The impact of increased efficiency in the use of energy: A computable general equilibrium analysis for Spain*

Pablo AROCENA[a]
Universidad Pública de Navarra

Antonio G. GÓMEZ-PLANA[b]
Universidad Pública de Navarra

Sofía PEÑA[a]
Universidad Pública de Navarra

Abstract

The need to reduce emissions of greenhouse gases has been placed in recent years. The improvement in the efficiency of use is one of the pillars of the energy policies in most countries. Particularly, in Spain, rates of energy intensity are among the highest in the European Union. With an increasing level of CO2 emissions, the need to reduce energy consumption has come to occupy a central role in the political agenda to address both challenges. Rarely, however, are generally taken into account the considerations arising from the *rebound effect*. That is, the possibility of improving energy efficiency could lead to reductions in energy consumption lower than expected, or even increases in consumption. Less common is still being analyzed and quantified in which sectors and/or what types of energy is more likely to produce the desired effect, or what consequences might arise from an improvement in energy efficiency over other variables such as employment, prices or GDP. This paper analyzes these issues in the Spanish economy through a CGE model using the Input-Output Framework of the Spanish economy for the year 2005. The model we use is a static MEGA, which describes an open economy, disaggregated into 27 production sectors. Unlike similar models, it has the particular feature of including unemployment in labour markets, given the high level of unemployment in the Spanish economy. The simulations consist in improving the productivity of energy-related inputs. Specifically, it is simulated a reduction of the use of 5 energy intermediate inputs (all together and individually) by unity of output produced. This leaves as result: a decrease in the total consumption of electricity, gas and coal (positive *rebound effect* in the case of electricity and negative for the gas and coal), an increase in the consumption of petroleum products and the resulting increase in crude oil imports (*backfire effect*), a significant increase in the amount of energy as end use, an increase in the GDP and welfare of the economy of about 0.5% and a reduction in the unemployment rate of around 5%.

Key words: Energy Efficiency, Rebound Effect, General Equilibrium

JEL classification: Q41, Q43, D58

[a] Departamento de Gestión de Empresas. Campus de Arrosadia. 31006 Pamplona, Spain.
Tel. +0034948169684 Fax. +0034948169404
pablo@unavarra.es
sofia.pena@unavarra.es
[b] Departamento de Economía. Campus de Arrosadia. 31006 Pamplona, Spain.
Tel. +0034948169348
agomezgp@unavarra.es

*The authors acknowledge financial support from the Spanish Ministry of Innovation and Science (research projects ECO2010-21242-C03-03 and ECO20011-24304).

1. Introduction

The need to reduce emissions of greenhouse gases has been placed in recent years. The improvement in the efficiency of use is one of the pillars of the energy policies in most countries (e.g. Hanley, et al., 2006, Hartono and Resosudarmo, 2008, and at institutional level the IPCC's Fourth Assessment Report on Climate Change 2007 and the Stern Report). Environmental considerations are not the only force pushing towards more efficient use of energy. In most advanced economies there is widespread concern about energy dependence and the need to ensure the provision, which places the energy savings as a key to help meeting these objectives. Moreover, the increasing competitive pressure in markets for goods and services requires companies to an on-going quest to reduce their costs and achieve greater efficiency in the use of all inputs, including energy.

In Spain, with rates of energy intensity[1] among the highest in the European Union (e.g., Mendiluce et al 2010), with an increasing level of CO2 emissions, the need to reduce energy consumption has come to occupy a central role in the political agenda to address both challenges (Linares, 2009). This is the objective of the strategy and plans for energy conservation and efficiency promoted by the Government of Spain (MITYC, 2007, 2011). In general, the aim is obtaining the same level of services provided by energy with a smaller amount of energy consumption. To this end, those plans are based on promoting good consumer practices and technological innovation, which ultimately represents the engine for continuous improvement in the use of energy and its transformations (Berkhout et al., 2000 and Binswanger, 2001).

These plans estimate potential energy savings under alternative scenarios that could result from improved energy efficiency. Rarely, however, are generally taken into account in these considerations predictions derived from *the rebound effect* (i.e. the possibility of improving the energy efficiency can lead to reductions in energy consumption lower than expected, or even increases its consumption). Less common is still being analyzed and quantified in which sectors and / or what types of energy are more likely to produce the desired effect, or what consequences could result from improved energy efficiency on other variables such as employment, prices or GDP. In this paper we analyse these issues in the Spanish economy through a computable general equilibrium (CGE) model.

[1] Usually measured as the ratio between energy consumption and Gross Domestic Product.

The paper is organized as follows. Section 2 briefly summarizes the relationship between energy efficiency and the rebound effect. Section 3 presents the model used, and section 4 describes the calibration and data. The results are shown in section 5. Section 6 includes a large sensitivity analysis on crucial assumptions. Section 7 summarizes the main conclusions.

2. Energy efficiency and rebound effect

Energy inefficiency means that a certain amount of output can be reached with less energy inputs. Therefore, an improvement in the efficiency in energy use should result in a proportional savings of the amount of energy consumed. However, the *potential* energy savings (PES) may not correspond to *actual* energy savings (AES). In other words, some of the "engineering" PES estimates of the energy savings could be offset by what is known as rebound effect (RE). A simple way to approximate the rebound effect as a gap between PES and AES is:

$$RE = [1- (AES/PES)].100$$

For example, in the case of an estimate of PES of 10 units and an AES of 6 units, the rebound effect would be equal to 40%, which means that 40% of estimated energy savings have been offset by the increase in energy consumption after the improvement of energy efficiency. The rebound effect usually varies between 0 and 100%, although it may be even higher than 100%, which is known in the literature as the *backfire effect* (Saunders, 2000, 2009, and Sorrell 2009a). In the latter case, there are not savings in energy, since the consumption after improvement in energy efficiency is higher than before (i.e., AES < 0).

Jevons (1865) developed the idea about how an improvement in energy efficiency affects energy consumption. He observed that the introduction of new efficient steam engines initially reduced coal consumption, which led to a price cut. This meant not only more people could afford to use coal, but also coal was becoming economically viable for new uses, which ultimately led to increase the tonnage of consumed coal.

These considerations led to the pioneering Saunders (1992) to state the *Khazzoom-Brookes postulate:* "energy efficiency improvements that, on the broadest considerations, are economically justified at the micro level, lead to higher levels of energy consumption at the macro level", based on early research from Khazzoom (1980) and Brookes (1978). See Sorrell (2009a), Jenkins et al. (2011) or Maxwell et al. (2011) for recent reviews of the theoretical and empirical literature.

Figure 1: The decomposition of rebound effect (Sorrell, 2009a).

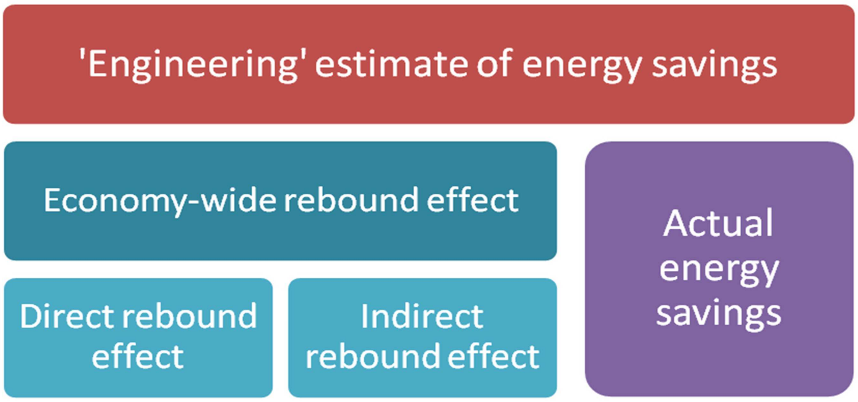


Figure 1 illustrates the different components of the rebound effect (Sorrell, 2009a; Saunders, 2013a). The rebound effect in the economy is decomposed into two effects: the direct and indirect effects.

The direct effect may be due in turn to two effects for consumers and producers: the substitution effect and income/output effect. For the final consumers of energy, the substitution effect occurs when, after the energy efficiency improvement, cheaper energy service consumption substitutes the consumption of other goods and services, maintaining the same level of utility. The income effect occurs when the cheaper energy inputs increase real income. This involves a higher utility level through consumption of additional energy services. In the case of producers, the substitution effect occurs when the lower-priced energy service substitutes the use of capital, labour or materials to produce a given level of output. The output effect occurs when it is achieved a higher level of output by the increase in the consumption of cheaper the energy inputs.

The indirect effect includes the income effect on consumers and producers who increase final and intermediate consumption in other goods and services different from energy services. Those additional goods also require energy services to be produced. The aggregation of direct and indirect effects can be defined as "economy-wide rebound effect". This is the effect that a computable general equilibrium (CGE) model can provide. There are other taxonomies of the decomposition of the rebound effects (see

Turner, 2013), but we focused on the concept of the rebound effect used in the model (see next section).

With respect to empirical studies, most focus on the analysis of direct rebound effects, often through experimental econometric methods. However, to estimate the total magnitude of the rebound effect it is required general equilibrium analysis (Greening et al., 2000, Sorrell, 2007). As noted by Wei (2010), CGE models are the most appropriate method to study the rebound effects for the whole economy. However, the number of analysis that take this approach is relatively scarce (see Allan, et al., 2007, Hanley et al., 2006, Hartono, and Resosudarmo, 2008, Sorrell and Dimitropoulos 2008, Wei, 2010). Guerra and Sancho (2010) developed a CGE model for the case of Spain. All obtain significant rebound effects, some of them exceeding 50% and in some cases providing evidence of backfire effect. As explained below, some assumptions included in the models can be behind the variance in the quantitative effect.

3. The model

The model we use is a static CGE model (Shoven, and Whalley, 1984) that describes an open economy, disaggregated into 27 production sectors, with 27 consumer goods, a representative consumer, the public sector and a simplified rest of the world. It allows performing a general equilibrium comparative static analysis.

Research has shown that six CGE model features are important for the resulting estimates of the impact of energy improvements on energy use (Allan et al., 2007). First of all, we explain how we overcome them. (1) Treatment of energy in the production function: we base the nestings on MIT-EPPA, which is backed with econometric estimates (see Paltsev et al., 2005). (2) Sensitivity of results to the elasticities of substitution with energy in production: we perform a deep sensitivity analysis on them in section 6. (3) Capital closure: we perform a sensitivity analysis on different capital closure rules in section 6. (4) Treatment of the labour market: Unlike similar models, this model has the particular feature of including unemployment as a specification derived from the literature of trade unions models, given the high unemployment rate of the Spanish economy. Additionally, we perform the sensitivity analysis of different assumptions on wage flexibility and substitutability in section 6. (5) The role of increased government revenue from increased economic activity: We apply a revenue neutral rule, isolating the role of the public sector in the model. (6) The modelling of the energy efficiency improvement: we apply an *autonomous energy efficiency improvement* (AEEI) at different quantitative levels, to check the robustness of the results.

Next we present a brief description of the model. The basis of the complete system of equations is shown in the appendix.

3.1. Equilibrium conditions

The equilibrium of the economy is given by a vector of prices and allocation of goods and factors that simultaneously solves three sets of equations:

- Zero profit conditions for all sectors.
- Market clearance in goods and capital markets.
- Restrictions on disposable income (which is matched with the expenditure incurred by all agents), an unemployment rule, and the macroeconomic closure of the model.

3.2. Production

The production is based on a nested technology of intermediate inputs, capital and labour. The producers' problem is to maximize profits (or, alternatively, minimize costs, in the dual approach), subject to technological constraints. The technological constraints are nested production functions with special detail in energy inputs and outputs (see Figures in Appendix 1; based on Paltsev et al., 2005). The solution to the problem yields the average cost functions, which are used in the zero profit conditions. The demands for factors and intermediate inputs are derived from the application of Shephard's lemma to the cost functions, and then used in the equilibrium market clearance equations of goods and factor markets. Firms operate under constant returns to scale and under a competitive pricing rule.

3.3. Consumption

There is a representative consumer who behaves rationally. The consumer's income level is determined from the endowments of capital and labour, plus exogenous net transfers received from the public sector. The consumers' problem is to choose the optimal consumption basket by maximizing a nested utility function (see Figure in Appendix 1, based on Paltsev et al., 2005) subject to its budget constraint. The preferences are represented by a nested utility function whose arguments are savings, leisure, and (consumption of) goods. The budget constraint includes total factors' income, plus exogenous net transfers received from the public sector, minus exogenous income taxes. The demand functions for savings, leisure and goods are derived from the first order conditions, and they are included in the equilibrium conditions of markets, as well as in the macroeconomic closure for savings.

3.4. Public sector

The public sector plays a dual role in the model: it owns resources and it acquires certain goods. As a resource holder, the income includes income from its capital income, net transfers paid to the representative consumer, net transfers received from the rest of the world, and tax revenues. In turn, taxes consist of social contributions paid by employers and employees, indirect taxes (value added tax, other net taxes on products, net taxes on production) and income taxes. All taxes are modelled as *ad valorem* effective rates calibrated from the initial data, except for income taxes that are taken as an exogenous transfer to the public sector.

3.5. Foreign sector

The model incorporates the small open economy assumption. That is, the economy would face a perfectly elastic export supply function. Furthermore it uses a CET function between domestic and foreign sales. With respect to imports, we assume that goods are differentiated according to their origin (i.e., domestic or foreign), following the Armington assumption. This allows for intra-industry trade (Armington, 1969). The foreign sector is closed by assuming that the difference between revenues and payments from the rest of the world is exogenous. This restriction would prevent, for example, the coexistence of a permanent increase in exports without changes in imports providing an unlikely scenario because it would mean capital outflows without any limit.

3.6. Factor markets

There are two primary inputs: capital and labour. With regard to capital, both the representative consumer and the public sector own fixed endowments. Capital rent adjusts to balance the domestic market of that factor. Capital is immobile internationally but there is perfect mobility among domestic sectors.

The sole owner of labour is the representative consumer. We assume the possibility of unemployment and leisure, so labour supply is elastic. We further assume that workers have some degree of market power and their wage demands are related to the level of unemployment in the economy. To do this we model the labour market including the equation 1 (see Kehoe et al.):

$$\mathrm{w} = \left(\frac{1 - u}{1 - \bar{\mathrm{u}}}\right)^{1/\beta}$$

where w is the real wage, u is the unemployment rate, $\bar{u}$ is the unemployment rate in the benchmark year, and β is a parameter that measures the flexibility of real wages with respect to the unemployment rate. Thus, when β approaches infinity, the real wage is close to its value in the benchmark year (which is 1, after the calibration process described in Section 4). This is the case of rigid wages, where real wage does not vary when the unemployment rate does. If β approaches zero, the unemployment rate is close to the benchmark year, indicating the flexibility of wages. Other intermediate values of β show the greater or lesser degrees of sensitivity of real wages to changes in the unemployment rate. As in the case of capital, labour is assumed immobile at international level but perfectly mobile across sectors.

3.7. Macroeconomic closure for investment and savings.

The total investment is distributed by sector using a fixed coefficient Leontief structure (Dervis et al., 1981). Note that, in our static framework, investment affects the economy as a component of final demand. The model incorporates a macroeconomic closure equation by which equates investment and savings (private, public and external).

Finally, the model is solved by the method of Rutherford (1999), which sets out the general equilibrium models as mixed complementarity problems (Mathiesen, 1985) and it is implemented in the empirical application using the GAMS / MPSGE program (for a presentation, see Hosoe et al., 2010).

4. Calibration, data and simulations

The model is calibrated using data for the Spanish economy. The calibration of benchmark equilibrium is represented by the National Accounts data, and is reflected in the Social Accounting Matrix (SAM) with a set of elasticities taken from the available empirical evidence. A detailed explanation of the calibration technique used can be found, e.g., in Mansur and Whalley (1984) or in Dawkins et al. (2001).

The SAM includes a transformation of the last available Symmetric Table for the Input-Output Framework of the Spanish economy, which corresponds to the year 2005. The starting point is in the 73 sector Input-Output framework for the Spanish economy in 2005. They are grouped in 27 sectors, achieving the highest possible level of disaggregation in the energy sectors and in energy intensive sectors. The SAM is accomplished with data from the National Accounts through the Accounts of institutional sectors. The description of economic activities comprising the 27 sectors is revealed in Table 1.

Moreover, as the elasticities play a key role in the model, a sensitivity analysis on the values selected in order to compare their possible effect on the results of the simulations is displayed in section 6.

The elasticity values applied for calibration are:

• Elasticities of substitution in the utility function:

- Between consumption and savings (σ_{CA}): 1
- Between final consumption and leisure (σ_{CO}): 1
- Among final consumption goods (σ_{BC}): 1

• Elasticities of substitution associated to production:

- Between intermediate inputs and value added (σ_{I}): 0
- Between labour and capital (σ_{LK}): values for sectors ranging from 0.20 to 1.68
- Armington elasticities (between domestic and imported goods): the values for the sectors are between 0.90 and 4.05

- CET elasticities (between national and foreign sales): the values of the sectors are between 0.70 and 3.90

Regarding the sources, the values of σ_{LK} and Armington elasticities σ_A are from Narayanan and Walmsley (2008), the elasticities of transformation by De Melo and Tarr (1992), and σ_{CO} is consistent with the empirical literature review conducted by Ballard and Kang (2003). The rest of the values used are those conventional in the literature.

The simulations consist in an energy efficiency improvement (see Löschel, 2002). Specifically, we simulate an energy augmenting technical change leading to a reduction in the use of five energy intermediate inputs (collectively and individually) per unit of output produced in all sectors, and also in the representative agent’s final consumption. The five intermediate inputs are those corresponding to Coal, Oil, Refining, Electricity and Gas (see Table 1). The AEEI improves the technology available to the producers and alters their production functions, and improves the consumers’ energy efficiency and also alters the welfare function.

5. Results

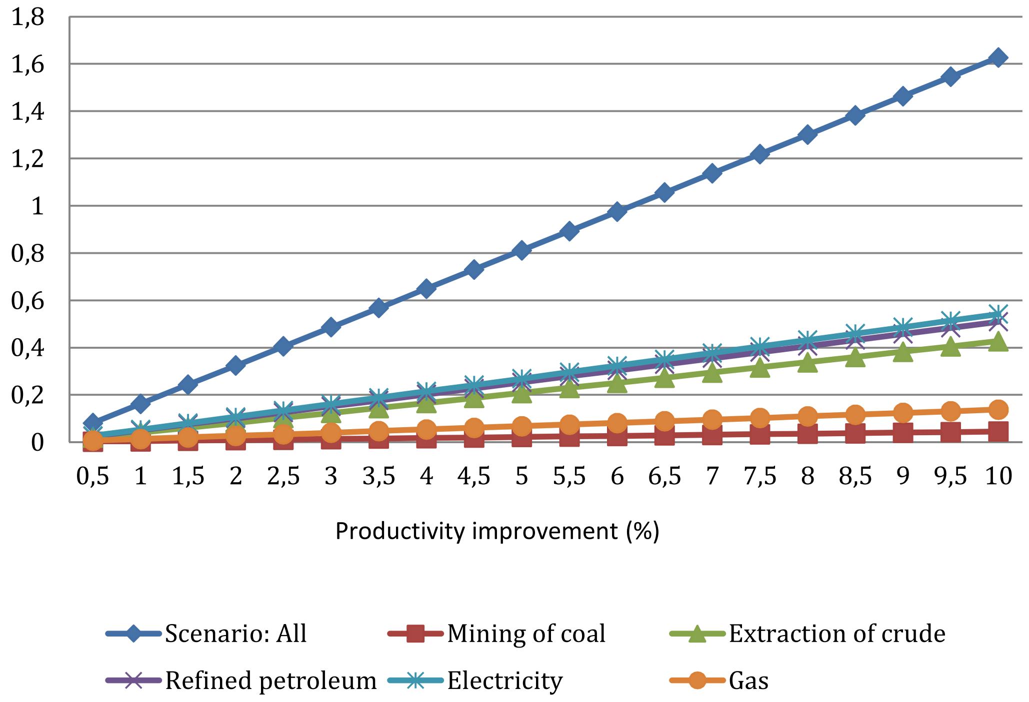
5.1. Macroeconomic results

The macroeconomic variables analysed are welfare, employment, unemployment rate, and real rents of labour and capital. The simulation consists of improvements an AEEI in (1) input productivity, with savings ranging from 1% to 10% of that input for the same unit of output; (2) consumers’ energy efficiency, with savings ranging from 1% to 10% of final energy consumption for the same unit of consumption. Obviously, a 10% improvement in productivity is unrealistic in most cases, but collecting the range between 1 and 10% enables a clearer understanding on the evolution of the different macroeconomic variables.

Results are displayed in Figures 2 to 6, under scenario denoted "*All*", comprising a simultaneous improvement of the five energy inputs in production and final consumption. Scenario “*Coal*” comprises a 1 to 10% AEEI on only Coal as input and final consumed good. Scenarios “*Oil*”, “*Refining*”, “*Electricity*” and “*Gas*” follow the same pattern. There are in sum six scenarios.

A first approach is by measuring changes in welfare for the whole country (excluding the public sector), measured by an index of equivalent variations. These results are shown in Figure 2, which shows that the efficiency improvement logically leads to an increase in the overall welfare of the economy. However significant differences were observed depending on the type of energy that reveals the improvements in productivity: the most positive effects are generated by the productivity gains in the Electricity and Refining sectors (see Table 1 for description of sectors), while the lowest would be driven by improvements in the use of Coal.

Figure 2. Change in Welfare (%)



The principal source of those welfare gains comes from primary factor markets, labour and capital: there are gains in the size of labour employed and in both factor rents. Full employment is assumed in the case of capital factor, while involuntary unemployment represents a relevant characteristic of the Spanish labour market. This allows a simultaneous increase in employment and reduction of unemployment derived from productivity improvements. Sectoral employment is studied in the section 5.2, but at macroeconomic level there is an increase in employment (Figure 3) and a decrease in the unemployment rate (Figure 4). As with welfare, the productivity gains in the Electricity, Refining and also Oil sectors lead the employment gains, while Gas and Coal report small gains.

Figure 3. Change in Employment (%)

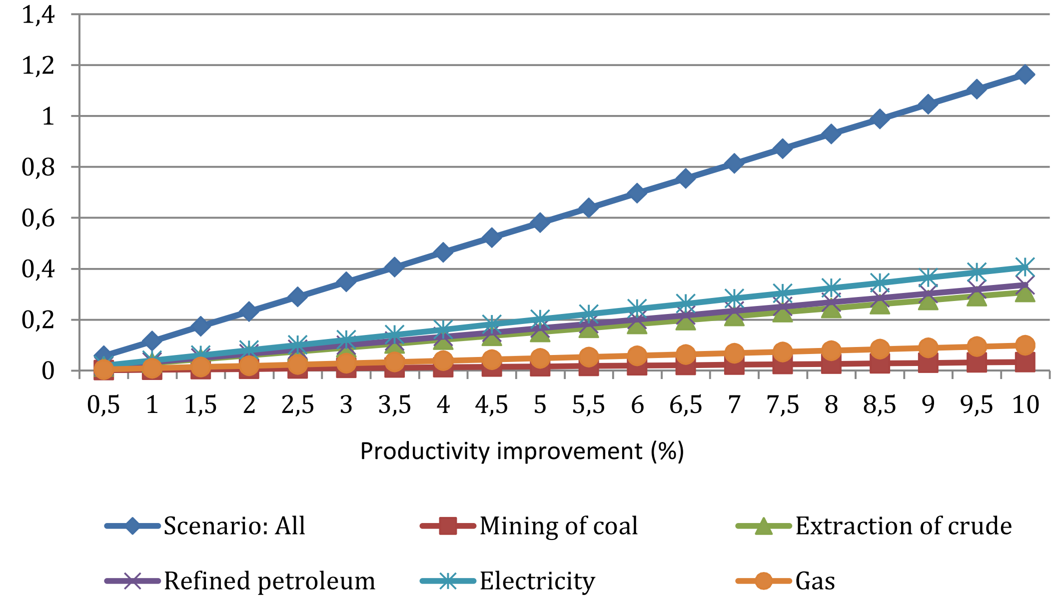
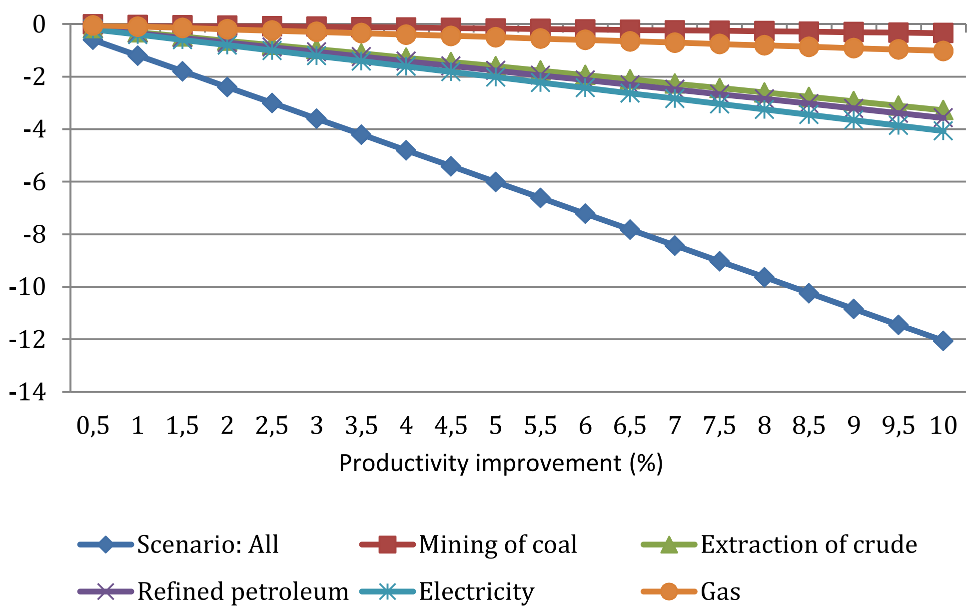
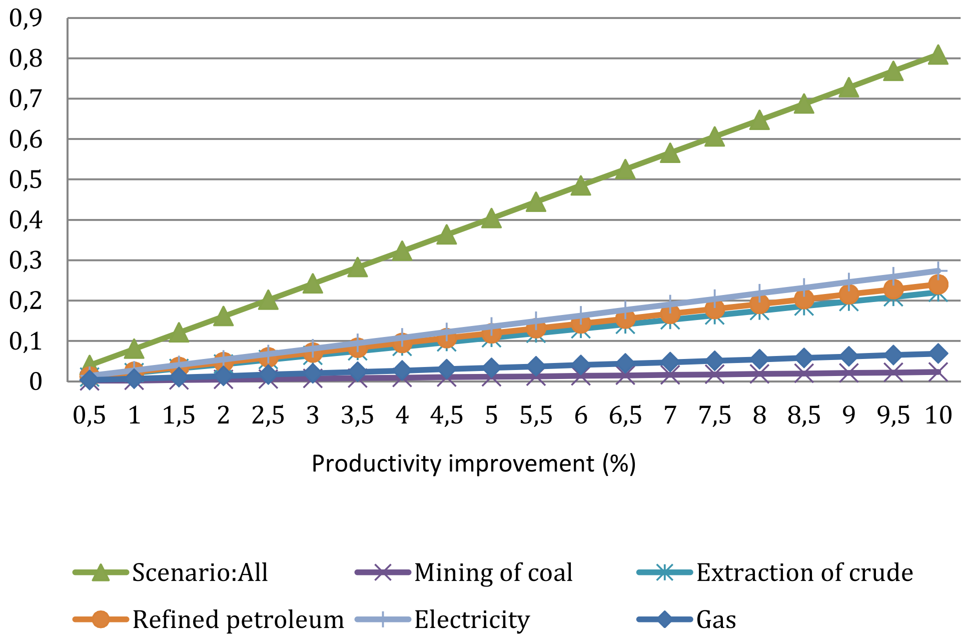


Figure 4. Change in the Unemployment rate (%)



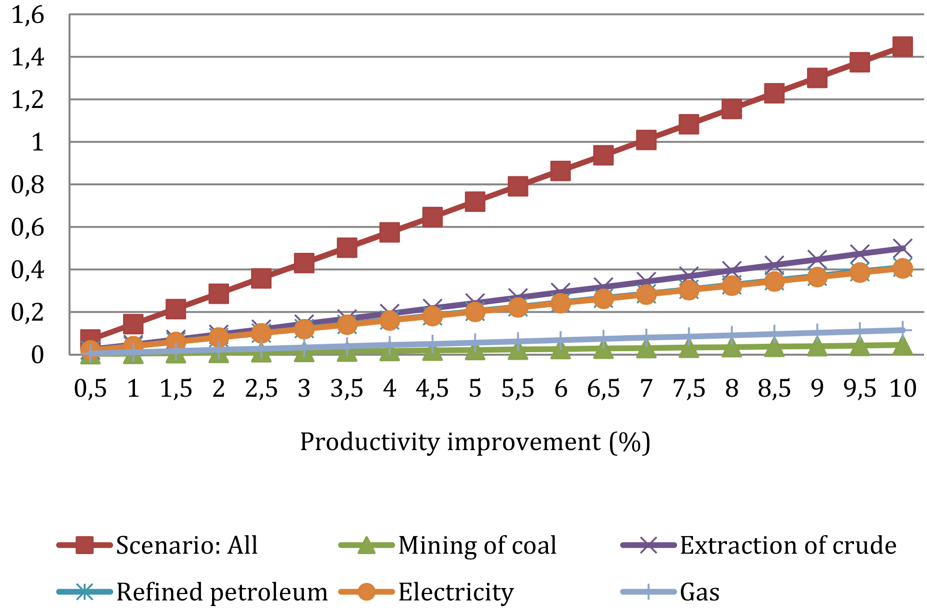
The improvement in real factors income (Figures 5 and 6), along with higher employment, is the generator of welfare growth. Both workers and capital owners would improve their unitary real incomes. However, the improvement in capital rents exceeds quantitatively the improvement in real wages, implying that improvements in energy efficiency would have a redistributive effect in relative terms. Several forces generate this lower relative improvement of wage. Labour supply is elastic and there is the possibility of unemployment, while the endowment of capital is fixed and it is fully employed, which implies a vertical supply function of capital. An economic expansion, therefore, would lead to a further increase of capital rent in relation to the increase in labour wage. The main energy sectors (Electricity, Refining, Gas) are capital intensive, so their rebounds effects (see next section 5.2) stimulates especially the capital demand over labour demand.

Figure 5. Change in Real wages (%)



The evolution of real wages is particularly favourable in scenarios that involve efficiency improvements in Electricity, Refining and Oil. However, although in the evolution of real rent of capital are also these three sectors that generate the largest increase in real rents, is the Oil sector, which shows a comparatively higher increase. This is the more labour intensive energy sector.

Figure 6. Change in Real rent of capital (%)



5.2. Microeconomic results

Results at the microeconomic level are presented solely for the scenario in which all energy inputs show a 5% improvement in its efficiency (scenario *All* in the previous section 5.1). Table 3 provides numerical results: Table 3a displays the percentage change in some variables at sectoral level: consumption of energy intermediate inputs (Coal, Oil, Refining, Electricity and Gas); labour and capital inputs employed; output; final consumption, exports and imports; and real price (with respect to the numeraire, namely the CPI in this model). Table 3b shows the rebound effect estimated through equation (1).

First, we find different levels of rebound effect by type of energy. Despite the expansionary effect of the measure, there is a reduction in the quantity consumed of all energy inputs except Refining (measured in physical units). The change ranks from negative in Coal (-5.79%), Gas (-2.81%), Electricity (-1.79%) and Oil (-0.09%), to positive for Refining (4.89%). The increase in productivity was fixed at 5%, so the rebound effect does not arise in Coal, but it surges in Gas (43.8%), Electricity (64.1%) and Oil (98.2%), with a backfire effect in Refining (197.9%). In this later case, all potential savings from the efficiency improvement are offset. Those results serve to underscore the role of general equilibrium framework adopted in this paper.

Second, the nested structure in the intermediate inputs of production functions determines the changes in the use of different energy inputs. Table 2 shows the significant differences among sectors with respect to the magnitude of the impact of energy efficiency improvement in final consumption of energy, and ultimately, the rebound effect. For example, change in the use of energy inputs in any sector ranks from -10.50% use of Electricity and Gas in Coal, or the -7.6% use of Coal, Oil, Electricity and Gas in Gas, to increases of 1.66% in the use of Refining in Refining and Chemicals.

Third, the nested structure matters not only in quantitative changes in use of inputs, but also determines the changes in the input-mix for each unity of output. The changes in input-mix vary a lot among sectors. For example, in Coal there is an unequal fall in the use of energy inputs: decreases the use of Coal (-7.65%), Electricity (-10.50%) and Gas (-3.80%). Other example of this unequal change is Chemicals, where there are also increases in the use of some energy inputs: a fall in intermediate consumption of Coal (-3.23%) and Gas (-0.47%) but an increase in Refining (1.66%) and Electricity (0.44%).

Fourth, the changes in the input-mix depend on the size of the AEEI and do not follow a proportional change. As example, panels in Figure 7 show a change in the energy input-mix for three sectors (Electricity, Metallurgy and Refining) with a change in AEEI ranging from 0% to 15%. There is quasi-lineal decrease in the use of all energy inputs, with small quantitative differences among inputs in Electricity (panel A). Metallurgy experiences a fall in some energy inputs (Coal, Electricity and Gas), and an increase in Refining (panel B). Panel C shows that Refining combines inputs where the negative or positive change depends on the AEEI size (Oil and Gas), with other inputs always increasing (Electricity and Gas) and other decreasing but changing the tendency (Coal).

Fifth, final private consumption of energy decreases for all types of energy. There is a decrease in the final use of Coal (-3.79%), Refining (-6.59%), Electricity (-5.41%) and Gas (-5.39%). Given the increase of 5% in energy productivity, the rebound effect in final consumption only takes place in Coal (24.3%).

Sixth, trade flows play a role. Imports are very relevant in energy sectors in Spain (and also exports in Refining). Results show that changes in exports and imports are, in general, quantitatively relevant in this scenario. For this reason, in section 6 we perform a sensitivity analysis on the energy foreign sector assumptions.

Seventh, the labour employment does not growth in all sectors. As explained in section 5.1, employment grows 0.58%, but sectoral changes are diverse. The most employment creator is Refining (2.63%), as well as Chemicals (1.28%) and Non-market services (1.10%). But other sectors fall in employment, with relevant falls in Coal (-5.78%), Electricity (-3.39%) and Gas (-2.91%). This effect can be exacerbated with the capital fixed-endowment assumption. The model also uses the assumption of free mobility of labour and capital across sectors, but not internationally. If capital use is going to increase in a specific sector, it must decrease in other sector or sectors. This restriction is less rigid to labour, given the existence of unemployment and leisure. This case is further discussed in section 6.

Eighth, with respect to changes in the output, these are largely determined by the use of factors. Thus it is found that the evolution of the physical output is highly correlated with the use of the productive factors. Furthermore, in relation to these two factors, in Figures 5 and 6 it is shown the relative increase in capital rent relative to wages, and Table 2a confirms that this leads to a further decline (or smaller increase) in use of capital relative to labour for each sector.

Finally, changes in real prices are measured relative to a CPI. Therefore, there will be a series of sectorial prices that are below the price level of the index, while for other sectors the change in prices is above the weighted average. As expected, the last column of Table 2a shows that sectorial prices descend more for the energy sectors (e.g., Refining (-5.20%), Electricity (-3.21%), Gas (-3.17%)). This is due to the result of declining demand for its products (derived from the efficiency improvement in the use of energy inputs for the remaining sectors).

6. Sensitivity analysis

This section develops the sensitivity analysis for the six key points highlighted in section 3 following the Allan et al. (2007) critique. Tables 3 and 4 show the results for macroeconomic variables and for the variable output at sectoral level. The benchmark scenario is *All* and results are compared to it. The results are:

(1) and (2) On the treatment of energy in the production function and sensitivity of results to the elasticities of substitution with energy in production. We check not only

the production functions but also the welfare function (which determines the final demand functions). Here we present only a subset of the analysis on elasticities and functional forms (the full set can be required to authors). Columns (a) to (d) show the cases of including Leontief and Cobb-Douglas functions (i.e., zero and one elasticities of substitution, respectively), instead the nested CES function already applied. The results reveal, to a certain extent, the relevance of the design of the functional forms in the results.

(3) Capital closure (column e). We perform a sensitivity analysis changing the perfect mobility across sectors assumption for the specific factor assumption (i.e., immobility across sectors). This scenario can be also interpreted as a short-run scenario. At macro level, real gains for capital decrease, but improve for labour. Nevertheless changes with respect to benchmark are tiny. At sectoral level, output changes less in energy sectors, and in a similar amount for the rest.

(4) Treatment of the labour market: We perform the sensitivity analysis on two different assumptions on wage flexibility: less rigid wages (column f) and more rigid wages (column g). Welfare is sensitive to this assumption, with more welfare gains with wage rigidity, giving the logical stronger positive impact on labour and on capital rents. At sectoral level effects are also different, with a more positive impact on output for the same rigid-wages scenario. We also check different levels of substitutability between labour and capital (columns h and i), and there is not a relevant sensibility of the results.

(5) The role of increased government revenue from increased economic activity. We apply a revenue neutral rule, so the role of the public sector in the model is isolated.

(6) The modelling of the AEEI. In previous section 5.2, the seventh point highlighted this issue. The level of AEEI matters in a different way in accord with the sector modelled and its production function. This is quite relevant conclusion not frequently seen in the literature.

References

Allan, G., Hanley N., McGregor P., Swales K., Turner K. (2007), The impact of increased efficiency in the industrial use of energy: a computable general equilibrium analysis for the United Kingdom. *Energy Economics* 29, 779-798.

Armington, P. S. (1969), A theory of demand for products distinguished by place of production, *IMF Staff Papers*, 16: 159-176.

Ballard, C. L. y Kang, K. (2003), International ramifications of US tax-policy changes, *Journal of Policy Modeling* 25: 825-835.

Berkhout P.H.G., Muskens J.C., Velthuijsen J.W. (2000), Defining the rebound effect. *Energy Policy* 28, 425-432.

Binswanger M. (2001), Technological progress and sustainable development: what about the rebound effect? *Ecological Economics* 36, 119-132.

Dawkins, C., Srinivasan, T.N. y Whalley, J. (2001), Calibration, in J.J. Heckman and E.E. Leamer (ed.) *Handbook of Econometrics*, volume 5, chapter 58, 3653-3703, Elsevier, Amsterdam.

De Melo, J. y D. Tarr (1992), A general equilibrium analysis of US foreign trade policy, Cambridge, Massachusetts: The MIT Press.

Dervis, K., De Melo, J. and Robinson, S. (1981), A general equilibrium analysis of foreign exchange shortages in a developing economy, *The Economic Journal*, 91: 891-906.

Gómez A., (2005), Simulación de Políticas económicas: Los modelos de equilibrio general aplicado. *Cuadernos Económicos de ICE*, 69, 197-218.

Greening, L. A., Greene, D. L. and Difiglio, C. (2000), Energy efficiency and consumption –the rebound effect- a survey, *Energy Policy*, 28, 389-401.

Guerra, A. and Sancho, F. (2010), Rethinking economy-wide rebound measures: an unbiased proposal, *Energy Policy*, 38, 6684-6694.

Hanley N., McGregor P., Swales K., Turner K. (2006), The impact of a stimulus to energy efficiency on the economy and environment: a regional computable general equilibrium. *Renewable Energy* 31, 161-171.

Hartono, D. and Resosudarmo, B. P. (2008), The economy-wide impact of controlling energy consumption in Indonesia: an analysis using a social accounting matrix framework. *Energy Policy*, 36, 1404-1419.

Hosoe, N., Gasawa, K. and Hashimoto, H. (2010), Textbook of computable general equilibrium modelling-programming and simulations.

INE (2011): Contabilidad Nacional y Marco Input-Output 2005.

Jevons, W.S. (1865), The coal question: can Britain survive? In the coal question: an inquiry concerning the progress of the nation, and the probable exhaustion of our coal-mines, A.W. Flux ed, Augustus M. Kelley, New York.

Linares, P. (2009) Eficiencia energética y medio ambiente. *Información Comercial Española, ICE: Revista de Economía*, 847, 75-92.

Mansur, A. y Whalley, J. (1984), Numerical specification of applied general equilibrium models: Estimation, calibration, and data, in H. E. Scarf y J. B. Shoven (eds.), *Applied general equilibrium analysis*, Cambridge: Cambridge University Press: 69-127.

Mathiesen, L. (1985), Computation of economic equilibria by a sequence of linear complementarity problems, *Mathematical Programming Study*, 23: 144-162.

Mendiluce M., Pérez-Arriaga, J.I. y Ocaña, C. (2010), Comparison of the evolution of energy intensity in Spain and in the EU15. Why is Spain different?, *Energy Policy*, 38(1): 639-645.

MITYC (2007) *Estrategia de Ahorro y Eficiencia Energética en España 2008-2012*. Instituto para la Diversificación y Ahorro de la Energía. Ministerio de Industria, Turismo y Comercio, Madrid.

MITYC (2011) *Plan de Ahorro y Eficiencia Energética en España 2011-2020*. Instituto para la Diversificación y Ahorro de la Energía. Ministerio de Industria, Turismo y Comercio, Madrid.

Narayanan G., B. y Walmsley, T.L. (eds.) (2008), *Global Trade, Assistance, and Production: The GTAP 7 Data Base*, Center for Global Trade Analysis, Purdue University.

Rutherford, T. F. (1999), Applied general equilibrium modelling with MPSGE as a GAMS subsystem: An overview of the modelling framework and syntax, *Computational Economics*, 14: 1-46.

Saunders, H. D. (1992), The Khazzoom-Brookes postulate and neoclassical growth, *The Energy Journal*, 13.4, 131-148.

Saunders H. D. (2000), A view from the macro side: rebound, backfire, and Khazzoom-Brookes. *Energy Policy* 28, 439-449.

Saunders H. D (2009), Theoretical foundation of the rebound effect, in Evans J. and L. Hunt (eds.) *International handbook on the economics of energy*, chapter 8, 164-198.

Schipper L., Grubb M. (2000), On the rebound? Feedback between energy intensities and energy uses in IEA countries. *Energy Policy* 28, 367-388.

Shoven, J.B., Whalley J. (1984), Applied General-Equilibrium models of taxation and international trade: an introduction and survey. *Journal of Economic Literature* 22, Issue 3, 1007-1051.

Sorrell S., (2007), The rebound effect: an assessment of the evidence for economy-wide energy savings from improved energy efficiency. UK Energy Research Centre Technical Report.

Sorrell S., (2009a), Jevons' paradox revisited: the evidence for backfire from improved energy efficiency. *Energy Policy* 37, 1456-1469.

Sorrell S. (2009b) The rebound effect: definition and estimation, in Evans J. and L. Hunt (eds.) *International handbook on the economics of energy*, chapter 9, 199-233.

Sorrell S., Dimitropoulos J. (2008), The rebound effect: microeconomic definition, limitations and extensions. *Ecological Economics* 65, 636-649.

Sorrell S., Dimitropoulos J., Sommerville M. (2009), Empirical estimates of the direct rebound effect: a review. *Energy Policy* 37, 1356-1371.

Wei T. (2010), A general equilibrium view of global rebound effects. *Energy Economics* 32, 661-672.

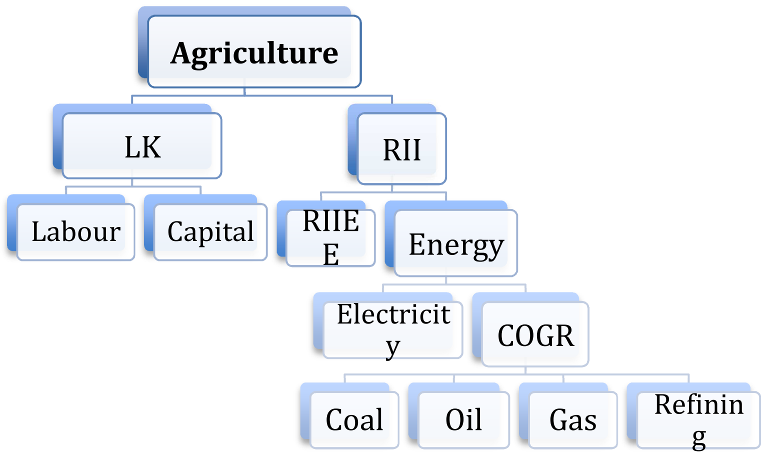
Tables

Table 1. List of sectors

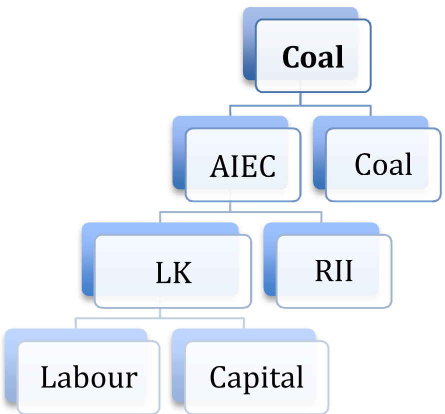
SECTOR	Industries	CNAE-93
AGRICULTURE	Agriculture, Livestock and Fisheries	01,02,03
COAL	Extraction of coal, lignite and peat	10
OIL	Extraction of crude petroleum and natural gas. Extraction of uranium and thorium	11,12
MINERAL	Mining of metallic and nonmetallic	13,14
REFINING	Manufacture of coke, refined petroleum products and nuclear fuel	23
ELECTRICITY	Production and distribution of electricity	401
GAS	Production and distribution of gas	402-403
WATER	Collection, purification and distribution of water	41
FOOD	Food , Beverages and Tobacco	15,16
TEXTILE	Textile, leather and footwear	17,18
CHEMISTRY	Chemistry	24
RUBBER	Rubber and plastics	25
CEMENT	Manufacture of cement, lime and plaster	265
GLASS	Manufacture of glass and glass products	261
CERAMIC	Ceramic industries	262-264
OTHER NON-METALLIC P.	Manufacture of other non-metallic mineral products	266-268
METALLURGY	Metallurgy	27
P.METÁLICOS	Manufacture of metal products	28
MACHINERY	Machinery and equipment	29-33
TRANSPORT MAT.	Transport material	34,35
PAPER	Paper, printing and publishing	21,22
OTHER	Other manufacturing	20,36,37
CONSTRUCTION	Construction	45
TRADE	Trade	50-52, 55.1-55.5
TRANSPORT	Transport	60-63
MARKET SERVICES	Market services	64-67,70-74, 80p,85p,90p,91p,92p,93
NON-MARKET SERVICES	Non-market services	75,80p,85p,90p,91p,92p
PRIVATE CONSUMPTION FINAL	Private households	95

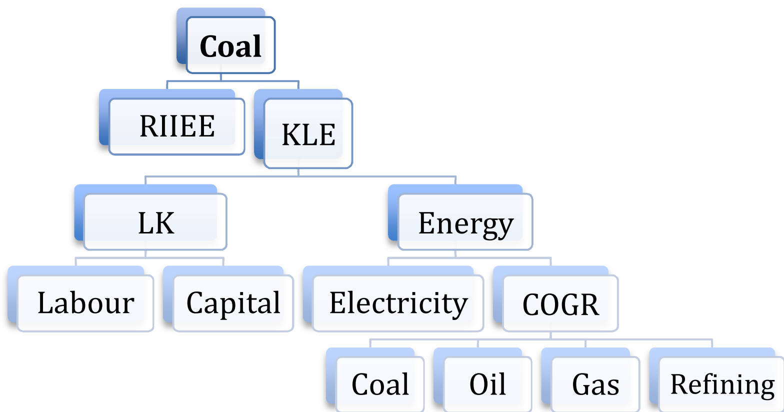
Table 2: Nesting productions functions:

- **Agriculture**: Agriculture, Livestock and Fisheries.

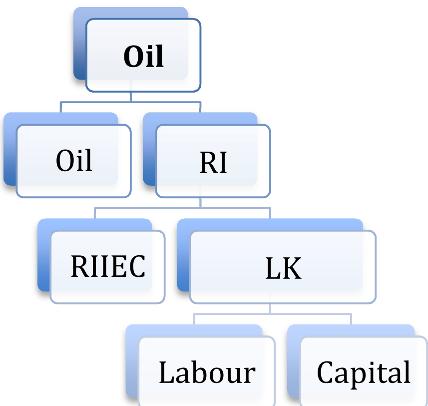


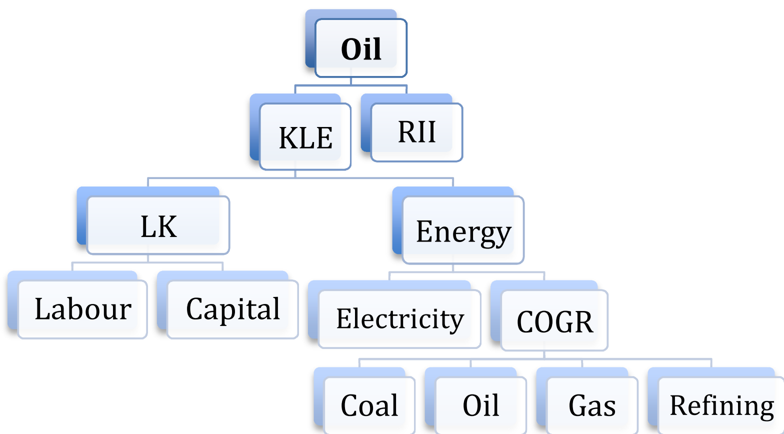
- **Coal**: Extraction of coal, lignite and peat.



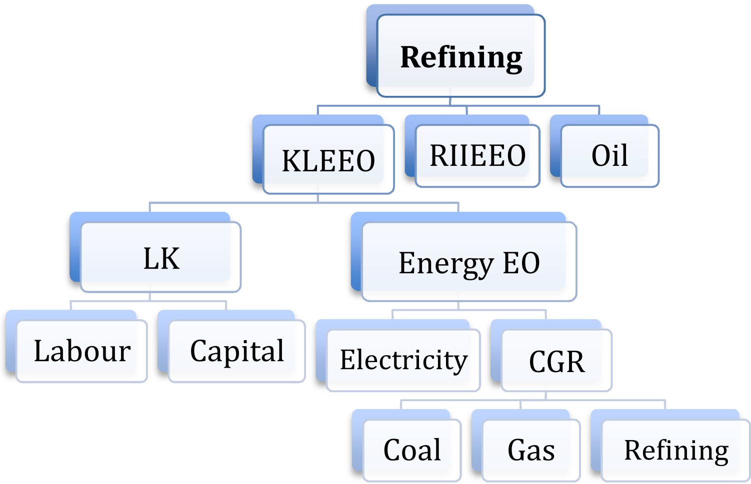


- **Oil**: Extraction of crude petroleum and natural gas. Extraction of uranium and thorium.

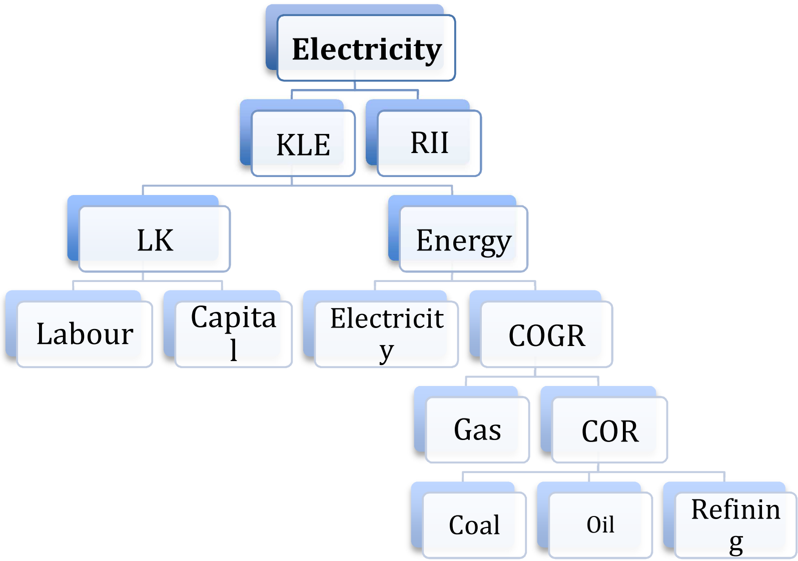




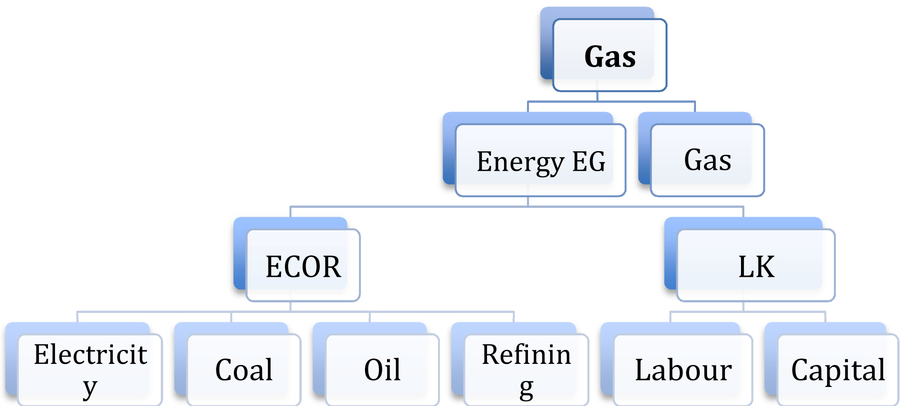
- **Refining**: Manufacture of coke, refined petroleum products and nuclear fuel.



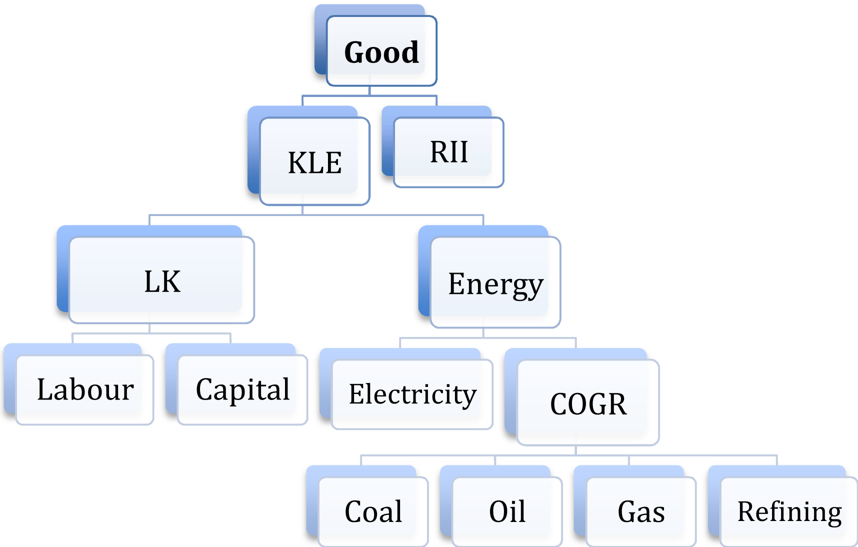
- **Electricity**: Production and distribution of electricity



- **Gas**: Production and distribution of gas.



- All sectors except energy.

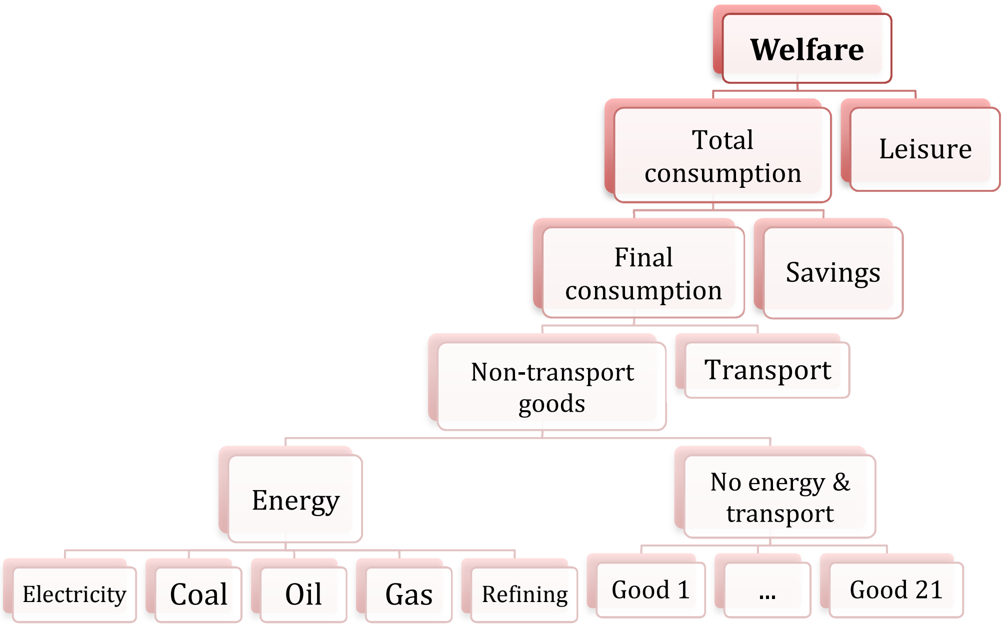


Note

AIEC_All inputs except coal
CGR_Coal, Gas, Refining
COGR_Coal, Oil, Gas, Refining
ECOR_Electricity, Coal, Oil, Refining
K_Capital
KLEEO_Capital, Labour, Energy, except Oil
L_Labour

RI_Rest of Inputs
RII_Rest of Intermediate Inputs
RIIEE_Rest of Intermediate Inputs except Energy
RIIEEO_Rest of Intermediate Inputs except Energy and Oil
RIIEO_Rest of Intermediate Inputs except Oil

Nesting utility function



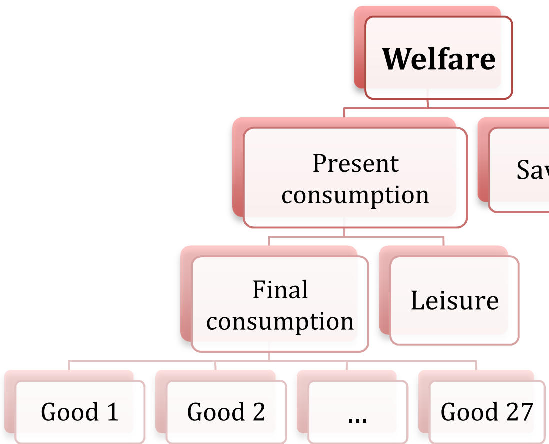


Table 3

Table 3a: 5% productivity gains

		COAL	OIL	REFINING	ELECTRICITY	GAS	LABOUR	CAPITAL	OUTPUT	REAL PRICE
AGRIC	10	-6,464		-1,742	-2,898	-3,802	-0,796	-0,870	-0,503	0,189
COAL	10	-7,647			-10,498	-10,498	-5,783	-5,842	-5,787	-0,418
OIL	10		-2,330	-5,092	-5,092	-5,092	-0,093	-0,155	-0,092	-0,604
MINERAL	10	-5,259		-0,477	-1,810	-2,564	-0,168	-0,231	0,578	-0,834
REFINING	10	-3,224	-0,350	1,662	0,583	-0,470	2,630	2,225	4,894	-5,204
ELECTRICITY	10	-5,887		-4,486	-5,141	-5,210	-3,387	-3,768	-1,793	-3,210
GAS	10	-7,671	-7,671		-7,671	-7,671	-2,527	-2,912	-2,812	-3,173
WATER	10			0,823	-0,221		0,583	0,186	0,743	-0,098
FOOD	10			1,103	-0,651	-1,017	0,152	-0,199	0,337	-0,016
TEXTILE	10			0,652	-1,206	-1,458	-0,426	-0,819	-0,235	-0,201
CHEMICALS	10	-3,226		1,659	0,440	-0,472	1,282	0,883	2,569	-1,199
RUBBER	10			0,391	-1,162	-1,714	-0,368	-0,762	0,083	-0,526
CEMENT	10			0,244	-0,832	-1,858	0,034	-0,361	0,435	-0,481
GLASS	10			0,757	-1,132	-1,355	-0,335	-0,728	0,069	-0,418
CERAMIC	10			1,199	-0,903	-0,923	-0,116	-0,510	0,369	-0,424
OTHER NON-METAL PRODUCTS	10			0,537	-0,747	-1,571	0,072	-0,323	0,482	-0,490
METALLURGY	10	-4,217		0,618	-1,666	-1,492	-0,823	-1,215	-0,211	-0,603
METAL PRODUCTS	10			0,556	-1,052	-1,552	-0,255	-0,649	-0,121	-0,238
MACHINERY	10	-4,520		0,300	-1,483	-1,803	-0,692	-1,084	-0,568	-0,275
TRANSPORT MAT.	10			0,040	-1,627	-2,057	-0,831	-1,222	-0,662	-0,154
PAPER	10			1,227	-0,774	-0,895	0,046	-0,349	0,246	-0,160
OTHER	10			0,318	-0,921	-1,785	-0,132	-0,526	-0,013	-0,137
CONSTRUCTION	10			0,871	-0,174		0,701	0,171	0,543	0,144
TRADE	10			0,317	-1,033	-1,787	0,812	0,282	0,696	0,180
TRANSPORT	10	-5,258	-5,081	-0,476	-1,607	-2,563	0,349	-0,179	0,824	-0,865
MARKET SERVICES	10	-4,636	-4,458	0,178	-1,129	-1,923	0,676	0,278	0,518	0,320
NON-MARKET SERVICES	10			0,725	-0,583	-1,387	1,103	0,703	1,161	0,152
PRIVATE CONSUMPTION FINAL		-3,786		-6,588	-5,414	-5,392				
EXPORTATION		-6,404	0,597	13,741	5,334	4,049				
IMPORTATION		-5,609	-2,654	-5,204	-9,365					
TOTAL		-5,787	-0,092	4,894	-1,793	-2,812	0,581	0,000		

Table 3b: Rebound effect

	REBOUND				
	COAL	OIL	REFINING	ELECTRICITY	GAS
AGRIC	-29,272		65,162	42,037	23,954
COAL	-52,940			-109,960	-109,960
OIL		53,409	-1,848	-1,848	-1,848
MINERAL	-5,185		90,464	63,802	48,726
REFINING	35,526	92,993	133,231	111,660	90,596
ELECTRICITY	-17,740		10,275	-2,816	-4,197
GAS	-53,428	-53,428		-53,428	-53,428
WATER			116,460	95,582	
FOOD			122,053	86,983	79,652
TEXTILE			113,043	75,870	70,831
CHEMICALS	35,483		133,185	108,803	90,551
RUBBER			107,823	76,764	65,720
CEMENT			104,882	83,358	62,841
GLASS			115,147	77,364	72,891
CERAMIC			123,985	81,933	81,543
OTHER NON-METAL PRODUCTS			110,746	85,055	68,583
METALLURGY	15,659		112,361	66,688	70,163
METAL PRODUCTS			111,127	78,963	68,955
MACHINERY	9,605		106,002	70,345	63,937
TRANSPORT MAT.			100,810	67,456	58,854
PAPER			124,547	84,518	82,094
OTHER			106,369	81,573	64,297
CONSTRUCTION			117,413	96,524	
TRADE			106,332	79,343	64,261
TRANSPORT	-5,169	-1,625	90,482	67,857	48,743
MARKET SERVICES	7,283	10,850	103,562	77,421	61,549
NON-MARKET SERVICES			114,508	88,332	72,266
PRIVATE CONSUMPTION FINAL	24,272		-31,755	-8,275	-7,848
EXPORTATION	-28,086	111,944	374,822	206,674	180,982
IMPORTATION	-12,183	46,914	-4,089	-87,292	
TOTAL	-15,743	98,163	197,887	64,144	43,760

Table 4: macroeconomic variables

	Welfare	Employment	Unemployment rate	Real wage	Capital real rent
Benchmark	0,812	0,581	-6,017	0,404	0,720
Beta = 0.15	0,508	-0,034	-0,930	0,627	0,503
Beta = 15	1,244	1,459	-13,282	0,089	1,028
KL/2	0,762	0,448	-5,139	0,345	0,777
KL*2	0,859	0,707	-6,853	0,460	0,665
K específico	0,837	0,641	-6,420	0,431	0,689
CD Producción	0,800	0,504	-5,575	0,374	0,788
Leontief Producción	0,662	0,210	-3,523	0,237	0,859
CD Welfare	0,789	0,646	-5,520	0,371	0,753
Leontief Welfare	0,834	0,512	-6,445	0,433	0,691
CET = 0	0,806	0,576	-5,970	0,401	0,711

Appendix

As a general rule, the notation in the model is as follows: the endogenous variables are denoted with capital letters, the exogenous variables in capital letters with bar, while the parameters are denoted by lower case and greek letters. There are 27 (i, j = 1,..., 27) production sectors and 27 (k = 1, ..., 27) consumer goods.

The equilibrium of this economy is defined by a vector of prices and an allocation of goods and factors that simultaneously solves three sets of equations:

• Zero profit conditions for all sectors.

• Equilibrium of goods and capital markets.

• Restrictions on disposable rent (which must be matched with the expenditure incurred by all agents), unemployment and macroeconomic closure of the model. These equations are described below.

A. 1. Production

The base model has constant returns to scale, and a rule of competitive pricing. Since the top nesting level is a Leontief function, the zero profit condition for sector i is:

$$PROFIT_i^X = PX_i\left(1 - oii_i^{II} - iva_i^{II}\right) - \left(R\overline{KF_i} + W\overline{LF_i}\right) - c_{0i}PVA_i - \sum_{j=1}^{27} c_{ji}PO_j = 0$$

$(i = 1,\ldots, 27)$ **(A1)**

in which, according to its nested structure, the unit cost of composite added value generated by sector i is a CES function:

$$PVA_i = \frac{1}{\alpha_i}\left(a_i^{\sigma_i^{LK}}\left(1 + socce_i + soccw_i\right)^{1-\sigma_i^{LK}} W^{1-\sigma_i^{LK}} + (1-a_i)^{\sigma_i^{LK}} R^{1-\sigma_i^{LK}}\right)^{\frac{1}{1-\sigma_i^{LK}}} \quad (i = 1,\ldots, 27)$$

(A2)

We assume that domestic producers maximize profits, and choose the optimal combination of domestic production and imports, and domestic sales and exports. This leads to the following zero profit conditions:

$$PROFIT_i^A = PA_i - \left(e_i^{\sigma_i^A} PX_i^{1-\sigma_i^A} + (1-e_i)^{\sigma_i^A} \left(\overline{PFX}FC\right)^{1-\sigma_i^A} \right)^{\frac{1}{1-\sigma_i^A}} = 0 \ (i = 1,\ldots, 27) \qquad \textbf{(A3)}$$

$$PROFIT_i^{CET} = PA_i - \frac{1}{\zeta_i}\left(d_i^{-\varepsilon_i} PO_i^{\varepsilon_i+1} + (1-d_i)^{-\varepsilon_i} \left(\overline{PFX}FC\right)^{\varepsilon_i+1} \right)^{\frac{1}{\varepsilon_i+1}} = 0 \ (i = 1,\ldots,27) \qquad \textbf{(A4)}$$

These conditions of zero profits are used to obtain the demand functions derived through the application of Shephard's Lemma of cost functions.

Then we introduce the equations corresponding to the equilibrium in the markets. On the left side are reflected the demands, and on the right side the supplies:

$$X_i\left(-\frac{\partial PROFIT_i^X}{\partial PO_j}\right) = II_{ji} \qquad (i, j = 1,\ldots, 27) \qquad \textbf{(A5)}$$

$$\sum_{i=1}^{27} X_i\left(\frac{\partial PROFIT_i^X}{\partial R}\right) = \overline{K_{RC}} + \overline{K_{SP}} \qquad \textbf{(A6)}$$

$$\sum_{i=1}^{27} X_i\left(\frac{\partial PROFIT_i^X}{\partial W}\right) = \left(\overline{L} - Q_l\right)(1-U) \qquad \textbf{(A7)}$$

$$A_i\left(-\frac{\partial PROFIT_i^A}{\partial PX_i}\right) = X_i \qquad (i = 1,\ldots, 27) \qquad \textbf{(A8)}$$

$$A_i\left(-\frac{\partial PROFIT_i^A}{\partial FC_i}\right) = IMP_i \qquad (i = 1,\ldots, 27) \qquad \textbf{(A9)}$$

$$A_i\left(-\frac{\partial PROFIT_i^{CET}}{\partial PO_i}\right) = O_i \qquad (i = 1,\ldots, 27) \qquad \textbf{(A10)}$$

$$A_i\left(-\frac{\partial PROFIT_i^{CET}}{\partial FC_i}\right) = EXP_i \qquad (i = 1,\ldots, 27) \qquad \textbf{(A11)}$$

$$X_i + IMP_i = O_i + EXP_i \qquad (i = 1,\ldots, 27) \qquad \textbf{(A12)}$$

$$I_i + \sum_{j=1}^{27} II_{ij} + CF_i = O_i \qquad (i = 1,\ldots, 27) \qquad \textbf{(A13)}$$

A. 2. Consumption

The functions of final demand for goods resulting from the maximization problem of a nested utility function, which represent the preferences of the representative consumer:

$$WF = (Q_c)^{1-\tau_{sav}} (Q_{sav})^{\tau_{sav}} \qquad \textbf{(A14)}$$

subject to budgetary constraints:

$$Y_{RC} = W\left(\overline{L} - Q_l\right)\left(1 - U\right) + R\overline{K_{RC}} + \overline{NTPS} + \overline{NTFS_{RC}} \qquad \textbf{(A15)}$$

$$Y_{RC} = P_{sav}Q_{sav} + \sum_{k=1}^{27} PB_k\left(1 + oii_k^{CF} + iva_k^{CF}\right)CFB_k^{RC} \qquad \textbf{(A16)}$$

in which the nesting of the utility function is defined by:

$$Q_c = \left(b^{\sigma^{CL}} Q_{cg}^{1-\sigma^{CL}} + (1-b)^{\sigma^{CL}} Q_l^{1-\sigma^{CL}}\right)^{\frac{1}{1-\sigma^{CL}}} \qquad \textbf{(A17)}$$

$$Q_{cg} = \prod_{k=1}^{21}\left(CFB_k^{RC}\right)^{\tau_k} \qquad \textbf{(A18)}$$

The transformation of productive goods into consumer goods follows a structure of fixed coefficients:

$$CFB_k = \left(\frac{CF_1}{f_{1k}}, ..., \frac{CF_{27}}{f_{27k}}\right) \qquad (k = 1,\ldots, 27) \qquad \textbf{(A19)}$$

and consumer goods can be purchased by the representative consumer and the public sector:

$$CFB_k = CFB_k^{RC} + CFB_k^{SP} \qquad (k = 1,\ldots, 27) \qquad \textbf{(A20)}$$

The solution of the maximization problem gives the saving demand function, leisure and final demand.

A. 3. Public sector

Public sector revenue is given by:

$$\overline{Y_{SP}} = R\overline{K_{SP}} + \sum_{i=1}^{21}\left(SOCCE_i + SOCCW_i + OII_i + IVA_i\right) + \sum_{k=1}^{21}\left(OII_k + IVA_k\right) - \overline{NTPS} + \overline{NTFS_{SP}} \qquad \textbf{(A20)}$$

in which tax revenues come from several sources:

$$SOCCE_i = Wsocce_i X_i \left(-\frac{\partial PROFIT_i^X}{\partial W} \right) \qquad (i = 1,\ldots, 27) \qquad \textbf{(A21)}$$

$$SOCCW_i = Wsoccw_i X_i \left(-\frac{\partial PROFIT_i^X}{\partial W} \right) \qquad (i = 1,\ldots, 27) \qquad \textbf{(A22)}$$

$$OII_i = PX_i oii_i^{II} X_i \left(-\frac{\partial PROFIT_i^X}{\partial PX_i} \right) + PO_i I_i oii_i^{FBC} \qquad (i = 1,\ldots, 27) \qquad \textbf{(A23)}$$

$$OII_k = PB_k CFB_k oii_k^{CF} \qquad (k = 1,\ldots, 27) \qquad \textbf{(A24)}$$

$$IVA_i = PX_i iva_i^{II} X_i \left(-\frac{\partial PROFIT_i^X}{\partial PX_i} \right) + PO_i I_i iva_i^{FBC} \qquad (i = 1,\ldots, 27) \qquad \textbf{(A25)}$$

$$IVA_k = PB_k CFB_k iva_k^{CF} \qquad (k = 1,\ldots, 27) \qquad \textbf{(A26)}$$

On the assumption of neutrality in the public sector behavior, the macroeconomic closure rules are:

$$\overline{BALPUB} = \overline{SAVPUB} - \overline{INVPUB} \qquad \textbf{(A27)}$$

$$\sum_{k=1}^{27} CFB_k^{SP} = \overline{Y_{SP}} - \overline{SAVPUB} \qquad \textbf{(A28)}$$

A. 4. Investment, savings and foreign sector

The macroeconomic closure of the model implies other restrictions relating to investment and savings in this open economy:

$$\sum_{i=1}^{27} PO_i \left(1 + oii_i^{FBC} + iva_i^{FBC}\right) I_i = PINV\,\overline{INVTOTAL} \qquad \textbf{(A29)}$$

$$\sum_{i=1}^{27} \overline{PFXEXP_i} - \sum_{i=1}^{27} \overline{PFXIMP_i} + \overline{NTFS_{RC}} + \overline{NTFS_{PS}} = \overline{D} \qquad \textbf{(A30)}$$

$$P_{sav} Q_{sav} + \overline{SAVPUB} - PINV \;\; \overline{INVTOTAL} = \overline{D} \;\; FC \qquad \textbf{(A31)}$$

A. 5. Factor markets

In conclusion, the equilibrium in the capital market is reflected in equation **(A6)** and the equilibrium in the labor market in **(A7)**, but in the latter case there is an additional equation which reflects the existence of unemployment and the relationship between real wages and unemployment rate:

$$\frac{W}{IPC} = \left(\frac{1-U}{1-\overline{\overline{U}}}\right)^{\frac{1}{\beta}} \quad \textbf{(A36)}$$

$$IPC = \frac{\sum_{k=1}^{27} \theta_k PB_k}{\sum_{k=7}^{21} \theta_k \overline{PB_k}} \quad \textbf{(A37)}$$

Table A1: Endogenous variables

Symbol	*Definition*
A_i	Armington aggregate (total supply of goods) sector i
CF_i	Final domestic consumption of goods produced by sector i
CFB_k	Final domestic consumption of good k
CFB_k^{SP}	Final domestic consumption of good k
CFB_k^{RC}	Private final domestic consumption of good k
EXP_i	Exports of sector i
FC	Conversion factor in local currency
I_i	Investment (gross capital formation) in goods produced by sector i
II_{ij}	Intermediate inputs of sector j used by sector i
IMP_i	Imports of goods from sector i
IPC	Consumer Price Index
IVA_i , IVA_k	Collection of VAT
O_i	Production of sector i sold in the domestic market
OII_i , OII_k	Collection of other indirect taxes
P_{sav}	Shadow price of savings
PA_i	Unit cost of Armington aggregate of sector i
PB_k	Price of commodity k
$PINV$	Unit cost of investment
PO_i	Unit cost of production of sector i sold in the domestic market
$PROFIT_i^A$	Unitary profit for Ai (depending on origin)
$PROFIT_i^{CET}$	Unitary profit for Ai (depending on destination)
$PROFIT_i^X$	Unitary profit for Xi
PVA_i	Unit costs of primary inputs used in sector i
PX_i	Price of goods produced in sector i
Q_c	Demand for aggregate consumption
Q_{cg}	Consumer demand for aggregate goods
Q_l	Leisure demand
Q_{sav}	Savings demand
R	Unit rent of capital
$SOCCE_i$	Collection of social contributions paid by employers in the sector i
$SOCCW_i$	Collection of social contributions paid by employees of the sector i
U	Unemployment rate
W	Wage
WF	Welfare
X_i	Production of sector *i*
Y_{RC}	Representative consumer disposable rent

Table A2: Exogenous variables and parameters

Symbol	*Definition*
$\overline{BALPUB}$	Public sector balance
$\overline{D}$	External balance
$\overline{INVPUB}$	Public sector investment
$\overline{INVTOTAL}$	Total investment of the economy
$\overline{K}_{RC}$	Capital endowment of the representative consumer
$\overline{K}_{SP}$	Capital endowment of public sector
$\overline{L}$	Labor endowment
$\overline{NTPS}$	Net transfers from public sector to representative consumer
$\overline{NTFS}_{RC}$	Net transfers from foreign sector to representative consumer
$\overline{NTFS}_{SP}$	Net transfers from foreign sector to public sector
$\overline{PB}_{i}$	Price of good k in the base year
$\overline{PFX}$	Foreign prices
$\overline{SAVPUB}$	Public sector savings
$\overline{U}$	Unemployment rate in the base year
$\overline{Y}_{SP}$	Public sector revenue
a_i, b, c_{0i}, c_{ji}, d_i, e_i, f_{ik}	Parameters of participation
$iva_i^{II}, iva_i^{FBC}, iva_k^{CF}$	Value added taxes, ad valorem, in sector i, levied on intermediate inputs, investment and final consumption, respectively
$oii_i^{II}, oii_i^{FBC}, oii_k^{CF}$	Other indirect taxes, ad valorem, in sector i, levied on intermediate inputs, investment and final consumption, respectively
$socce_i$	Social contributions, ad valorem, paid by employers in sector i
$soccw_i$	Social contributions, ad valorem, paid by employees in sector i
α_i, ζ_i	Scale parameters
ε_i	Elasticity of transformation in sector i
σ_i^A	Armington elasticity of substitution in sector i
σ^{CL}	Elasticity of substitution between consumption and leisure
σ_i^{LK}	Elasticity of substitution between labor and capital in sector i
τ_k, τ_{sav}	Share parameters