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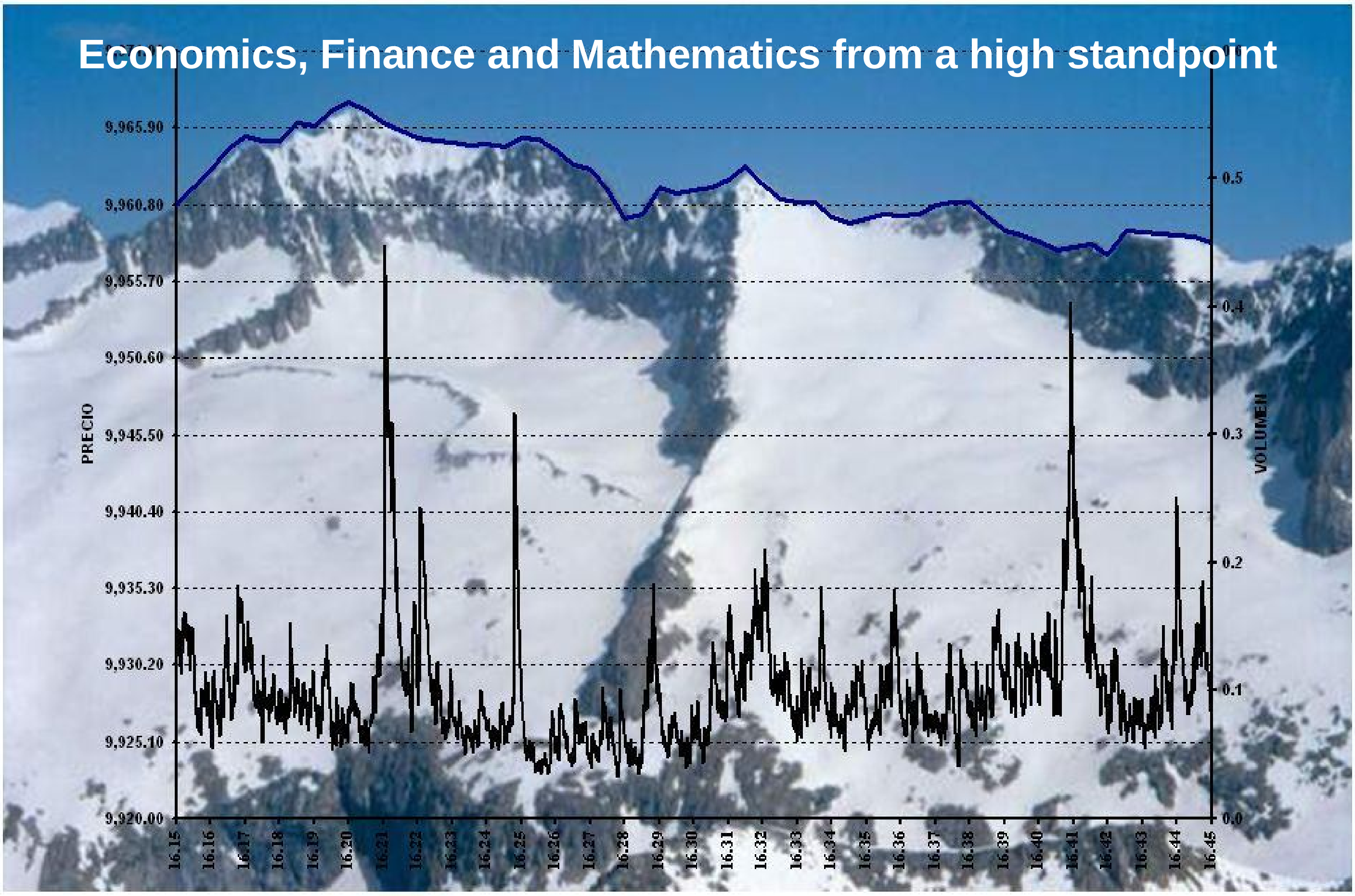

Economics, Finance and Mathematics from a high standpoint

An Energy AGE Model

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DT-DAEF 2009/8

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Edita:
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http://www.uclm.es/dep/daef/

Depósito Legal: AB-351-2009
ISSN: 1989-4856

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Abstract

This paper develops a Computable and Applied General Equilibrium model (AGE) for the estimation of energy demand. It is built on the Spanish symmetric Input-Output Table for 2005. It has been tested for the period 2005 to 2008 and used for forecasting energy demand for the years 2009 to 2012 under different scenarios.

Any AGE model relies on a quantity system and a price system, both of them interwoven. Our quantity system is based on Keynes' principle of effective demand. Production adjusts to demand; it is a multiple of expected autonomous demand. We develop broad input-output multipliers which endogeneize the bulk of final consumption. The price system is based on the classical (Sraffian) theory of prices of production. Commodities exit factories with a price label which gathers for full unit cost (including "normal profits"). The general price system is latter modified to account for the specificities of energy prices where (a) prices of gas and oil derivatives depend mostly on the international price of crude oil; (b) prices of electricity and gas are "administered"; (c) indirect taxes (on oil derivatives) and public transfers (on coal) are important.

The model is dynamic in nature since output and technology are changing at a specific rate, although this rate may be altered by a variety of shocks that impinge on relative prices. It is a mixed input-output and econometric model. Econometrics helps to compute price elasticities. Calibration is used to figure out the evolution of technical coefficients regardless of price changes.

We find that the amount and composition of energy demand depends mostly on: (a) the rate of growth of the economy (b) the type of growth, i.e. the industries playing the role of locomotives; and (c) relative prices of alternative sources of energy. Point (a) is, by far, the most important one.

Keywords: Input-Output Analysis, Computable and Applied General Equilibrium, Energy.

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 and easy 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 examines current models. Section 3 analyzes the structure and technology implicit in our “energy input-output table”. Section 4 develops the quantity system and derives the energy multipliers. Section 5 develops the price system and adapts it to the specificities of energy industries. Section 6 integrates the quantity and price systems and explores their dynamics. In section 7 we fill the model with Spanish data and forecast energy demand in a variety of scenarios. In section 8 we check the accuracy of the model comparing the estimation for the years 2006-08 with current data for energy demand. Our conclusions appear in section 9.

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[1] Previous versions of this paper were presented by O. Dejuán at the Eco-Mod Moscow Conference on “Energy and Environmental Modelling” (September 13-14, 2007) and published by Ali Bayar (2008). In years 2007-08, the model was applied to forecast the demand for the six main products derived from petrol. Research was financed by the Spanish CNE (Comisión Nacional de Energía). Other participants in the applied research were M.Ángeles Cadarso, Carmen Córcoles, Eladio Febrero, Nuria Gómez, Diego Pedregal, Luis López and M. Ángeles Tobarra. We would like to express our gratitude to them and to the CNE which provided data and technical support.

2. Review of the literature.

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: 2007, 2008 a; 2008 b). IEA estimates worldwide demand for different types of energy in the very long run (up to 25 years). We are looking for a more specific model that takes into 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 up the variables in a true AGE mathematgical 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, in percentage terms. They have problems predicting the impact on big changes on prices, whose impact is usually registered after several months (or years) and is never 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.

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[2] Our survey of the literature is not exhaustive. Kydes, Shaw & McDonald (1995) provides additional models and references.

[3] Studies focusing on energy consumption by households: Galli, 1998; Gately & Huntington, 2002; Labandeira et al, 2006, Lenzen, 2006. More general studies providing energy elasticities are: Hsiao & Hsiao, 1985; Longva, Olsen and Strom, 1988; Hisnanick & Kyer, 1995; Judson et al, 1999; Roca & Alcántara, 2002; Olatubi & Zhang, 2003; Lijesen, M.G., 2006; Barker, Ekins & Foxon, 2007; Labandeira, Labeaga & López-Otero, 2009.

[4] A survey is provided by Wiedmann, Lenzen, Turner & Barret (2007). Other useful references are: 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.

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 this purpose. The possibility of substitution among factors of production and among consumption goods is a remarkable feature of it. The strong and immediate influence of demand on prices and of prices on the quantities demanded is another one.

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 this 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 data as given 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 which makes 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 by 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 change of energy coefficients. This trend may be accelerated or delayed if there are significant fluctuations in the relative prices of the different sources of energy. Changes occur sequentially and, usually, 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 of production at year *t* (as well as energy demand) is a multiple of the expected level of autonomous

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[5] An overview of the neoclassical CGE models could 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).

demand for the same period. By the same token, the growth of output and 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. This theory goes back to Ricardo (1817) and was updated by Sraffa (1960). 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 the general model of "prices of production".

3. An input-output table and an input-output 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 2005 and considers 73 industries. Our "energy input-output" has 18 industries. Each of them 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 (regasification and distribution);
3. Electricity (generation and distribution);
4. Coal (extraction and distribution).

The remaining industries in the Spanish input-output table appear highly aggregated. Nevertheless we keep the industries which consume more energy separated. They are the four producers of energy and the four transport services (train, land, sea and air). Agriculture, Chemistry-Plastics and Restaurants-Hotels 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 19th column gathers final induced consumption by households. We exclude final consumption by tourists that is clearly "autonomous", i.e. independent on current domestic income. Row 19 gathers the part of value added that finance induced final consumption. Since the household sector does not generate value added, the 19th row adds up to the value of the 19th 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 allows us to compute the 19th row by extracting from each industry the percentage necessary to finance final consumption by households.

Table 1: An energy input-output table for Spain (2005)

Table 1 shows the structure of our energy input-output table. As everyone knows, an IOT can be read horizontally (as in [3.1]) or vertically (as in [3.2] and [3.3]). The horizontal reading shows the allocation of each commodity among intermediate and final uses. The vertical reading explains the cost structure of each industry: the cost of intermediate inputs and the cost of primary inputs (factors of production which receive value added).

$$(Z - M) + (Y' - M_y) = Z_d + Y'_d = q \qquad [3.1]$$

$$Z + PI' = (Z_d + M) + PI' = q \qquad [3.2]$$

$$Z' + PI = q \qquad [3.3]$$

q is the vector of total output produced in the economy (domestic production). In [3.1] it appears as a column vector. In [3.2] and [3.3] 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 commodity *i* when we read horizontally; purchases by industry *j* when we read vertically.

$\boldsymbol{Z_d}$ matrix of domestic intermediate consumption: *Z-M.*

Z' is the proper *interindustry table.* It can be obtained from *Z,* after equating to zero the cells of the last row corresponding to the household sector.

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

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. To simplify we have omitted the column altogether and included final consumption by tourists in the export column.

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

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

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

PI is a rectangular matrix of "primary inputs" or "non produced inputs". It has *n* columns and 5 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:*

$$A_t = Z\cdot(\hat{q})^{-1} \qquad [3.4]$$

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

$$A_m = M\cdot(\hat{q})^{-1} \qquad [3.5]$$

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[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, we deal with *n·n* matrices, being *n=19* the number of industries and commodities. Households occupy the last column and row. (c) In other cases, the order of the matrix or vector appears inside a bracket 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, where (0) the base year. (e) A dot indicates matrix multiplication. ⊗ indicates cell by cell multiplication.

We can also 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.

$$A_m = A_t \otimes m \qquad [3.6]$$

(c) *Matrix of domestic coefficients:*

$$A_d = Z_d \cdot (\hat{q})^{-1} = A_t - A_m = A_t \otimes (ii - m) \qquad [3.7]$$

"*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:*

$$v = PI \cdot (\hat{q})^{-1} \qquad [3.8]$$

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), profits (β), indirect taxes on energy (γ), VAT and other indirect taxes net of subsidies (δ), and imported crude oil and gas (λ). Note that the last cell of rows α and β are zero, because households do not generate value added. Conversely, most taxes are concentrated in the last cell corresponding to households. Vector λ only shows positive figures in cells 1 and 2, corresponding to petrol used in refining and regasification - distribution of gas.

In a disaggregated fashion we can rewrite [3.8] as:

$$v = \begin{bmatrix} \alpha_1 & \alpha_2 & \dots & \alpha_m & (\alpha_n = 0) \\ \beta_1 & \beta_2 & \dots & \beta_m & (\beta_n = 0) \\ (\gamma_1 \approx 0) & (\gamma_2 \approx 0) & \dots & (\gamma_m \approx 0) & \gamma_n \\ (\delta_1 \approx 0) & (\delta_2 \approx 0) & \dots & (\delta_m \approx 0) & \delta_n \\ \lambda_1 & \lambda_2 & \dots & (\lambda_m = 0) & (\lambda_n = 0) \end{bmatrix} \qquad [3.9]$$

Matrices and vectors in [3.4] till [3.9] contain the basic coefficients of the input-output model from which we shall derive the main tools of our analysis, namely, multipliers and price equations. Technical coefficients and propensities are supposed to remain constant during the period under analysis (from the date of publication of the IOT to the date of our projections). 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.

4. The quantity system and the energy multipliers.

The Leontief's inverse 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.

$$MQ_{(19\cdot 19)} = [I - A_d]^{-1} \qquad [4.1]$$

The first column of [4.1] shows the impact of the expansion of industry 1 (refined petrol here) 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 which gathers: (a) intermediate goods directly or indirectly used in the production of autonomous demand; (b) 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.

$$[I - A_d]^{-1} \cdot Y'_{d\,(0)(19\cdot 1)} = q_{(0)(19\cdot 1)} \qquad [4.2]$$ [7]

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[7] 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 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·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 keep 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.

The multiplier of income is computed by [4.3]. *v* is the row vector represented by [3.8]. It expresses the share of primary inputs in the value of total output.

$$Mv_{(1\cdot 19)} = v_{(1\cdot 19)} \cdot [I - A_d]^{-1} \qquad [4.3]$$

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 premultiply *MQ* by a unit matrix (*i'*). It is a 19·19 matrix where the first 4 rows are "ones", the remaining rows are "zeros".

$$ME_{(4\cdot 19)} = i'_{(19\cdot 19)} \otimes [I - A_d]^{-1} \qquad [4.4]$$

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*. Column 12, for instance, informs us that when rail transport delivers new services valued at 1 million Euros, the induced demand for refined petrol amounts to 0.456 million Euros; 0.0197 the demand for gas; 0.1348 the demand for electricity; and 0.0054 the demand for coal. Looking at the row "totals" we see that the four energy sectors are, by far, those which with the higher energy multiplier. The overall "dragging effect" of the electricity sector is 1.4629.

Table 2: Energy multipliers

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

Our quantity model (and the multipliers derived 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. The level of output is supposed to be a multiple of expected autonomous demand for the year under consideration. This 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.

Notice that the working of the multiplier mechanism requires firms to have some spare capacity. 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 adjustments easier 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, coal and gas follows the Keynesian pattern: supply adjusts to demand. In the petrol industry this pattern is not always possible. Refineries operate 24/7 so the possibility of adjusting to demand increases via capacity is negligible. Petrol stocks are significant but they cannot cope with a big and prolonged increase in demand. Refineries are supposed to forecast accurately the permanent increases in demand in order to build capacity in advance. If the increases in demand are too big and / or unexpected, the adjustment will occur via imports. Import coefficients would change, altering the value of the domestic multiplier. This is a troublesome complication of the quantity model that we do not consider here.

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

5. The price system.

A vertical reading of the IOT (as in [3.3]), 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 matrix unit costs (p). By construction each column of coefficients adds up to one

$$A_d + A_m + v = A_d + A_m + (\alpha + \beta + \delta + \gamma + \lambda) = \begin{bmatrix} 1 & 1 & \ldots & 1 \end{bmatrix} = p \qquad [5.1]$$

We can interpret the elements of [5.1] 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 (that we take as our reference) 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 (although 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 to 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 should keep in mind 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:

$$p_{(1\cdot19)} = \left(p\cdot A'\right)_{(1\cdot19)} + \left(p_m \cdot A'_m\right)_{(1\cdot19)} + i_{(1,19)}(\alpha + \beta + \gamma + \delta + \lambda)_{(5\cdot19)} = \begin{bmatrix} 1 & 1 & \ldots & 1 \end{bmatrix} \qquad [5.2]$$

The price of refined petrol, for example, could be computed in the following way:

$$p_1 = \sum_{i=1}^{19} p_i \cdot A'_{d,i1} + \sum_{i=1}^{19} p_i \cdot A'_{m,i1} + (\alpha_1 + \beta_1 + \gamma_1 + \delta_1 + \lambda_1) \qquad [5.3]$$

The preceding expression is not intended to be a price theory, but a description of how prices are made up. To have a proper theory of prices we should introduce two equilibrium conditions. (a) Prices should cover full costs of production which includes "normal profits". (b) "Normal profits" divided by the value of the capital invested should yield the "general" or "uniform" rate of profit (r^*). Relative prices are supposed to move until the last 100 M€ invested in any industry yield the same profit.

The second part of the next equation ($r^*\cdot\Sigma p_i\cdot k_{i1}$) computes unit profits in industry j as r^* times the value of fixed capital installed in it. 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 industries ($r_1=r_2=r^*$), while sectoral profit margins differ from each other ($b'_1\neq b'_2$). If industry 1 has the highest capital intensity, b'_1 should be higher than b'_2 in order to obtain the same rate of profit ($r_1=r_2$).

$$\beta_1 = r\cdot\left(\sum_1^{19} p'_i\cdot k_{i1}\right) = b'_1\cdot\left(\sum_1^{19} p_i\cdot a_{i1} + \sum_1^{19} p_{m,i}\cdot a_{m,i1}\right) \qquad [5.4]$$

Note also that the tendency to a uniform rate of profit is a long run phenomenon. In the short run some firms will get extra-profits while others will suffer economic losses (i.e. profits below average). They are encapsulated in the row vector δ, which also accounts for other indirect taxes and subsidies [8].

Let us define gross profit margins as $b_j=(1+b'_j)$ and introduce them into [5.2]. We obtain the competitive system of prices that can be expressed either in an additive or a multiplicative way.

$$p = p\cdot A\cdot\hat{b} + p_m\cdot A_m\cdot\hat{b} + (\alpha+\delta+\gamma+\lambda) = \begin{bmatrix}1 & 1 & \dots & 1\end{bmatrix} \qquad [5.5]$$

$$p = (\alpha+\delta+\gamma+\lambda+p_m\cdot A_m\cdot\hat{b})\cdot\left[I - A\cdot\hat{b}\right]^{-1} = \begin{bmatrix}1 & 1 & \dots & 1\end{bmatrix} \qquad [5.6]$$

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 instance, will push all prices up (as in an inflationary process). But the highest price increases will occur in labour intensive

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[8] 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 the first shock. The new computed prices do not warrant a uniform rate of profit in any meaningful sense. In our opinion this is a serious shortcoming of the CGE price system.

commodities. The same can be said of an increase in the price of crude oil and gas. *Table 3* shows the impact on relative prices when the international price of crude oil and gas doubles. The price of refined petrol and distributed gas will rise from 1 to 1.80 and 1.67 (in percentage terms 80% and 67%). The price of electricity should rise 32%. The increases in the prices of chemical products and land and air transport would be above 15%. The last cell shows the impact on the CPI. If all prices adjust fully and promptly the CPI would grow 8%. (We know that under these circumstances Governments try to delay the adjustment of administered prices like electricity and public transport).

Table 3: Price impact

The Classical or Sraffian theory of prices of production apply to "reproducible" commodities under competitive conditions. The bulk of industries included in an IOT adjust in fact to the cost-of-production pattern. Some energy products may be an exception for a variety of reasons that we shall analyze next. Yet, our conclusion will be that the tackles reasonably well 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, whose prices are taken as given in our AGE model. On the contrary, changes in domestic demand, no matter how big they are, do not influence international prices, because our country represents a small fraction of international demand. To compute the effects on prices of an increase in the international price of crude oil and natural gas we just have to alter λ_1 and λ_2 and apply the price system. All prices are supposed to rise but, most of all, prices of refined petrol, gas and commodities that are intensive in petrol and gas. Price variation (row vector *p'*) can be computed by the following expression.

$$p' = \begin{pmatrix} \Delta\lambda_1 & \Delta\lambda_2 \ldots & 0 \end{pmatrix} \cdot \left[I - A_d \cdot \hat{b} \right]^{-1} \qquad [5.7]$$

(b) *International prices.* The petrol industry is totally open to international competition. The same, but to a lesser extent, can be said of the coal industry. 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. 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 ("1" by definition). If international prices rise "*y*" points, δ_1 should rise by the same amount. For a time, oil refineries will suffer economic losses in the first case; they will enjoy extra profits in the second. A rise in the international price of refined petrol could be represented by the following expression where δ_1 ensures that prices of refined petrol move in line with international prices.

$$p' = (\delta_1 \quad 0... \quad 0) \cdot \left[I - A_d \cdot \hat{b} \right]^{-1} \qquad [5.8]$$

(c) *Oligopoly and price regulation in gas and electricity.* When there are few producers in an industry, their chances to collude in order to fix prices are enhanced. To avoid this outcome, most governments have created national agencies that regulate the prices of public utilities (electricity and gas, in particular). The Spanish regulator allows it to raise prices in line with costs but an official authorization is required before this can be done. The regulator performs the same task as our mathematical model (equation [5.6]), although with some delay. In conclusion, we do not have to worry about gas and electricity prices unless we wish to highlight price-cost deviations. Again, this adjustment will come via δ.

(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 the whole spectrum of commodities. Since we deal with IOT at base prices, any change in taxes and subsidies will show up in γ_{19}, the cell corresponding to households[9].

$$p' = \begin{pmatrix} 0 & 0 & \ldots & 0 & \Delta\gamma_{19} \end{pmatrix} \cdot \left[I - A_d \cdot \hat{b} \right]^{-1} \qquad [5.9]$$

6. Dynamics of the system: tendencies and elasticities.

Our AGE model is a dynamic one because some exogenous variables and some parameters are continuously moving. The vector of final autonomous demand is the "driving force" 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.

This section will focus not on the evolution of autonomous demand that shows up in the "multiplicand" but on the evolution of technical coefficient that determines the energy multiplier, and the price equations as well. Technological parameters, consumption propensities and import shares are taken as data but they cannot be considered "constant". To clarify the issue we shall distinguish between secular trends associated to technical change and short term deviations from the trend explained by price elasticities. In the last paragraphs we integrate both movements.

(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 technical coefficients constant for 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 a long time. Under these circumstances, energy prices will be more volatile with a tendency to rise. Firms will

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[9] To figure out the variation of γ_{19} we can simulate an increase in γ_1 (tax on fuels) and a decrease in γ_4 (subsidy on coal). The variation of the price of the consumption basket (industry 19) would indicate how much γ_{19} has to change.

try to save these resources and search for substitutes. This evidence justifies the yearly updating of energy coefficients, most of all in a study focusing on demand for energy[10].

It is right 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 in $\tau_{(2,19)}$ indicates that more gas enters into each unit of 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 from current movements in prices. To simplify, we'll suppose that prices remain constant at this point in time. 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 zero except the four producing and distributing energy. In the cells corresponding to these rows we find the secular trend (τ_{ij}) plus one.

$$\begin{aligned} A_{t(1)} &= A_{t(0)} \cdot (1+\tau_{ij})^1 \\ A_{t(2)} &= A_{t(0)} \cdot (1+\tau_{ij})^2 \\ A_{t(3)} &= A_{t(0)} \cdot (1+\tau_{ij})^3 \\ A_{t(4)} &= A_{t(0)} \cdot (1+\tau_{ij})^4 \end{aligned} \qquad [6.1]$$

Table 4: Secular tendencies of energy coefficients.

Table 4 shows the tendencies we have found. There is a τ for each energy source (petrol, gas, electricity and coal) and for each industry. To find the precise numbers we have combined three methods.

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

Econometric methods. Econometrics provides some useful hints. It gives some values for tendencies and price elasticities informing about the reliability (R^2) of the parameters estimated elsewhere. The "non observable components" method has been particularly helful. (Pedregal et al, 2009; Young et al, 1999; Harvey, 1989). It yields price elasticities and the inner tendencies of parameters that are unrelated to current price movements. The estimates of "inner tendencies" obtained from this technique cannot be directly incorporated into our model because the energy sources and the industries considered are not the same. Yet they provide a useful way of checking the values obtained by calibration.

Direct calibration. By comparing each technical coefficients of IOT-2005 with the homonymous coefficients of IOT-2000, we can derive the yearly rate of growth or decline of technical coefficients for each energy source in each industry. We can even distinguish between total, domestic and imported coefficients. In principle, it is all we need. Unfortunately IOTs appear with considerably delay and we need to up-date coefficients using complementary sources or information.

Indirect calibration. From the release of the last symmetric input-output table to the time in which we compute our predictions there is usually a span of three to eight years. Energy agencies (CNE in Spain) are very efficient in the provision of fresh data. They provide information, both in physical units and at current prices, about domestic production, imports and exports of energy. The INE also provides information about aggregate demand. From this information we can figure out the evolution of energy coefficients.

As we know, the matrix of total technical coefficients results from adding up the matrices of domestic and imported coefficients. We shall consider energy source *i* (electricity, for example). The row of calibrated total coefficients of energy *i* (A^c_{ti}) can be obtained by multiplying the original row by the gross tendencies or by adding up the calibrated matrices of domestic and imported coefficients.

$$A^{c}_{ti(1)} = A_{ti(0)} \otimes (1+\tau_i) = A_{di(0)} \otimes (1+\theta_i) + A_{mi(0)} \otimes (1+\eta_i) \qquad [6.2]$$

Figures in brackets refer to the year: (0) is the base year to which the original IOTs refer; (1) is the year we want to calibrate. Tendencies appear as scalars, one for each energy source *i*. τ_i stands for the tendency of total coefficients of energy i; θ_i for the tendency of domestic coefficients; and η_I for the tendency of imported coefficients. Σ indicates that we sum up the coefficients of row *i*.

From here we can obtain the gross tendency of total coefficient of energy *i* as a weighted average of the tendencies of the domestic and imported coefficients, which we are going to calibrate next.

$$(1+\tau_i) = (1+\theta_i) \otimes \left(\frac{\Sigma A_{di(0)}}{\Sigma A_{ti(0)}} \right) + (1+\eta_i) \otimes \left(\frac{\Sigma A_{mi(0)}}{\Sigma A_{ti(0)}} \right) \qquad [6.3]$$

The *domestic* production of electricity (source *i*) can be computed as the sum of the intermediate demand for electricity by industries and households ($Z_{d,i}$), plus autonomous demand (dealing with energy, it broadly coincides with exports, X_i).

$$q_{i(1)} = \Sigma Z_{di(1)} + X_{i(1)} \qquad [6.4]$$

We ignore the value $Z_{d(1)}$ but we can approximate it by multiplying the output of year (1) by coefficients of years (0). To obtain the actual values in year (1) these coefficients should be multiplied by their gross tendency $(1+\theta_i)$.

$$q_{i(1)} = \left(\Sigma A_{di(0)} \cdot q_{i1}\right) \otimes (1+\theta_i) + X_{i(1)} \qquad [6.5]$$

The gross tendency of domestic coefficients of electricity will be:

$$(1+\theta_i) = \frac{q_{i(1)} - X_{i(1)}}{\Sigma A_{di(0)} \cdot q_{i1}} \qquad [6.6]$$

And the calibrated matrix of domestic coefficients:

$$A^c_{di(1)} = A_{di(0)} \cdot (1+\theta_i) \qquad [6.7]$$

By a similar procedure we can obtain the gross tendencies of import coefficients.

$$M_{i(1)} = \Sigma Z_{mi(1)} = \Sigma A_{mi(1)} \cdot q_{i(1)} = (\Sigma A_{mi(0)} \cdot q_{i(1)}) \otimes (1+\eta_i) \qquad [6.8]$$

$$(1+\eta_i) = \frac{M_{i(1)}}{\Sigma A_{mi(0)} \cdot q_{i(1)}} \qquad [6.9]$$

The calibrated matrix of import coefficients would be.

$$A^{*c}_{m(1)} = A^*_{m(0)} \otimes (1+\eta_i) \qquad [6.10]$$

The tendencies that appear in *table 4* derive from direct calibration (i.e. from the comparison of symmetric input output tables for years 2000 and 2005). We have increased or decreased each energy row according to the results of indirect calibration for years 2005 and 2008. At the end of this section we shall comment on them.

(b) Short-term price elasticities and their impact on technical coefficients.

Econometric studies (quoted in footnote 3) 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 fuel in industries and households. The negative tendency τ_1 will increase in absolute value. An increase 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 tendency τ_2 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. In our model, these effects belong to the long term tendencies that are calibrated from time to time and included in τ_{ij}..

Own price elasticity measures the percentage variation (always negative) in the demand of commodity *i* when its price rises a given percentage. If the price of petrol and electricity doubles people will stop using their cars so much and start paying more attention to switching off electrical appliances when they are not in use. *Table 5* shows the estimated price elasticity for firms and households, only for the cases when they are statistically significant [11]. We observe that electricity has the highest price-elasticity (in absolute terms) both in proper industries and in households.

Table 5: Price elasticities.

The figures in the previous table reflect the impact on quantities demanded when prices double (i.e. a one-hundred percent increase). If the increase in prices is 25% we

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[11] Apart from our own estimations we have considered certain results given in econometric studies (Labandeira & López, 2002; Labandeira, Labeaga & Rodríguez, 2005; Longva, Olsen & Strom (1988).

have to multiply the number given in *table 5* by 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 5)[12].

We add this result to the matrix or secular tendencies to obtain the matrices of "adjusted tendencies". We can write:

$$\tau^{*}_{(19\cdot 19)} = \tau_{(19\cdot 19)} + \langle pd \rangle_{(19\cdot 19)} \cdot \varepsilon_{(19\cdot 19)} \qquad [6.11]$$

The evolution of the matrix of technical coefficients (A_t) from year 0 to year 4 will be described by the following equations. Note that we have substituted matrix τ of [6.1] by matrix τ*.

$$\begin{aligned} A^{*}_{t(1)} &= A^{*}_{t(0)} \otimes (1+\tau^{*}) \\ &\ldots \qquad\qquad\qquad\qquad [6.12] \\ A^{*}_{t(5)} &= A^{*}_{t(4)} \otimes (1+\tau^{*}) \end{aligned}$$

Two additional comments on technology:

(1) The impact of prices is distributed over several years, but it does not last forever. The release of a new symmetric IOT marks a new starting point. At this moment the permanent impact of prices (if it exists) would be integrated into the long run tendency.

(2) Energy-saving technical change is not reversible. This is the so called "ratchet effect", that will be illustrated with a couple of 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 looks to producing low-petrol-consumption motors. The industry will not go back to previous models even if oil prices fall.

(c) Evaluation of trends and elasticities.

How important is the impact on energy demand associated to changes in aggregate demand, technical progress and price changes? Analyzing the evidence presented in tables 4 and 5 we can extract several conclusions. (1) In general, energy coefficients

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[12] We remind the reader that the initial prices have been set equal to one (our initial vector *p*). After a change in costs, the price equations will render vector *p'*. Price deviation of commodity *i* will be: $pd_i = \dfrac{p'_i - p_i}{p_i} = p_i - 1$

tend to decline, despite some relevant exceptions in gas and electricity. (2) The rate of decline of energy coefficients evolves faster in industries than in households. The exception is coal. (3) Gas is a clear substitute for petrol and coal in the generation of electricity. In both cases the cross elasticity is positive and has been introduced into the long run tendencies of coefficients. For the remaining products cross elasticities are not significant and require time to materialize. (4) Own price elasticities are low; they are more significant for households than for industries. (5) Income and product elasticities are important. This justifies a model like ours where the main determinant of energy demand is the growth of output and income.

7. Forecasting energy demand in Spain.

Our AGE model has been designed to forecast energy demand under different “growth and price” scenarios. 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 precise and fresh 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 for the different sources of energy. We can even distinguish between what is produced in the country and what is imported.

The base year of our predictions will be 2008. Using the calibration procedures commented on in the previous section, we have computed the Spanish IOT for year 2008 from which we obtain our analytical tools: multipliers and price equations. Our predictions refer to the period 2009-2012.

To illustrate the working of the model we are going to consider four scenarios. They result from the combination of three parameters.

(a) *Economic growth.* (P= Pessimistic; O = Optimistic). In the two pessimistic scenarios (1 and 2) the rate of growth of the economy is nil or negative. 0.006 (i.e. 0.6%) in 2008; -0.04 in 2009; -0.02 for 2010 and zero for 2011 and 2012. In the two optimistic scenarios (3 and 4) the rates of change are similar for 2008 and 2009 (since they reflect the real ones) but they increase in the following years: 0,01 in 2010; 0,03 in 2011 and 2012.

(b) *International price of crude oil and natural gas*. (C = constant; R = rising). In scenario 4 the international price of crude oil stabilizes at 65 Euros/barrel. (The international price of gas is related to it). This figure results from multiplying the dollar price of a barrel (84.5) times the exchange rate (1.3 Dollars per Euro). In the remaining scenarios the Euro price rises steadily: from 65 Euros/barrel in 2009 to €100 in 2010, to €120 in 2011 and in 2012.

(c) *Price of electricity*. (F = fixed; V = variable). In scenarios 2 and 4 the price of electricity remains constant at the level fixed by the Government (which coincides with the 2008 price). In scenarios 2 and 4 the price of electricity adjusts to the cost of production, so any increase in the price of petrol and gas puts up the price of electricity.

Table 6: Scenarios

In the four panels of figure 1 we show the evolution of the demand for refined petrol, gas, electricity and coal from 2008 (our base year) to 2012. The four lines that appear in each graph correspond to different scenarios. Several conclusions may be drawn from the graphs.

(a) In scenario 1 the economy suffers a stagflation, the worst of all possible outcomes. Scenario 4 corresponds to the rosiest situation with high growth and constant prices of energy. The differences in demand are important.

(b) Comparing scenarios 1 and 3 we observe the importance of economic growth. It is especially relevant for coal and petrol.

(c) The comparison between scenarios 1 and 2 gives an idea of the impact of crude oil and gas on the price of electricity and the reaction of demand to rising prices in electricity. If electricity prices had been allowed to adjust to the cost of production (scenario 2) the demand for electricity in 2012 would have been 25 percentage points lower.

Figure 1: Evolution of the energy demand for each scenario (2008 – 2012).

8. Accuracy of the model.

To what extent can we rely on the predictions of our energy AGE model? To answer this crucial question we can apply the model to a period (2006-2008) for which we already know the actual data. Then we compare the estimated rate of change for each source of energy in each year with the real ones.

In the four panels of figure 2 we contrast the real and estimated demand for the four sources of energy. Table 7 reports the error in predictions for each energy source (E_i) in each year (t). We compute it as the difference between the estimated rate of change of demand for energy i ($\hat{E}^{e}_{i,t}$) and the real rate of change ($\hat{E}_{i,t}$). A positive figure would imply that we have overestimated demand. In the last column (at the bottom of the table) we compute the *means of absolute errors* (MAE) for each source of energy i in the three-year period (2006-08). Since we are dealing with absolute values all the figures are positive.

$$MAE_i = \frac{1}{3}\sum_{1}^{t}\left|\hat{E}^{e}_{i,t} - \hat{E}_{i,t}\right| \qquad [8.1]$$

Except for coal, the errors of predictions are clearly below 5%, which is usually considered the threshold of acceptance. The problem with coal arises from a 14% fall in the demand for coal in the production of electricity in 2006, a year in which the Spanish economy was booming. It might be due to a problem of periodification since we observe than in the following years real demand is higher than estimated[13]. As reflected in table 7, our model predicts the changes in tendencies quite accurately.

Figure 2: Contrast between real and estimated energy demand.

Table 7: Errors of prediction (%)

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[13] We have run trials for the period 2000-05 and the estimated demand for coal behaves properly.

9. Conclusions.

Any AGE model contains a quantity system and a price system linking each other. The quantity system of our energy AGE model is based on the Keynesian principle of effective demand and deployed through the energy multipliers. The price system is based on Sraffian equations of "cost of production", that have been redesigned in order to account for exogenous energy prices fixed by Government or in international markets.

In our AGE model, technology (the evolution of energy coefficients, to be more precise) provides the basic link between the system of prices and the system of quantities. Energy coefficients show a tendency that we have computed via calibration and econometric methods. These secular trends may be speeded up or slowed down when there is a significant change in the relative prices of different energy sources.

Our paper provides fresh evidence on energy multipliers, long-term trends of energy coefficients and short-term elasticities. Apart from the interest of such empirical results, the papers proves that it is possible to build an energy AGE model that is simple enough to be computed with official data and to be run with a spreadsheet.

The model helps to figure out the demand for energy sources in different scenarios. They refer to the expected rate of growth of the economy, the expected evolution of international prices of crude oil and natural gas and the behaviour of the national regulator (fixing the price of electricity or allowing it to adjust to changing costs of production). We can introduce new parameters (like taxes) and we can find new applications (like the impact on pollution and climate change).

The accuracy of the adjustment between estimated and actual trends has proved to be quite positive. This proves that our AGE models has formalized properly the main determinants of energy demand. The most important one is the growth of the economy. The second one is technical progress, which depends both on exogenous and on endogenous components.

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.

Barker, T.; Ekins, P.; Foxon, T. (2007): "Macroeconomic effects of efficiency policies for energy-intensive industries: The case of the UK Climate Change Agreements, 2000-2100", *Energy Economics*, v. 29, pp. 760-778.

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*, Madrid, Comisión Nacional de la Energía (CNE), 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.

Hisnanck, J.J. & Kyier, B.L. (1995): "Assessing a disaggregated energy input using confidence intervals around a translog elasticity estimates", *Energy Econoics*, v. 17, n. 2, pp. 125-132.

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

Hsiao, F.S.T. & Hsiao, M.W. (1985): "Elasticities, ratios and energy modelling", *Energy Economics*, July, pp. 153-158

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

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

IEA (2008 a), *Energy Balances of OECD Countries, 2003-2004*, Paris, OECD.

IEA (2008 a): *World Energy Outlook*, Paris, OECD.

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.

Labandeira, X.; Labeaga, J.M. López-Otero, X. (2009): "Estimation of Elasticity Price of Electricity with Incomplete Information", *Documento de Trabajo 2009-18*¸ Fedea-Iberdrola

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

Lijesen, M.G. (2006): "The real-time price elasticity of electricity", *Energy Economics*, v. 29, pp. 249-258.

Longva, S.; Olsen, O. & Strom, S. (1988): "Total elasticities of energy demand analysed within a general equilibrium model", *Energy Economics,* October, pp. 298-308.

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.

Pedregal, D.; Dejuán, O.; Gómez, N.; Tobarra, M.A. (2009): "Modelling demand for crude oil products in Spain", *Energy Policy*

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.

Wiedmann, T.; Lenzen, M.; Turner, K. & Barrett, J. (2007): "Examining the global environmental impact of regional consumption activities: Part 2: Review of input-output models for the assessment of environmental impacts embodied in trade", *Ecological Economics,* pp. 15-26

Table 1. En energy input-output table for Spain. (Symmetric total IOT at base prices; thousand million Euros, year 2005).

(continue)

IOT 2005 total	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. Air	16. Restauration
1. Petrol	5532,7	28,5	3072,4	275,5	6,6	686,3	3179,9	1019	273,6	483,5	319,7	37,7	3736,8	438,9	1591,5	575,4
2. Gas	3,9	0,6	3145,8	30,4	14,6	8,7	346,6	1036,2	180,7	19,6	374,6	2,5	109,9	4,8	0,1	71,1
3. Electricity	72,5	28,6	5410	343,5	3,7	459,8	704,4	3322,7	2160	526,4	1530,6	198,2	79,7	52,2	33,4	501,2
4. Coal	0,8	5,7	1887,1	70,1	0	8,5	543,7	4300,8	57,9	1465	38,7	0	2,3	0	0	4,6
5. Extraction (others)	64,0	63,6	0,0	0,0	2,9	0,0	2,7	0,0	0,0	0,0	0,0	0,0	1,7	0,0	0,0	0,0
6. Agriculture	0,1	0	0,5	0	0	2315,7	87,7	1389,6	1,6	22,9	23815,1	0	1,3	8,1	0	1436,3
7. Chemistry	42,2	2,9	14,6	326	2,6	1369,7	10948,3	6858,8	2548,8	1269,4	2899,2	0,1	15,7	9,4	0,3	1161,5
8. Intermediate Goods	20,5	9,1	145,2	194,7	5,2	353,2	1677,6	29824,7	33060,8	29643,6	9592,9	3,6	355	5,8	10,7	1005,4
9. Capital Goods	218,5	4,7	1263,7	503,6	22,9	1431,8	1156,9	9999,6	51915,7	21230,3	5169,4	233,6	1281,2	93,1	257	1135,4
10. Construction	32,1	16,1	434,9	70,2	0,4	205,4	141,2	572,5	358,3	97947,4	763,2	98	139,5	8,2	36	1200,1
11. Consumption Goods	26,9	1,2	106,9	33,2	0,9	6398,4	422	779,6	1088,5	2325,5	30296,7	6,3	304,1	91	105,3	18772,9
12. Tr. Railways	12,5	0,1	19,3	1,9	0	8,5	42,2	87,6	83,2	13,5	47,1	14,8	11,1	2,5	5,1	1,3
13. Tr. Land	444,8	4,8	178,6	274,5	0,1	205,1	1263,3	5966,8	2511,3	1825,6	5263,8	1,6	469,1	52,7	23,5	112,2
14. Tr. Sea	33,2	0	21,2	0,8	0,3	31,9	91	112,1	127,5	33,3	116	0,1	10	2,3	0,8	3
15. Air	12,3	0,5	23,5	5,6	0,9	3,2	104	83,5	130,3	36,9	41,9	1,1	0,8	3,4	519,2	1,5
16. Restauration	13,9	3,4	54,6	4,4	1	15	240,7	160	193,6	246,7	130,5	15,1	52,9	6,3	48,2	61,1
17. Market Services	1610,5	255,4	4746,2	1013	75,5	3716,4	7388,3	19487,6	19928,5	23925	22721,6	514,4	14322,4	1092,9	2478,4	14723
18. Non Mark. Serv.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19. Households	2360,4	1501,6	6848,7	1402,2	4,9	16081,7	6490,2	22503,5	25662,2	56811,7	19864,4	832,3	11129,3	585,6	1690,8	37392,8
Σ Intermediate Consumption	10501,8	1926,8	27373,2	4549,6	142,5	33299,3	34830,7	107504,6	140282,5	237826,3	122985,4	1959,4	32022,8	2457,2	6800,3	78158,8
Taxes on Energy	1,3	9,8	-56,4	43,1	1,3	-234,3	127,6	286,0	194,6	594,1	-1119,9	8,0	1278,7	5,5	5,1	478,5
Other industry taxes	700,3	57,7	340,5	60,4	2,3	-1693,6	97,3	454,6	-79,5	1859,4	-1557,5	-0,4	1211,9	-4,6	1,6	810,3
Rest of Added Value	1387,2	882,5	4024,7	824,1	2,9	9450,7	3814,1	13224,6	15080,9	33386,5	11673,7	489,1	6540,4	344,2	993,6	21974,5
Imports (Oil & Gas)	17679,6	4875,5	0,0	0,0	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	244,3	0,0	0,0	0,0
Production	30270,2	7752,3	31682,0	5477,2	149,2	40822,1	38869,7	121469,8	155478,5	273666,3	131981,7	2456,1	41298,1	2802,3	7800,6	101422,1
Imports	9369	0,1	501,4	3968,3	0	7976,5	27299,1	29482,7	99886,2	16,1	34635,5	27	2610	150	3239,8	1038
Total Inputs	39639,2	7752,4	32183,4	9445,5	149,2	48798,6	66168,8	150952,5	255364,7	273682,4	166617,2	2483,1	43908,1	2952,3	11040,4	102460,1

(continue)

IOT 2005 total	17. Market Services	18. Non Mark. Serv.	19. Households	Intermediate Demand	Final Consumption Expenditure	Final Consumption Expenditure of Households	Final Consumption Expenditure of NPISH	Final Consumption Expenditure of General Government	Gross Capital Formation	Gross Fixed Capital Formation	Changes in Inventories and Net Acq. Of Valuables	Exports	Non resident National Consumption	Total Exports	Final Demand	Total Output
1. Petrol	2233,7	721,8	7723,5	31937,0	0		0	0	219	0	219	7483,2	0	7483,2	7702,2	39639,2
2. Gas	716	293,4	1281,2	7640,7	0		0	0	0,5	0	0,5	111,2	0	111,2	111,7	7752,4
3. Electricity	8178,8	2055,4	6095,4	31756,5	0		0	0	9,7	0	9,7	417,2	0	417,2	426,9	32183,4
4. Coal	171,8	30,7	92,9	8680,6	0		0	0	39,5	0	39,5	725,4	0	725,4	764,9	9445,5
5. Extraction (others)	2,7	0,0	0,0	137,6	0,0		0,0	0,0	0,9	0,0	0,9	10,7	0,0	0,0	11,6	149,2
6. Agriculture	1328	174	9399,9	39980,8	0		0	0	812,5	461,1	351,4	8005,3	0	8005,3	8817,8	48798,6
7. Chemistry	3771	3167,3	6436,2	40844,0	6856,2		0	6856,2	23,3	0	23,3	18445,3	0	18445,3	25324,8	66168,8
8. Intermediate Goods	15000,1	2042,5	5141,0	128091,6	6,7		0	6,7	-230,1	151	-381,1	23084,3	0	23084,3	22860,9	150952,5
9. Capital Goods	15328,5	4154,7	23460,7	138861,3	169,9		0	169,9	51427,6	51276,4	151,2	64905,9	0	64905,9	116503,4	255364,7
10. Construction	19568,6	1825	4359,7	127776,8	0		0	0	145896,6	145896,6	0	9	0	9,0	145905,6	273682,4
11. Consumption Goods	7444,1	1891	62282,9	132377,4	0		0	0	4522,8	4090,4	432,4	23086,5	6630,5	29717,0	34239,8	166617,2
12. Tr. Railways	224,4	74,5	1143,6	1793,2	343,6		0	343,6	20,1	20,1	0	90,4	235,8	326,2	689,9	2483,1
13. Tr. Land	10721,5	684,6	6137,7	36141,6	754,5		0	754,5	171,4	171,4	0	6453	387,6	6840,6	7766,5	43908,1
14. Tr. Sea	455,8	51,5	273,1	1363,9	28,8		0	28,8	25,4	25,4	0	1424	110,2	1534,2	1588,4	2952,3
15. Air	1979,4	646,3	1617,7	5212,0	238,4		0	238,4	0	0	0	4348	1242,0	5590,0	5828,4	11040,4
16. Restauration	4850,2	1242,1	76742,9	84082,6	0		0	0	0	0	0	0	18377,5	18377,5	18377,5	102460,1
17. Market Services	151085,8	21214,8	241257,2	551556,9	17342,3		39,6	17302,7	42361,3	42357,8	3,5	39211,6	8685,4	47897,0	107600,6	659157,5
18. Non Mark. Serv.	0	0	2145,6	2145,6	145552,4		8007,4	137545	0	0	0	0	28,4	28,4	145580,8	147726,4
19. Households	234034,0	64869,0	0													
Σ Intermediate Consumption	477094,4	105138,6	455591,1													
Taxes on Energy	3219,0	4660,6	19937,6													
Other industry taxes	9936,6	-194,3	34536,8													
Rest of Added Value	137534,5	38121,5	0,0													
Imports (Oil & Gas)	127,9	0,0	0,0													
Production	627912,4	147726,4	510065,5													
Imports	31245,1	0	0													
Total Inputs	659157,5	147726,4	510065,5													

Table 2. Energy multipliers.

(continue)

Me 2005	1. Petrol	2. Gas	3. Electricity	4. Coal	5. Extraction (others)	6. Agriculture	7. Chemistry	8. Intermediate Goods	9. Capital Goods	10. Construction
1. Petrol	1,1362	0,0126	0,0962	0,0722	0,0545	0,0431	0,0659	0,0378	0,0246	0,0318
2. Gas	0,0029	1,0045	0,1250	0,0221	0,1116	0,0117	0,0174	0,0224	0,0115	0,0116
3. Electricity	0,0125	0,0175	1,2157	0,1115	0,0682	0,0546	0,0472	0,0733	0,0502	0,0470
4. Coal	0,0008	0,0016	0,0260	1,0116	0,0042	0,0040	0,0117	0,0232	0,0059	0,0146
Total	1,1524	1,0362	1,4629	1,2173	0,2385	0,1134	0,1422	0,1568	0,0921	0,1050

(continue)

Me 2005	11. Consumption Goods	12. Tr. Railways	13. Tr. Land	14. Tr. Sea	15. Air	16. Restauration	17. Market Services	18. Non Mark. Serv.	19. Households
1. Petrol	0,0356	0,0456	0,1022	0,1511	0,1765	0,0345	0,0326	0,0330	0,0445
2. Gas	0,0149	0,0197	0,0115	0,0104	0,0064	0,0114	0,0118	0,0123	0,0132
3. Electricity	0,0572	0,1348	0,0390	0,0497	0,0301	0,0470	0,0535	0,0525	0,0542
4. Coal	0,0052	0,0054	0,0031	0,0026	0,0020	0,0037	0,0042	0,0036	0,0039
Total	0,1129	0,2055	0,1558	0,2139	0,2150	0,0966	0,1021	0,1015	0,1158

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

(continue)

1. Petrol	2. Gas	3. Electricity	4. Coal	5. Extraction (others)	6. Agriculture	7. Chemistry	8. Intermediate Goods	9. Capital Goods	10. Construction
1,8008	1,6788	1,3278	1,1481	1,1363	1,1265	1,1894	1,1100	1,0823	1,0642

(continue)

11. Consumption Goods	12. Tr. Railways	13. Tr. Land	14. Tr. Sea	15. Air	16. Restauration	17. Market Services	18. Non Mark. Serv.	19. Households
1,0969	1,0886	1,1602	1,2267	1,2472	1,0770	1,0717	1,0419	1,0885

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

(continue)

	1. Petrol	2. Gas	3. Electricity	4. Coal	5. Extraction (others)	6. Agriculture	7. Chemistry	8. Intermediate Goods	9. Capital Goods	10. Construction
1. Petrol	0,0762442	-0,01635451	-0,0712701	-0,04251946	-0,12854829	-0,0588031	-0,07910186	-0,06319849	-0,08332463	-0,12875716
2. Gas	-0,54620706	-0,14704122	0,12615509	0,77683573	0,23634483	-0,19271352	-0,15891207	-0,14790492	-0,21668803	-0,41436468
3. Electricity	-0,19635786	0,15929423	0,00556332	-0,02842246	-0,09051785	0,10134863	0,08033986	0,04143749	0,0484866	0,0070988
4. Coal	0	0	-0,04214816	0	0	0	0	0	0	0

(continue)

	11. Consumption Goods	12. Tr. Railways	13. Tr. Land	14. Tr. Sea	15. Air	16. Restauration	17. Market Services	18. Non Mark. Serv.	19. Households
1. Petrol	-0,04506205	-0,07284275	-0,04689902	-0,00679613	0,03544925	-0,082956	-0,07662001	-0,09365059	-0,06079944
2. Gas	-0,10389674	-0,13463679	0,45816394	0,18665586	-0,82466957	-0,20171609	-0,1316291	-0,14705306	-0,14649499
3. Electricity	0,0721241	0,03754189	-0,2473579	0,1243099	0,30502315	0,04113539	0,06970367	0,03127115	0,01815228
4. Coal	0	0	0	0	0	0	0	0	0

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

		Price Elasticity
INDUSTRIES	1. Petrol	-0,03
	2. Gas	0
	3. Electricity	-0,797
	4. Coal	0
HOUSEHOLDS	1. Petrol	-0,08
	2. Gas	-0,047
	3. Electricity	-0,61
	4. Coal	0

Table 6: Scenarios

	Growth of the economy	**International price of crude oil and natural gas**	**Price of electricity**
Scenario 1 (P,R,V)	Pessimistic	Rising price	Variable price (Cost of production)
Scenario 2 (P,R,F)	Pessimistic	Rising price	Fixed price
Scenario 3 (O,R,V)	Optimistic	Rising price	Variable price (Cost of production)
Scenario 4 (O,C,F)	Optimistic	Constant price	Fixed price

Table 7. Errors of prediction

		2006	2007	2008	
ACTUAL RATES OF CHANGE OF ENERGY DEMAND	1. Petrol	-0,08	1,27	-3,28	
	2. Gas	3,16	4,68	10,95	
	3. Electricity	2,95	3,08	1,03	
	4. Coal	-12,77	9,52	4,49	
ESTIMATED RATES OF CHANGE OF ENERGY DEMAND	1. Petrol	-1,35	0,03	-4,36	
	2. Gas	1,08	6,34	2,20	
	3. Electricity	2,86	8,08	-2,05	
	4. Coal	2,71	3,66	-0,82	**MAE 06 - 08**
ERRORS OF PREDICTION (estimated - actual)	1. Petrol	1,28	1,24	1,08	1,20
	2. Gas	2,07	1,66	8,75	4,16
	3. Electricity	0,10	4,99	3,08	2,72
	4. Coal	15,49	5,86	5,32	8,89

* MAE = Means of absolute errors.

Figure 1. Evolution of energy demand in different each scenarios (2008 – 2012). *(Scenarios are explained in table 6)*

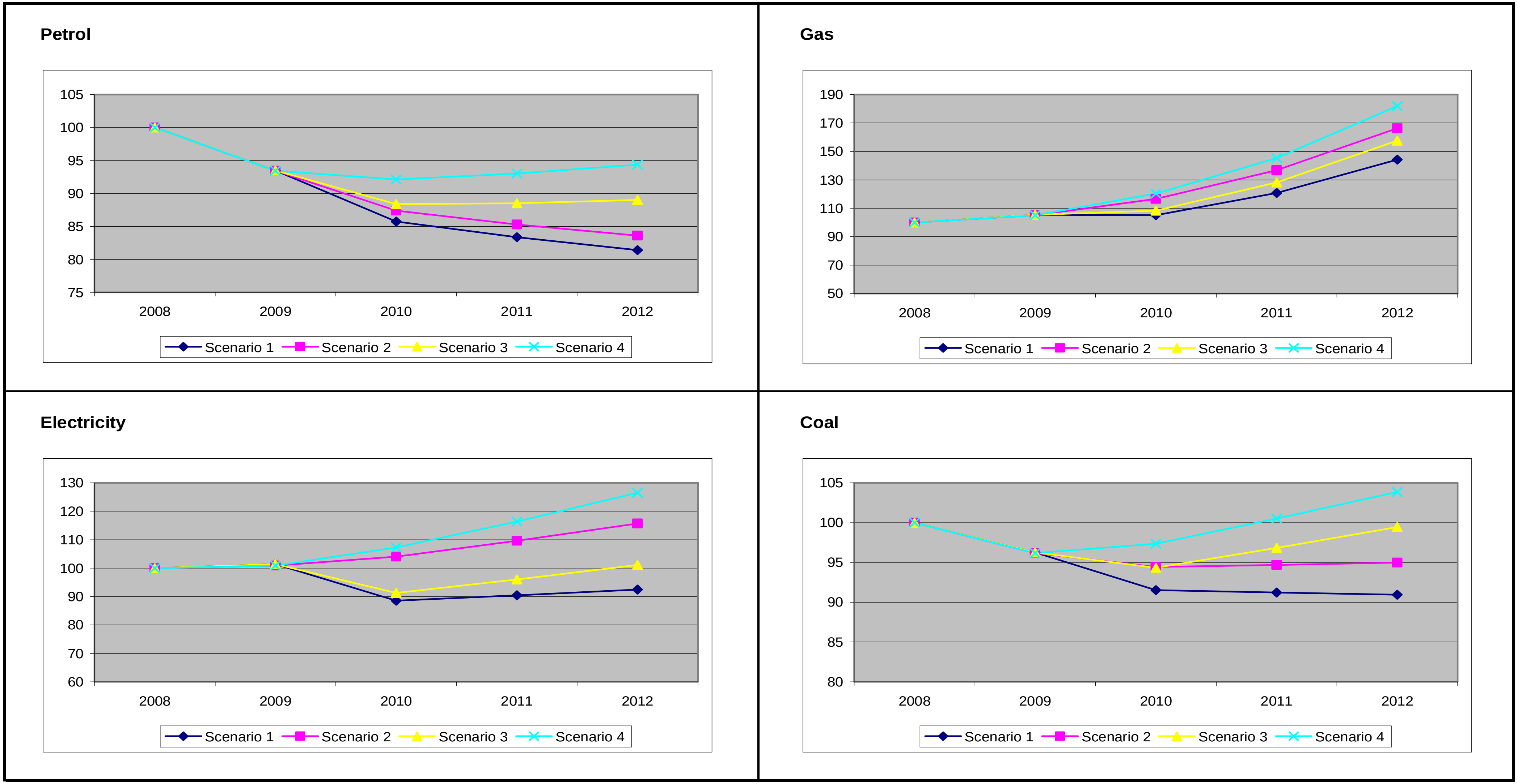

Figure 2. Contrast between actual and estimated energy demand.