers to the year under consideration, being (0) the base year.
(e) A dot indicates matrix multiplication. $\otimes$ indicates cell by cell multiplication.

(b) *Matrix of import coefficients (imports per unit of output):*

$$A_m = M \cdot (\hat{q})^{-1} \qquad [2.5]$$

We can obtain A_m multiplying A_t by *m*. *m* is a ($n \cdot n$) matrix of "import shares" or "import propensities" derived from the original tables.

$$A_m = A_t \otimes m \qquad [2.6]$$

(c) *Matrix of domestic coefficients:*

$$A_d = Z_d \cdot (\hat{q})^{-1} = A_t - A_m = A_t \otimes (ii - m) \qquad [2.7]$$

"*ii*" is a unit matrix with ones in all cells. We subtract import shares and multiply the result by A_t. The result is the matrix of domestic technical coefficients (A_d) with is the main ingredient of the multipliers.

(d) *Vector of primary inputs shares:*

$$v = PI \cdot (\hat{q})^{-1} \qquad [2.8]$$

v is a row vector which expresses the share of primary inputs in the value of total production (*q*). Alternatively we can present it as a rectangular matrix with as many columns as industries and six rows corresponding to the share of wages (α), the share of profits (β), the share of indirect taxes on energy (γ), the share of other indirect taxes and rents (δ), and the share of imported crude oil and gas. Note that the last (*n*) cell of α and β are zero, because households do not generate value added. Conversely, all the cells of γ and δ are nil except the last one, because in a system of base prices, indirect taxes are paid by households. Vector λ only shows positive figures in cells 1 and 2, corresponding to petrol refining and regasification and distribution of gas [7].

In a disaggregated fashion we can rewrite [2.7] as:

[7] In the Spanish IOT this is not always the case, since γ and δ include the part of indirect taxes that cannot be transferred to final consumers.

$$v = \begin{bmatrix} \alpha_1 & \alpha_2 & \ldots & \alpha_m & \alpha_n = 0 \\ \beta_1 & \beta_2 & \ldots & \beta_m & \beta_n = 0 \\ \gamma_1 = 0 & \gamma_2 = 0 & \ldots & \gamma_m = 0 & \gamma_n \\ \delta_1 = 0 & \delta_2 = 0 & \ldots & \delta_m = 0 & \delta_n \\ \lambda_1 & \lambda_2 & \ldots & \lambda_m = 0 & \lambda_n = 0 \end{bmatrix} \qquad [2.9]$$

Matrices and vectors in [2.3] till [2.6] contain the basic coefficients of the input-output model from which we shall derive the main tools of analysis namely: multipliers and price equations. Technical coefficients and propensities are supposed to remain constant during the period of analysis (from the date of publication of IOT to the date of our previsions). This is the general rule. It does not apply to the rows of energy producing sectors. The competitive pressure to save energy is stronger than for any other intermediate good because energy prices are more volatile and represent a huge part of costs. In section 5 we shall explain how energy coefficients are adapted from the year IOT are released to the year our forecasts are projected.

3. The quantity system and the energy multipliers.

The inverse of Leontief corresponding to the expanded domestic coefficients matrix (A_d) can be identified with the multiplier of total output. All the other multipliers derive from it.

$$MQ_{(19 \cdot 19)} = [I - A_d]^{-1} \qquad [3.1]$$

The first column of [3.1] shows the impact of the expansion of industry 1 (refined petrol in our case) on the production of the remaining industries. By reading the cells of the column we can even identify the specific contribution of each industry to the global impact on output. It is a broad multiplier because it gathers: (a) intermediate goods directly used in the production of autonomous demand; (b) intermediate goods indirectly required in the production of autonomous demand; (c) consumption goods purchased by the workers employed, directly or indirectly, in the production of autonomous demand.

Total output of the economy at the base year (0) can be computed as a multiple of the vector of domestic autonomous demand for the same period.

$$[I - A_d]^{-1} \cdot Y_{d\,(0)(19\cdot 1)} = q_{(0)(19\cdot 1)} \qquad [3.2]^{8}$$

The multiplier of income is computed by [3.3]. *v* is the row vector represented by [2.5]. It expresses the share of primary inputs in the value of total output.

$$Mv_{(1\cdot 19)} = v_{(1\cdot 19)} \cdot [I - A_d]^{-1} \qquad [3.3]$$

The multiplier of employment and the multiplier of energy could be computed in a similar fashion (Dejuán & Febrero, 2000). First we fill the vectors of direct requirements of labour (*l*) and different sources of energy (*E*). Then we post-multiply these vectors by *MQ*. The singularity regarding energy multipliers is that energy requirements are already accounted for in the matrix of technical coefficients. Rows 1 to 4 of A_t and A_d gather the unit requirements of refined petrol, gas, electricity and coal. Consequently, the energy multiplier will be a rectangular matrix coinciding with the first four rows of matrix *MQ*. To detach the energy rows from the Leontief's inverse we premultipy *MQ* by a unit matrix (*i*). It has 19 rows and columns and rows. The first 4 rows are "ones", the remaining ones are "zeros".

$$ME_{(4\cdot 19)} = i_{(4\cdot 19)} \otimes [I - A_d]^{-1} \qquad [3.4]$$

The interpretation of the energy multiplier is the usual one. Column *j* computes the demand for the four energy products dragged (directly or indirectly) by the production of one additional unit in industry *j*.

[8] There are different ways to derive the structural multiplier. All of them may be correct and compatible provided they are interpreted properly. The theoretical perspective does also matters for the computation and interpretation of the multipliers. Miyazawa & Masegi (1963) and Kurz (1985) adopt a Classical-Keynesian perspective akin to our theoretical model. In a previous paper (Dejuán, Cadarso, Córcoles, 1994) we added induced final consumption directly to the cells of the original $m \cdot m$ table. Here we have followed the more common procedure of adding a column and a row corresponding to the household sector (m+1=n). When using the last procedure we should have in mind that the n cell of q should not be added to the preceding ones. The reason being that national accounts do not consider "human capital" as part of total output.

Table 2: Energy multipliers

The energy demand has a variety of applications. We can predict the increase in different energy sources associated to an increase of final autonomous demand. The increase may be harmonic or differentiated by expenditures (private investment, public expenditures, exports…) or by goods (petrol, cars, …).

Our quantity model and the multiplier that results from it are based on Keynes principle of effective demand. According to this principle the level of output at year *t* does not depend on capacity installed and/or on the available labour supply. In addition it is independent on prices. The level of output is supposed to be a multiple of expected autonomous demand for the year under consideration. The principle can be extrapolated in time to conclude that the paths of output, employment and energy demand will depend on the expected growth of autonomous demand. The vector of autonomous demand at the base year ($Y'_{(0)}$) and its expected rate of growth (g_y) are the key exogenous variables of a Keynesian AGE model.

The working of the multiplier mechanism requires firms to have some spare capacity and stocks. Otherwise they could not increase production to match unexpected increases in demand. As a matter of fact, modern technology has evolved in order to make easier adjustments through capacity utilization. In most industries, the desired degree of capacity utilization is far below the engineering or technical limit. This margin allows firms to match the peaks of demand by using the installed capacity more hours per day during boom periods

The demand for electricity and gas follow the Keynesian pattern: supply follows demand. This is not the case for the coal industry and, most of all, for petrol one. Refineries are usually operated 24 hours a day, so the possibility to adjust to demand increases via capacity is negligible. Petrol stocks are significant but they cannot cope either with a big and prolonged increase in demand. Refineries are supposed have to forecast accurately the permanent increases in demand and increase capacity in advance. If the increases in demand are too big and / or unexpected, the adjustment will occur via imports.

The matrix of import shares (*m*) cannot be considered fixed, Coefficients in the first and fourth rows (corresponding to refined petrol and coal) will depend on the expected rate of growth (apart from the gap between national and international prices).

The main conclusion to be emphasized at this point is that changes in demand do not alter prices. In the next sections we are going to see that prices are supply determined, i.e. they depend on technology and distribution. We shall also see that prices changes exert only a tiny influence on the quantities demanded via the alteration of technical coefficients.

4. The price system.

A vertical reading of the IOT (as it was done in [2.3]), shows the cost structure of the *n* industries of the economy. After dividing each column *j* by the value of the sectoral output (q_j) we obtain the unit costs. By construction each column of coefficients adds up to one

$$A_d + A_m + v = A_d + A_m + (\alpha + \beta + \delta + \gamma + \lambda) = \begin{bmatrix} 1 & 1 & \ldots & 1 \end{bmatrix} \qquad [4.1]$$

We can interpret the elements of [4.1] as the product of undetermined quantities of outputs, inputs and factors by their respective prices, prices that have been set equal to one. We are not saying that one ton of petrol is worth one million euros (1 M€). We simply say that an undefined quantity of petrol is worth 1 M€. We also state that in order to produce it, we need (for instance) 0,2 undefined units of electricity (whose unit price is 1 M€) and 0,05 undefined units of labour (each unit gaining 1 M€).

This assumption allows us to write the price of the good produced by industry *j* as the value of domestic inputs per unit of output, the unit value of imported inputs (crude oil and natural gas are included in λ), the unit labour costs (α), the unit profit (β), and the unit indirect taxes (γ, δ). γ refers to special taxes on energy, that in a system of base prices are charged on households (cell 19). δ gathers net value added tax (also translated to final consumers) and net extra profits and rents per unit of output. We remind that *A'* is the matrix of technical coefficients, after equating to zero the last row, corresponding to the household sector. In matrix notation we can write:

$$p_{(1\cdot 19)} = (p \cdot A')_{(1\cdot 19)} + (p_m \cdot A'_m)_{(1\cdot 19)} + i_{(1,19)}(\alpha + \beta + \gamma + \delta + \lambda)_{(1\cdot 19)} = [1 \quad 1 \quad \ldots \quad 1] \qquad [4.2]$$

The price of refined petrol (to choose an example) could be computed in the following way:

$$p_1 = \sum_{i=1}^{19} p_i \cdot A'_{d,i1} + \sum_{i=1}^{19} p_i \cdot A'_{m,i1} + (\alpha_1 + \beta_1 + \gamma_1 + \delta_1 + \lambda_1) \qquad [4.3]$$

The preceding expression is not a theory of prices, but a description of how prices are made up. To have a proper theory of prices we should introduce all the equilibrium conditions. In competitive markets prices may fulfil two conditions: (a) They cover full costs of production which includes “normal profits”. (b) They warrant a “normal”, “general” or “uniform” rate of profit (r^*) on the fixed capital invested. Relative prices are supposed to move until the last 100 M€ invested in any industry yield the same profit. The first part of [4.3] (below) computes unit profits in industry 1 as r^* times the value of fixed capital installed ($p_i \cdot k_{ij}$). Since IOTs do not inform about fixed capital requirements we can express profits as a net margin (b') on circulating capital (the value of intermediate goods domestically produced or imported). Notice that the rate of profit is uniform across the industries ($r_1 = r_2 = r^*$), while sectoral profit margins are different ($b'_1 \neq b'_2$). If industry 1 is capital intensive, $b'_1 > b'_2$ is a condition to obtain the general and uniform rate of profit in both industries.

$$\beta_1 = r \cdot \left(\sum_1^{19} p'_i \cdot k_{i1}\right) = b'_1 \cdot \left(\sum_1^{19} p_i \cdot a_{i1} + \sum_1^{19} p_{m,i} \cdot a_{m,i1}\right) \qquad [4.4]$$

Notice also that the tendency to a uniform rate of profit is a long run phenomenon. In the short run some firms will get extraprofits while other will suffers economic losses (i.e. profits below average). They are encapsulated in the row vector δ, that do also account for other indirect taxes and subsidies) [9].

Let us define gross profit margins as $b_j=(1+b'_j)$ and introduce them into [4.2]. We obtain the competitive system of prices that can be expressed either in an additive or a multiplicative way. In

$$p = p \cdot A \cdot \hat{b} + p_m \cdot A_m \cdot \hat{b} + (\alpha + \gamma + \delta + \lambda) = [1 \quad 1 \quad ... \quad 1] \qquad [4.5]$$

$$p = (\alpha + \gamma + \delta + \lambda + p_m \cdot A_m) \cdot \left[I - A \cdot \hat{b}\right]^{-1} = [1 \quad 1 \quad ... \quad 1] \qquad [4.6]$$

The preceding equations allow us to compute changes in relative prices after a variety of "shocks" impinging on technology, distribution and redistribution (taxes and subsidies). A rise in nominal wages, for example, will push all prices up (as in an inflationary process). But the highest price increases will occur in labour intensive and petrol intensive commodities.

The Classical or Sraffian theory of prices of production apply to "reproducible" commodities under competitive conditions. The bulk of goods of an IOT adjust in fact to the cost of production patterns. Energy products may be an exception for a variety of reasons. Notwithstanding, we are going to show that our model is well suited to tackle the special features of energy prices.

(a) *Strong dependence on natural resources (crude oil and natural gas)*. In a situation of scarcity, demand recovers full prominence in the determination of prices. This conclusion applies only to big changes in the international demand for crude petrol and natural gas that we take as given. Changes in domestic demand, no matter how big they are, do not influence international prices. To compute the effects on prices of an increase of the international

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[9] To obtain equilibrium prices it is necessary to link profits with any measure of the capital invested. There are different ways to do so (Sekerka et al., 1998; Brody, 1970). Surprisingly, the competitive long-term equilibrium condition is absent in neoclassical CGE models. Even if they start in a competitive equilibrium, prices cease to be in equilibrium after a shock. The new computed prices do not warrant a uniform rate of profit in any meaningful sense. In our opinion this is the main shortcoming of the CGE price system.

price of crude oil and natural gas we have just to alter λ_1 and λ_2 and apply the price system. All prices are supposed to rise but, most of all, prices or refined petrol, gas and the commodities intensive in petrol and gas. Price variation (row vector *p'*) can be computed by the following expression.

$$p' = (\Delta\lambda_1 \quad \Delta\lambda_2 \ldots \quad 0) \cdot \left[I - A_d \cdot \hat{b}\right]^{-1} \qquad [4.7]$$

Table 3 shows the effect of doubling the price of crude oil and natural gas on the whole spectrum of prices. Since the original prices are have been set equal to unity, p'_1=1,6702 means that the price of refined petrol has risen by 67%. The last cell gets the price impact on the consumption baskets of households (i.e. the price deflator). p'_{19}=1,0344 suggest a 3,44% rise in consumption prices.

Table 3: Price impact

(b) *International prices.* Petrol industry is fully open to international competition. Coal industry is opened to a lesser extent. Consequently, deviations of domestic prices from international ones cannot be too high and cannot last for too long. If the price of fuel rises in Spain due to a rise in wages or indirect taxes or any other domestic cause, Spanish traders will purchase petrol from international marine bunkers. To deal with globalization we should relate import shares to the gap between domestic and international prices, as we are going to do in the next section. When internationalization is so strong that domestic prices cannot diverge at all, we can use vector δ to correct any deviation in domestic costs. If α_1 (wages in petrol industry) rises *x* points, δ_1 has to fall by the same amount to keep the domestic prices in line with the international one. If the international price rises *y* points, δ_1 should rise by the same amount. For a time, oil refineries will suffer economic losses in the first case and will enjoy extra profits in the second. A rise in the international price of refined petrol could be represented as follows:

$$p' = (\delta_1 \quad 0\ldots \quad 0) \cdot \left[I - A_d \cdot \hat{b}\right]^{-1} \qquad [4.8]$$

(c) *Oligopoly and price regulation in gas and electricity.* There are few producers in each industry. Their chances to collude in order to fix prices are enhanced. To avoid this outcome, government creates national agencies that regulate prices of public utilities (electricity and gas, in particular). As a matter of fact, regulators allow to increase prices in proportion to changes in costs. They perform the same task as our mathematical model (equation [4.6]), although with some delay.

(d) *Specific taxes and subsidies.* Some energy products support heavy indirect specific taxes (refined petrol is the outstanding example). Other products (like domestic coal) enjoy huge subsidies. Row γ accounts for specific taxes on energy (net of subsidies). If taxes on petrol consumption (by firms and households) double, the price of petrol will increase a lot and will reverberate on the prices of all whole spectrum of commodities. Since we deal with IOT at base prices, any change in taxes and subsidies will show up in δ_{19}, the cell corresponding to households. It will only affect consumer prices. We could also simulate that the tax on fuels and the subsidy on domestic coal is charged to the is charged to the corresponding sectors. Then we could see how it impinges on market prices[10].

$$p' = \left(\Delta\delta_1 \quad 0 \quad 0 \quad \nabla\delta_4 \qquad 0\ldots \quad 0\right)\cdot\left[I - A_d \cdot \hat{b}\right]^{-1}$$

5. Dynamics of the system: tendencies and elasticities.

Our AGE model is dynamic one because some exogenous variables and some parameters are continuously moving. The vector of final autonomous demand is the "motor" of the system. The economy will grow in accordance to the rates of growth of the elements of autonomous demand, rates that we take exogenously. Technological parameters, consumption propensities and import shares are taken as data but they cannot be considered "constant". In this section we are going to see the patterns of evolution of these parameters,

[10] The only purpose of the simulation is to see the impact on market prices of a change in taxation. We shouldn't mix magnitudes at base prices with magnitudes at market prices.

propensities and shares. We shall distinguish between secular trends associated to technical change and short term deviations from the trend explained by price elasticities.

(a) Secular trends of technical coefficients.

Technical coefficients of matrix A_t were obtained directly from the original IOT. Every five years, or so, a fresh symmetrical IOT is released with new coefficients reflecting technical change and, perhaps, a different mix in the goods that fill the basket of commodities produced in each industry. Keeping constant technical coefficients during five years seems plausible for most inputs. Not so for energy products which depend on a natural resource whose reproduction is not possible or takes long time. Under these circumstances, energy prices will be more volatile with a tendency to grow. Firms will try to save these resources and search for substitutes. This evidence justifies their yearly updating of energy coefficients, most of all in a study focusing on demand for energy[11].

It is the moment to open the black box of technology and analyze the typical energy coefficient (a_{ij}) of matrix A_t. We shall examine the coefficient in the base year (0) and its evolution through time (five years). Let's call τ the "technological trend" or "inner tendency of technical coefficients". A negative $\tau_{(1.19)}$ implies an improvement in technology: there is less petrol in the basket purchased by households because new cars have reduced fuel consumption. A positive trend like $\tau_{(2,19)}$ indicates that more gas enters into the consumption basket because petrol-heating is being substituted by gas-heating.

These trends may be influenced by previous changes in relative prices, but they are independent of current movements in prices. To simplify, we'll suppose at this moment that prices remain constant. The evolution of the matrix of technical coefficients ($A_{t(0)}$ in the base year) can be traced by the following equations. $(1+\tau)$ is a matrix of order 19·19 although all the rows are

[11] We also observe a strong tendency towards a "labour saving technical change". But the increases in labour productivity have been absorbed by wages. The unit labour cost has been kept rather constant for many years. Such "matching effect" has not been registered with respect to energy costs per unit of output.

zero except the four producing and distributing energy. In the cells corresponding to these rows we find the secular trend plus one.

$$
\begin{aligned}
A_{t(1)} &= A_{t(0)} \cdot (1+\tau)^1 \\
A_{t(2)} &= A_{t(0)} \cdot (1+\tau_{ij})^2 \\
A_{t(3)} &= A_{t(0)} \cdot (1+\tau_{ij})^3 \\
A_{t(4)} &= A_{t(0)} \cdot (1+\tau_{ij})^4
\end{aligned} \qquad [5.1]
$$

Table 4: Secular tendencies of energy coefficients.

Table 3 shows the tendencies we have found. There is a τ for each energy source (petrol, gas, electricity and coal) and for each of the five sectors considered (energy, other industries, transports, others services and households). To find the precise numbers we have combined calibration and econometric methods. The analysis of previous input-output tables has been useful to differentiate the evolution of energy coefficients by industries.

Our analysis has relied mostly on “calibration”. We know the true demand for petrol, gas, electricity and coal in years 2001 to 2006. If out model is correct, we should obtain these figures multiplying the vector of final autonomous demand times the energy multipliers. We adjust the matrix of tendencies so that we obtain for years 2001 to 2006 the technical coefficients and the energy multipliers that bring about the true (known) results.

Econometrics provides some useful hints. It gives some values for tendencies and price elasticities informing about the reliability (R^2) of the parameters estimated. Particularly helpful has been the method of “non observable components” (Harvey, 1989; Young, Pedregal & Tych, 1999). It yields price elasticities and the inner tendencies of parameters that are unrelated to current price movements. The estimates obtained from this technique cannot be directly incorporated to our model because the energy sources and the industries considered are not the same. Yet these estimates provide a useful check for the values obtained by calibration.

(b) The impact of price-elasticity on technical coefficients.

Econometric studies (quoted in footnote 3 in section 1) show that price elasticity is very low, at least in the short run. Energy demand is hardly altered by movements in the relative prices of energy. In our model prices affect demand indirectly, through technical change. A (strong) increase in the price of petrol will accelerate the tendency to save fuels in industries and households. The negative τ will increase in absolute value. A rise in the price of gas will decelerate the tendency to use more gas per unit of output in the different industries and households. The positive τ will decrease.

Economists distinguish between cross elasticity and own price elasticity. The first one measures the percentage variation in the quantity consumed of commodity *i* when the relative price of commodity *j* changes in a given proportion. If the price of fuel rises over and above the price of gas, the tendency to shift from fuel-heating to gas-heating will be accentuated. The impact will take several months (even years) to be implemented. It will be incorporated to the tendencies that are revised from time to time. We should write a lower $\tau_{(1,19)}$ and a higher $\tau_{(2,19)}$).

Own price elasticity measures the percentage variation (always negative) in the demand of commodity *i* when its price rises in a given percentage. If the price of petrol and electricity doubles people will save some unnecessary drives and, more frequently, will switch off electrical appliances when they are not in use. Firms do have more difficulties to save energy at once because its consumption is a technical requirement. *Table 4* shows the estimated price elasticity for households, only for the cases they are statistically significant.

Table 5: Price elasticities.

Figures in this table reflect the impact on quantities demanded when the price doubles (one hundred percent increase). If the increase in price has been 25% we have to multiply the number given in *table 5* times 0,25. In matrix notation we obtain the impact on the energy demanded by multiplying the diagonal matrix of price deviations (<*pd*>) times the matrix of price elasticities (ε

in table 4)[12]. We add this result to the matrix or secular tendencies to obtain the matrix of "adjusted tendencies" (τ^*).

$$\tau^*_{(19\cdot19)} = \tau_{(19\cdot19)} + \langle pd \rangle_{(19\cdot19)} \cdot \varepsilon_{(19\cdot19)} \qquad [5.2]$$

The evolution of the matrix of technical coefficients (A_t) from year 0 to year 4 will be described by the following equations. Notice that we have substituted matrix τ of [5.1] by matrix τ*.

$$\begin{aligned} A^*_{t(1)} &= A^*_{t(0)} \otimes (1+\tau^*) \\ &\ldots \\ A^*_{t(5)} &= A^*_{t(4)} \otimes (1+\tau^*) \end{aligned} \qquad [5.3]$$

(c)) Variations of import shares and import coefficients.

The energy multipliers are based on the matrix of domestic coefficients (A_d). We know from [2.7] and [2.6] that A_d=A_t-A_m and that A_m=$A_t \otimes m$. A_m is the matrix of import coefficients. m is the matrix of import shares. There is not warranty that these shares remain constant through time. They may change if there is a gap between domestic and international prices. They also increase, when firms are unable to increase domestic production at the same rhythm than demand.

Let's define ε_m as the price elasticity of imports. It is a $n \cdot n$ matrix although all shares in the same row tend to be equal (import propensity of good i is independent on the industry that purchases it). We focus only in the four energy rows. And we fill only the elasticities that have proved to be econometrically significant.

Table 6: Import elasticities.

[12] We remind that the initial prices have been set equal to one (p). After a change in costs the price equations render vector p'. Price deviation of commodity i will be:

$$pd_i = \frac{p'_i - p_i}{p_i} = p_i - 1$$

Figures in *table 5* reflect the percentage change in import shares when the international price gap has been doubled (an increase of one hundred per cent). The actual impact will depend on the international price gap, measured by the diagonal matrix <*pdm*>. Initially both, domestic prices (p) and international prices (p_m) are set equal to one. The gap will appear when energy prices rise in the international markets (we take them as exogenous data) or when an increase in domestic costs leads to a rise in domestic prices (according to our price equations)[13]. The final impact will be:

$$\varepsilon_m^{'} = \langle pdm \rangle \cdot \varepsilon_m \qquad [5.4]$$

Import shares may also change in industries where firms usually operate at full capacity and are unable to match increase in demand over and above a given rate. In Spain this is the case for petrol refining and, to a lesser extent, coal extraction. An econometric study of the behaviour of imports shares in the last two decades shows that they rise significantly when the rate of growth of the economy is above 3,5%. Below this threshold, we shall suppose constant import shares. Above it, imports shares will grow *a* times the growth differential (*g'*=*g*-0,035). *a* is a parameter to be estimated econometrically.

Let us define μ as the tool that allows adapting import shares.

$$\mu^* = a \cdot g' + \langle pdm \rangle \cdot \varepsilon_m \qquad [5.5]$$

The evolution of import shares (*m*) from year (=0) to year (4) will be:

$$\begin{aligned} & m_1 = m_0 \otimes \mu^* \\ & \ldots \\ & m_5 = m_4 \otimes \mu^* \end{aligned} \qquad [5.6]$$

At its turn, the matrix of import coefficients will evolve in this way:

[13] The price gap for commodity *i* will be computed by the following expression (where new prices are marked with a dash). $dpm_i=1$ means that the international price gap is twice as large.

$$dpm_i = \frac{\left(p_i^{'} / p_{mi}^{'}\right) - \left(p_i / p_{mi}\right)}{p_i / p_{mi}} = \left(p_i^{'} - p_{mi}^{'}\right) - 1$$

$$m_1 = m_0 \otimes \mu^*$$
$$\ldots \qquad [5.7]$$
$$m_5 = m_4 \otimes \mu^*$$

A couple of observations are in order before closing the section on technology.

(1) The impact of prices on elasticities are distributed in several years. But they are not perpetual. The release of a new IOT marks a new starting point.

(2) Energy-saving technical change is not reversible. This is the so called “ratchet effect”, that will be illustrated with two examples. (a) Households that shift from petrol heating to gas heating after a rise in petrol prices, will not go back to the original heating system when prices recover their previous levels. (b) In an age of rising and volatile oil prices, the car industry is interested in producing motors with low petrol consumption. The industry will not go back to previous models even if oil prices stabilized at very low levels.

6. Forecasting energy demand in Spain.

Our AGE model has been designed to forecast energy demand under different scenarios during a period of five years. The key parameters of the scenario are the expected rate of growth of the economy (that depends on the expected rate of growth of autonomous final demand, *Y’*) and the Euro price of crude oil and natural gas. The change in demand may be general, or limited to an element of final autonomous demand (public expenditures or exports), or specific for an item (petrol refined to be exported). The Euro prices of crude oil and gas depend on the international price in dollars and on the valuation of the dollar.

The main output of the model consists in the rate of change of the physical demand for different sources of energy. National energy agencies have good and recent data of the number of barrels demanded and refined, the Kw of electricity demanded and generated and the tones of coal demanded and extracted. Applying the rates of change generated by our model to these data we obtain the physical demand of the different sources of energy, the part that it is produced in the country and the part that it is imported.

Once we know the energy demand associated to different scenarios we can explore a range of issues: gas emissions, tax collected, inflation, energy balance… At his moment we shall focus on the main “outputs” and “inputs” of our AGE model. To simplify the exposition we shall comment two of the typical graphs produced by our model.

Figure 1 shows the impact on the demand for the four sources of energy associated to the following scenario. In scenario 1 the economy grows at the actual rates registered during years 2004 till 2007 (around 3,8%). We expect that in 2008 and 2009 the economy will enter in recession and the rate of growth will be reduced to 1%. Prior to 2007 the international prices of crude oil and natural gas kept rather constant. By 2007-08 the Euro price doubled. We expect that it will keep constant at this level during 2008 and 2009. Figure 1 graphs the results given by our mathematical model. We observe that the demand of all products rises steadily during the first period (2004-07) due to the high rate of growth. When the economy stagnates the demand for petrol becomes flat. 1% of economic growth is just enough to math for the declining petrol coefficients; the negative secular tendency of petrol is accentuated when the prices of crude double. On the contrary, gas demand continues to increase during the recession although at a moderate rate; the reason being that the secular tendencies of gas coefficients are positive and rather high. Electricity and coal occupy a intermediate position.

Figure 1

Figure 2 shows the impact on the demand for refined petrol, associated to three alternative scenarios. Scenario 1 coincides with the one we have contemplated in figure 1.

Scenario 2 is an optimistic one. It considers the same prices changes as in figure 1 but assumes that the economy will be fully recovered in 2007. During 2008 and 2009 the expected rate of growth will be 2,7%. The impact on petrol demand would be minimum because price elasticity is quite low.

Scenario 3 is a gloomy one. Price had doubled by 2007 and double again during this year. The impact of prices would be more important now. We further assume that as a consequence of the higher price of petrol the economy enters into a deep recession (g=0). The result would be a significant fall in petrol demand. (If the result is similar in other countries, oil producing countries could not maintain the new prices for long).

Figure 2

How much can we rely on the previsions of our energy AGE model? To answer this important question we can apply the model to a period for which we already know the true data. In our previous simulations, we had actual data for the first part of the period 2004-07. In figure 3 we graph the data of petrol demand provided by Spanish CNE for these years. We compare these data with the results of our model. We verify that the adjustment is quite good. The model predicts the general trend and most of the changes.

Figure 3

7. Conclusions.

Our energy AGE model can be summarized in two relationships: the quantity system and the price system, both are somehow linked through technical change.

The key determinant of energy is economic growth that reaches energy demand through energy multipliers. They are the corner stone of the quantity system. Technical change is the second determinant of energy demand. Energy coefficients show a secular tendency that can be computed via calibration and econometric methods. The secular rate of change of energy coefficients may be speeded up or slowed down when there is a significant change in relative prices. Technical progress constitutes the vehicle that transmits the impact of prices changes into quantities.

How important are the impact on energy demand associated to changes in aggregate demand, technical progress and price changes? In our analysis of the Spanish economy we have reached the following conclusions. (1) In general, energy coefficients tend to decline. The exception is gas, whose coefficients continue to grow because gas is replacing petrol in many industries and households. (2) The rate of decline of energy coefficients goes faster in industries than in households. The exception is coal. (3) Gas and petrol are clear substitutes; the cross elasticity between them is significant. Gas and coal are also close substitutes in the production of electricity. In both cases the cross elasticity is positive; in the remaining cases cross elasticities are non significant or require time to materialize. (4) Own price elasticities are low and they are only significant for households. (5) Income and product elasticities are important. They justify a model like ours which relies on technical coefficients and propensities.

Apart from the interest of empirical results, our paper has proved that it is possible to build an energy AGE model, simple enough to be computed with official data and to be run with an ordinary spreadsheet. The goodness of the adjustment between forecasted and actual trends has proved to be quite good.

REFERENCES

Alcántara, V. & Padilla, E. (2003): "Key Sectors in Final Energy Consumption: an Input-Output Application to the Spanish case", *Energy Policy*, 31(5): 1673-1678.

André, F.; Cardenete, M.; Velázquez, E. (2005): "Performing an Environmental Tax Reform in a Regional Economy. A Computable General Equilibrium Approach", *Annals of Regional Science*, 39 (2): 375-392

Arellano, M. (2003): "Modelling Optimal Instrumental Variables for Dynamic Panel Data Models", Working Paper 2003_0310, CEMFI, Madrid.

Bayar, Ali (ed): *Energy and Environmental Modeling*, EcoMod Press, Florence, MA, 2007.

Brody, A. (1970): *Proportions, Prices and Planning,* Amsterdam: North Holland,

Capros, A. et al (1996): "First Results of a General Equilibrium Model Linking the EU-12 Countries". *In* Carraro, C. y Siniscalo, D. (eds.): *Environmental Fiscal Reform and Unemployment*, Dordrecht, Kluwer, pp. 193-228.

Casler, S. & Willbur, S (1984): "Energy Input-Output Analysis. A Simple Guide", *Resources and Energy*, 6: 187-201.

Dejuán, O.; Cadarso, M.A. & Córcoles, C. (1994): "Multiplicadores input-output kaleckianos: una estimación a partir de la tabla input-output española de 1990", *Economía Industrial*, 298:129-144.

Dejuán, O. & Febrero, E. (2000): "Measuring Productivity from Vertically Integrated Sectors", *Economic Systems Research*, 12 (1): 65-82.

Dejuán, O. (2006): "A Dynamic AGE Model from a Classical-Keynesian-Schumpeterian Approach", Salvadori, N. (ed): *Economic Growth and Distribution: on the Nature and Causes of the Wealth of Nations*, Edward Elgar, Cheltenham, UK., pp. 272-291.

Dejuán, O. (2007): "A model for forecasting energy demand in Spain", in Bayer, A. 8ed): *Energy and Environmental Modeling*, chapter 15, EcoMod Press, 2007, Florence, MA.

Dejuán, O. et al. (2008): *Modelo de previsión de la demanda de productos derivados del petróleo en España*, Trabajo presentado a la Comisión Nacional de la Energía, Madrid.

Duchin, F. (1998): *Structural Economics: Measuring Change in Technology, Lifestyles, and the Environment*, Washington, Island Press,

Ferguson, L.; McGregor, P.; Swales, J; Turner, K.; Yin, Y. (2005): "Incorporating Sustainability Indicators into a Computable General Equilibrium Model of the Scottish Economy", *Economic Systems Research,* 17 (2): 103-140.

Galli, R. (1998): "The Relationship Between Energy Intensity and Income Levels: Forecasting long-term Energy Demand in Asian Emerging Economies", *The Energy Journal*, 19 (4): 85-105.

Gately, D. y Huntington, H.D. (2002): "The Asymmetric Effects of Changes in Prices and Income on Energy and Oil Demand", *The Energy Journal*, 23 (1): 19-55.

Gibson, B. & Seventer, D. van (2000): "A Tale of Two Models: Comparing Structuralist and Neoclassical Computable General Equilibrium Models for South Africa", *International Review of Applied Economics*, 14 (2).

Ginsburgh, V. & Keyzer, M (2002): *The Structure of Applied General Equilibrium Models,* Cambridge, MA, The MIT Press.

Grubb, M.; Köhler, J. & Anderson, D. (2002): "Induced Technical Change in Energy and Environmental Modelling: Analytic Approaches and Policy Implications", *Annual Review of Energy and Environment,* 27: 271-308.

Hanley, N.; McGregor, P.; Swales, K; Turner, K. (2006): "The Impact of a Stimulus to Energy Efficiency on the Economy and the Environment. A Regional Computable General Equilibrium Analysis", *Renewable Energy*¸ 31 (2): 161-171.

Harvey, A.C. (1989): *Forecasting Structural Time Series Models and the Kalman Filter,* Cambridge, Cambridge University Press.

Herendeen, R. (1978): "Total Energy Cost of Household Consumption in Norway, 1973", *Energy*, 3: 615-630.

Hoekstra, R. (2005): *Economic Growth, Material Flows and the Environment*, Cheltenham, Edward Elgar.

IEA (International Energy Agency) (2003): *Energy Prices and Taxes*, Paris, OECD.

IEA (2006 a), *Energy Balances of OECD Countries, 2003-2004*, Paris, OECD.

IEA (2006 b): *World Energy Outlook,* Paris, OECD.

IEA (2007): "World Energy Model Methodology and Assumptions". Available at: www.worldenergyoutlook.org/docs/annex_c.pdf.

Judson, R.A., Schmalensee, R. y Stoker, T. M. (1999): "Economic Development and the Structure of the Demand for Commercial Energy", *The Energy Journal*, 20 (2): 29-57.

Kehoe, P. & Kehoe, T. (1994): "A Primer on AGE Models"¸ *Federal Reserve Bank of Minneapolis Quarterly Review,* 18 (2): 2-16. (Available in http://www.minneapolisfed.org).

Kehoe, T. Srinivasan, T. & Whalley, J. (eds) (2004): *Frontiers in Applied General Equilibrium Modelling*, Cambridge, Cambridge University Press.

Keynes, J.M. (1936): *The General Theory of Employment, Interest and Money*, London, Mcmillan.

Kurz, H.D.(1985): "Effective Demand in a 'Classical' Model of Value and Distribution: the Multiplier in a Sraffian Framework", *Manchester School of Economic and Social Studies,* 53 (2): 121-37.

Kydes, A.S., Shaw, S.h. & McDonald, D.F. (1995): "Beyond the Horizon: Recent Directions in Long-Term Energy Modelling", *Energy*, 20 (2),131-149.

Labandeira, X., Labeaga, J.M. y Rodríguez, M. (2006): "A Residential Energy Demand System for Spain", *The Energy Journal*, 27 (2): 87-111.

Lenzen, M. (2006): "A Comparative Multivariate Analysis of Household Energy Requirements in Australia, Brazil, Denmark, India and Japan", *Energy*, 31: 181-207.

Manresa, A.; Sancho, F. & Vegara, J.M. (1998): "Measuring Commodities's Commodity Content", *Economic Systems Research*, 10 (4): 357-365.

McKibbin, W.J. y Wilcoxen, P.J. (1993): "The Global Consequences of Regional Environmental Policies: an Integrated Macroeconomic, Multisectoral Approach". In Kaya, Y., Nakicenovic, N. Nordhaus, W.D. y Toth, F.L. (eds.): *Costs, Impacts and Benefits of* CO_2 *Mitigation*, Luxemburg, Austria, IIASA, pp. 161-178.

Miyazawa, K. & Masegi, S. (1963): "Interindustry Analysis and the Structure of Income Distribution", *Metroeconomica,* 15 (2-3): 161-95.

Olatubi, W.O. y Zhang, Y. (2003): "A Dynamic Estimation of Total Energy Demand for the Southern States", *The Review of Regional Studies*, 33 (2): 206-228.

Pyatt, G. & Round, J. (eds.)(1985): *Social Accounting Matrices. A basis for Planning*, Washington, DC. The World Bank.

Ricardo, D. (1824/1951): *The Principles of Political Economy and Taxation*, Cambridge, Cambridge University Press.

Roca, J. & Alcántara, V. (2002): "Economic Growth, Energy Use and CO_2 Emissions"; in Blackwood, J.R. (ed): *Energy Research at the Cutting Edge*, New York, Novascience, pp. 123-134.

Roca, J. & Serrano, M. (2007): "Income Growth and Atmospheric Pollution in Spain: An Input-Output Approach", *Ecological Economics*, pp. 230-242

Sekerka, B. Kyn, O. & Hejl, L. (1998): "Price Systems Computable from Input-Output Coefficients", in Kurz, H.D., Dietzenbacher, E. & Lager, C: *Input-Output Analysis*, vol. III, pp. 223-243, Cheltenham, UK, E. Elgar.

Sraffa, P. (1960): *Production of Commodities by Means of Commodities. Prelude to a Critique of Economic Theory,* Cambridge, Cambridge University Press.

Sun, J.W. (1998): "Changes in Energy Consumption and Energy Intensity: a Complete Decomposition Model", *Energy Economics*, 20: 85-100.

Vringer, K. & Blok, K. (1995): "The Direct and Indirect Energy Requirements of Households in the Netherlands", *Energy Policy*, 23 (10), 893-910.

Welsch, H. & Ehrenheim, V. (2004): "Environmental Fiscal Reform in Germany: a Computable General Equilibrium Analysis", *Environmental Economics & Policy Studies*, 6 (3): 197-219.

Young, PC.; Pedregal, D.J. & Tych, W. (1999): "Dynamic Harmonic Regression", *Journal of Forecasting*, 18: 369-394.

Table 1. Spanish Input Output Table (2000) Symmetric IOT at basic prices, thousand million euros year 2000.

		Z (=Zd+M) (induced demand = intermediate consumption + final consumption households)																			Y'(Aut. F.D)		Y (final demand, FD)				Total output
		1. Petrol	2. Gas	3. Electricity	4. Coal	5. Extraction (others)	6. Agriculture	7. Chemistry	8. Intermediate G	9. Capital Goods	10. Construction	11. Consumption Goods	12. Tr. Railways	13. Tr. Land	14. Tr. Sea	15. Tr. Air	16. Restau-ration	17. Market Services	18. Non Mark.Serv	19. Households			Cpr	G	I	X	
Z	1. Petrol	2	0	2	0	0	1	3	1	0	0	0	0	3	0	1	0	2	1	6	5		6	0	0	5	27
	2. Gas	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0		1	0	0	0	4
	3. Electricity	0	0	3	0	0	0	1	2	1	0	1	0	0	0	0	0	4	1	4	0		4	0	0	0	20
	4. Coal	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	2
	5.Extraction(others)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0
	6. Agriculture	0	0	0	0	0	3	0	1	0	0	22	0	0	0	0	1	1	0	8	8		8	0	1	7	45
	7. Chemistry	0	0	0	0	0	2	15	4	8	3	4	0	0	0	0	1	5	1	4	20		4	5	0	15	67
	8. Intermediate G	0	0	0	0	0	0	2	22	20	18	6	0	0	0	0	1	10	1	3	15		3	0	0	15	100
	9. Capital Goods	0	0	1	0	0	1	1	7	42	13	4	0	1	0	0	1	12	3	18	99		18	0	42	56	203
	10. Construction	0	0	0	0	0	0	0	0	0	28	0	0	0	0	0	1	12	1	3	79		3	0	79	0	126
	11. Consumption G	0	0	0	0	0	5	1	0	1	0	25	0	0	0	0	13	5	1	50	29		56	0	4	19	131
	12. Tr. Railways	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0		1	0	0	0	2
	13. Tr. Land	1	0	0	0	0	0	1	4	2	1	3	0	0	0	0	0	6	0	5	6		5	0	0	5	31
	14. Tr. Sea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		0	0	0	1	2
	15. Tr. Air	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	4		2	0	0	3	8
	16. Restauration	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	51	16		68	0	0	0	73
	17.Market Services	2	0	2	0	0	3	7	12	14	13	16	0	9	1	2	9	96	12	170	70		177	10	26	27	440
	18. Non Mark.Serv.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	98		2	98	0	0	99
	19. Households	2	1	5	0	0	16	8	17	23	30	18	1	9	0	1	28	164	47	0	0		0	0	0	0	371
PI´	Primary Inputs not linked to consump.	14	3	3	0	0	7	5	9	12	17	7	0	7	0	1	16	95	28	42							
q(dom. prod.)		21	4	20	1	0	39	44	80	125	125	107	2	29	2	6	73	418	99	371							
	Wages	0	0	2	1	0	4	8	14	23	31	18	1	5	0	1	22	118	64	0			0	0	0	0	0
	Profits	2	1	6	0	0	21	5	12	11	15	10	0	8	0	1	21	134	9	0			0	0	0	0	0
	Taxes on energy	0	0	0	0	0	0	0	0	0	0	-1	0	1	0	0	0	1	0	4			4	0	2	0	7
	Other ind. taxes	0	0	0	0	0	-1	0	0	0	1	-2	0	1	0	0	1	7	3	35			8	0	10	30	56
	Imports (Oil & Gas)	13	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0
Eq.imports		6	0	0	1	0	6	23	20	78	0	23	0	2	0	2	1	22	0								
Total Inputs		27	4	20	2	0	45	67	100	203	126	131	2	31	2	8	73	440	99								

Table 2. Energy multipliers.

Me 2004	1. Petrol	2. Gas	3. Electricity	4. Coal	5.Extraction (others)	6. Agriculture	7. Chemistry	8. Intermediate Goods	9. Capital Goods	10. Construction	11. Consumption Goods	12. Tr. Railways	13. Tr. Land	14. Tr. Sea	15. Tr. Air	16. Restauration	17.Market Services	18. Non Mark.Serv.	19. Households
1. Petrol	1,0823	0,0089	0,0813	0,0650	0,0866	0,0416	0,0631	0,0340	0,0227	0,0305	0,0304	0,0425	0,0704	0,0819	0,1311	0,0334	0,0306	0,0311	0,0393
2. Gas	0,0044	1,0026	0,0537	0,0116	0,0317	0,0087	0,0153	0,0200	0,0094	0,0098	0,0114	0,0118	0,0081	0,0077	0,0059	0,0095	0,0096	0,0102	0,0109
3. Electricity	0,0290	0,0140	1,2333	0,1157	0,0776	0,0470	0,0482	0,0685	0,0459	0,0439	0,0498	0,1203	0,0507	0,0473	0,0280	0,0438	0,0503	0,0511	0,0504
4. Coal	0,0021	0,0007	0,0596	1,0060	0,0040	0,0025	0,0026	0,0051	0,0026	0,0026	0,0027	0,0061	0,0027	0,0025	0,0016	0,0024	0,0027	0,0029	0,0027

Me 2009																			
1. Petrol	1,0843	0,0074	0,0783	0,0645	0,0893	0,0377	0,0586	0,0305	0,0201	0,0272	0,0270	0,0390	0,0616	0,0725	0,1211	0,0290	0,0266	0,0269	0,0334
2. Gas	0,0048	1,0029	0,0580	0,0128	0,0344	0,0097	0,0171	0,0223	0,0106	0,0109	0,0127	0,0136	0,0091	0,0087	0,0065	0,0106	0,0108	0,0115	0,0119
3. Electricity	0,0296	0,0142	1,2341	0,1172	0,0796	0,0496	0,0523	0,0749	0,0498	0,0467	0,0535	0,1353	0,0546	0,0510	0,0291	0,0463	0,0539	0,0548	0,0509
4. Coal	0,0020	0,0007	0,0568	1,0058	0,0039	0,0025	0,0026	0,0052	0,0027	0,0026	0,0027	0,0065	0,0027	0,0025	0,0015	0,0024	0,0027	0,0029	0,0026

Note: Me of year 2009 takes into account the evolution of energy coefficients (secular trends and impact of price elasticity) from 2000 to 2009. (We suppose that oil and gas prices double in 2007 and keep constant at the new level)

Table 3. Price impact when the Euro price of crude oil and natural gas doubles.

1. Petrol	2. Gas	3. Electricity	4. Coal	5.Extraction (others)	6. Agriculture	7. Chemistry	8. Intermediate Goods	9. Capital Goods	10. Construction	11. Consumption Goods	12. Tr. Railways	13. Tr. Land	14. Tr. Sea	15. Tr. Air	16. Restauration	17.Market Services	18. Non Mark.Serv.	19. Households
1,6702	1,6911	1,1368	1,0461	1,0877	1,0482	1,0559	1,0376	1,0177	1,0213	1,0290	1,0307	1,0750	1,0757	1,0968	1,0282	1,0259	1,0164	1,0344

Table 4. Secular tendencies of energy coefficients (τ).

	Energy	Other Industries	Transport	Other Services	Households
1. Petrol	0,02	0	-0,01	-0,028	-0,025
2. Gas	0,015	0,02	0,015	0,03	0,02
3. Electricity	0	0,025	0,03	0,03	-0,035
4. Coal	-0,01	0	0	0	-0,051

Table 5. Price elasticities of energy demand (ε) *(after a 100% change in prices)*

	Industry	Households
1. Petrol	0	-0,04
2. Gas	0	-0,01
3. Electricity	0	-0,01
4. Coal	0	0

Figure 1. Evolution of energy demand (four sources in a single scenario).

Scenario 1:

- From 2004-2007 demand grows at the actual rates (around 3,8%). For years 2008 y 2009 the economy stagnates (g=1%).
- In year 2007 the price of crude oil and natural gas doubles and keeps constant at the new level during 2008 and 2009.

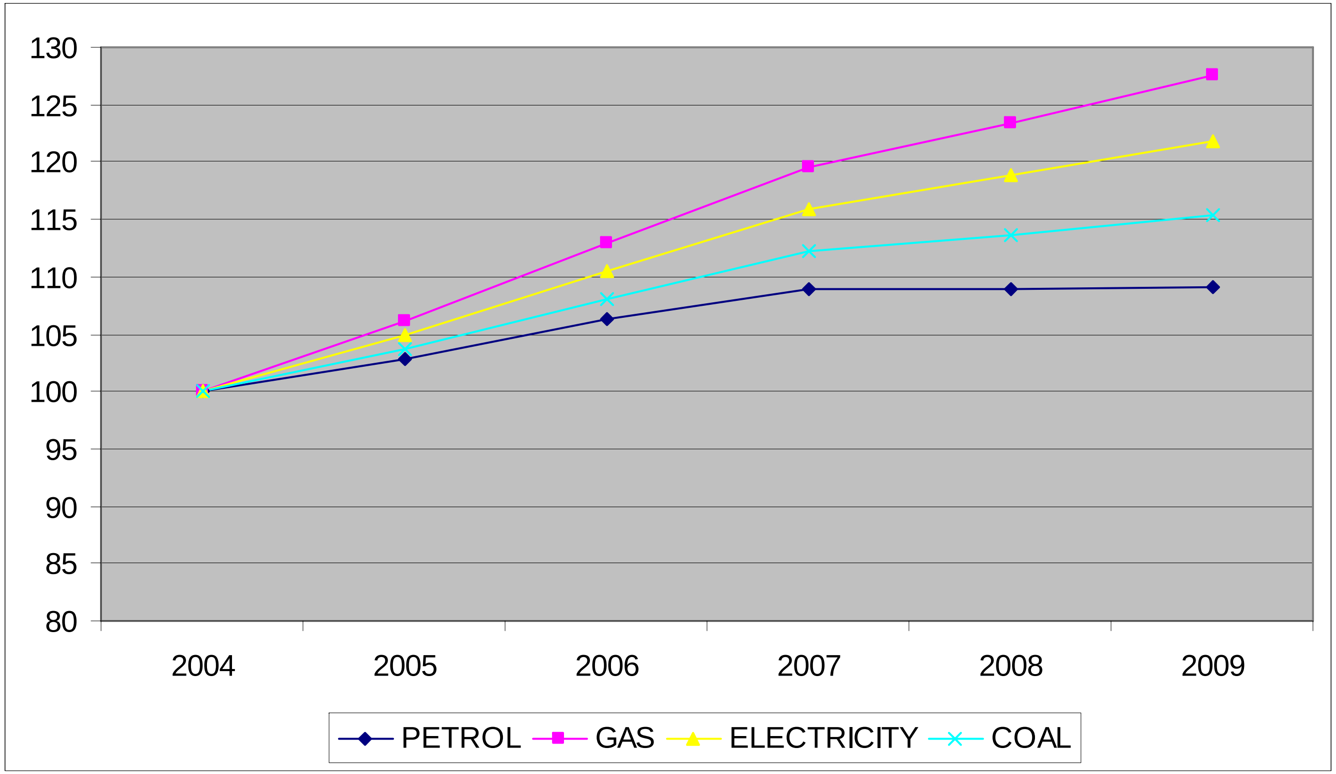

Figure 2. Evolution of the demand for petrol in three different scenarios.

Scenario 1: As the previous one (figure 1). g=1% in 2008, 2009
Scenario 2 (an optimistic one). In 2008 and 2009 demand grows at 2,7%. Constant prices after the increase in 2007.
Scenario 3 (a pessimistic one). The prices of crude oil and natural gas had doubled by 2007 and double again in 2007. As a consequence the economy experience a deep recession (g=0).

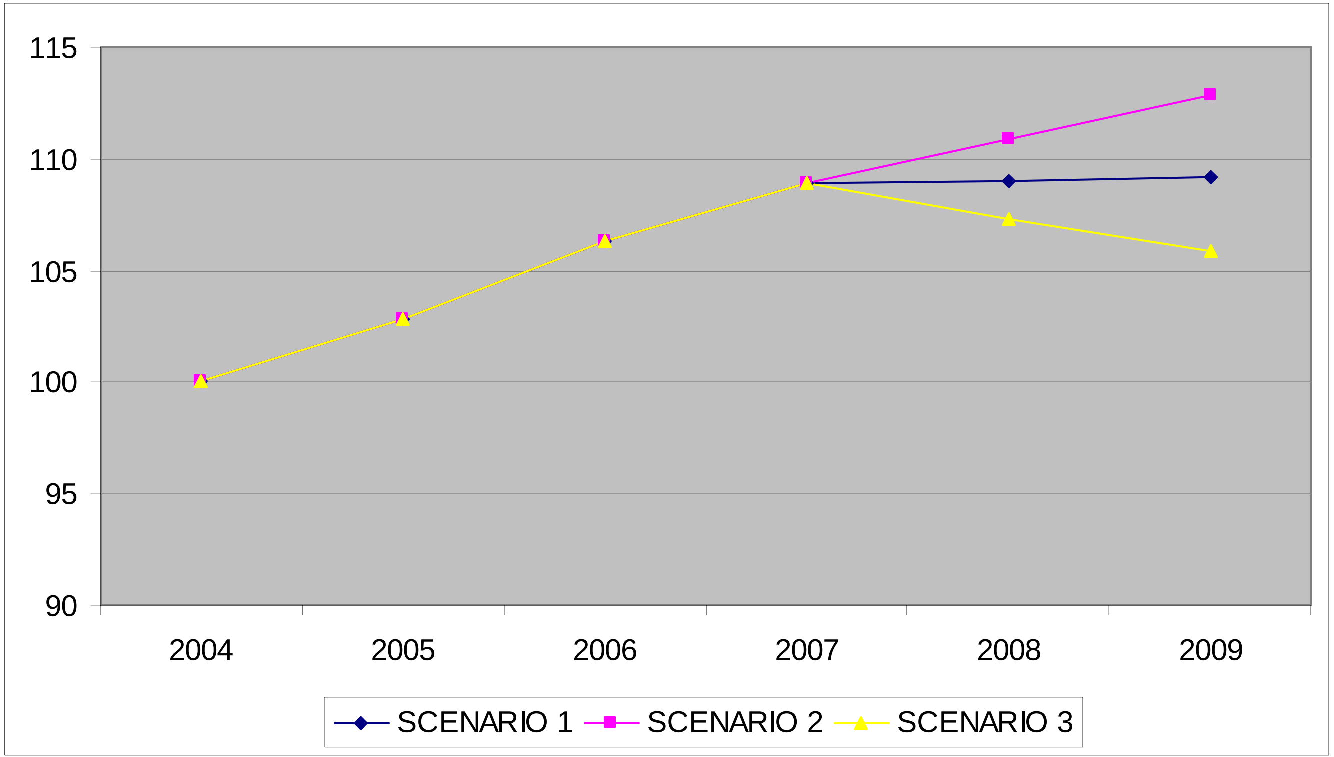

Figure 3. Simulated and actual evolution of petrol demand.