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

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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

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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). 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 ongoing quest to reduce their costs and achieve greater efficiency in the use of all inputs, including energy.

In Spain, with rates of energy intensity, usually measured as the ratio between energy consumption and gross domestic product, 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 (MITT, 2007, 2011). In general, it is aimed at obtaining the same level of services provided by energy with a smaller amount of energy consumption. To this end, these 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 (Binswanger, 2001, and Berkhout, Muskens and Velthuijsen, 2000).

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 is 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 analyze these issues in the Spanish economy through a computable general equilibrium (CGE) model.

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. The results are shown in section 5. Section 6 summarizes the main conclusions.

2. Energy efficiency and rebound effect

The energy inefficiency means that you can achieve the same level of output with less energy consumption. Therefore, one would expect that an improvement in the efficiency in energy use should result in a proportional savings of the amount of energy consumed (Schipper and Grubb, 2000). However, there are several reasons why the *potential* energy savings may not correspond to *actual* savings. In other words, some of the "engineering" estimates of the energy savings could be offset by what is known as rebound effect.

This idea about how the improvement in energy efficiency affects energy consumption was first developed by Jevons (1865). Jevons observed that the introduction of that 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 coal is becoming economically viable for new uses, which ultimately led to increase the tonnage of coal consumed.

These considerations led in the early 80's last century Khazzoom and Brookes to state that "energy efficiency improvements that, on the broadest considerations, are economically justified at the microlevel, lead to higher levels of energy consumption at the macrolevel" what Saunders (1992) called Khazzoom-Brookes postulate.

Diagram 1: The decomposition of rebound effect (Sorrell, 2009b).

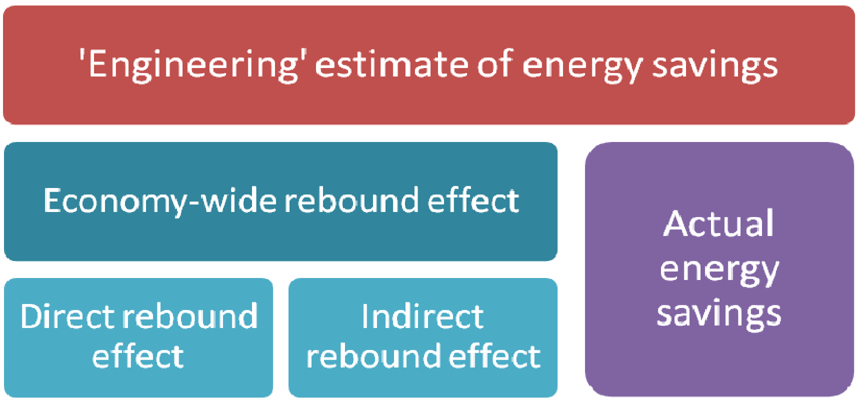


Diagram 1 illustrates the different components of the rebound effect. The rebound effect in the economy is decomposed into two effects: the direct and indirect effects. The direct effect may be due in turn to two effects: the substitution effect and income /output effect. For the final consumers of energy, the former occurs when, after the energy efficiency improvement, energy service consumption substitutes the consumption of other goods and services, maintaining the same level of utility. The latter occurs when it is get a higher utility level through consumption of other goods and services as well as energy services themselves. This is possible by the increase in real income.

In the case of producers, the substitution effect occurs when the energy service substitutes the use of capital, labor or materials to produce a given level of output. The output effect occurs when it is achieve a higher level of output by the increase in the consumption of all inputs, including the energy ones.

The indirect effect includes a number of effects related to changes in economic structure (e.g. growth of energy-intensive activities), changes in relative prices of inputs and economic growth resulting from the improved productivity of the economy.

Following Guerra and Sancho (2010), the simplest way to define the rebound effect is

$$RE = 1- (AES/PES)$$

where AES is the actual energy savings and PES denotes the potential energy savings, usually derived from engineering estimates. Therefore, in the case of an estimate of energy saving of 100% and an actual savings of 60%, the rebound effect would be equal to 40% (1- 0.6 / 1), 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 this case, there is not produced the expected savings in energy, since the consumption after improvement in energy efficiency is higher than before.

With respect to empirical studies, most focus on the analysis of direct rebound effects, either through experimental econometrics 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 jobs that take this approach is relatively scarce (Allan, et al., 2007, Hanley et al., 2006, Hartono, and Resosudarmo, 2008, Sorrell and Dimitropoulos 2008, Wei, 2010). In the case of Spain, we only have the recent work of Guerra and Sancho (2010). Sorrell, Dimitropoulos and Sommerville (2009) provide a review of studies that use CGE models to study the rebound effect. All these are significant rebound effects, some of them exceeding 50% and in some cases it provides evidence of backfire 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, a public sector and a simplified rest of the world. Unlike similar models, this 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. Next we present a brief description of the model. The basis of the complete system of equations is shown in the appendix.

3.1. Production

The production is based on a nested technology of intermediate inputs, capital and labor. The business problem is to maximize the profit (or, alternatively, minimize costs, in the dual approach), subject to technological constraint. The average cost functions are obtained from solving this business problem, and then used in zero profit conditions. In turn, 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 equations of goods and factor markets.

Companies operate under constant returns to scale and under a rule of competitive pricing.

3.2. Consumption

In the model there is a representative consumer who behaves rationally. The consumer's level of income is determined from their endowments of capital and labor, plus the exogenous net transfers received from the public sector. The decision problem of the representative consumer is to choose the optimal consumption basket by maximizing a nested utility function 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 revenues of factors, plus exogenous net transfers received from the public sector, minus income taxes (exogenous). The demand functions of 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.

3.3. Public sector

The public sector plays a dual role in the model: it owns resources and it acquires certain goods. As a resource holder, its income includes income from their 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, the value added tax, other net taxes on products, net taxes on production and income taxes. All taxes are modeled as ad valorem effective rates calibrated from the initial data, except for income taxes that are taken as an exogenous fixed amount that the representative consumer transfers to the public sector.

3.4. Foreign sector

The model incorporates the assumption of small open economy. That is, the economy would face a perfectly elastic export supply function. Furthermore it would use a transformation function between domestic sales and foreign of constant transformation elasticity. With respect to imports, we assume that goods are differentiated according to their origin (i.e., interior or exterior), following the Armington assumption, which reflects the possibility of 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 imports vary an unlikely scenario because it would mean capital inflows without any limit.

3.5. Factor markets

In the model there are two inputs: capital and labor. With regard to the capital factor, both the representative consumer and the public sector have fixed endowments. Capital income are adjusted to balance the domestic market of that factor, which implies that capital is immobile internationally but there is perfect mobility of it between domestic sectors.

The sole owner of labor is the representative consumer. We assume the possibility of unemployment and leisure, so labor supply would be 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 labor market including the equation:

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

where w is the real wage, u is the unemployment rate, ū is the unemployment rate in the reference 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 base 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 base 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, the work is assumed immobile at international level but perfectly mobile within the country.

3.6. 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 saving (private, public and external).

3.7. 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.
- Equilibrium of goods and capital markets.
- Restrictions on disposable income (which must be matched with the expenditure incurred by all agents), unemployment and macroeconomic closure of the model.

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 (Gómez, 2005, and Hosoe, Gasawa and Hashimoto, 2010).

4. Calibration, data and simulations

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

For the preparation of the Social Accounting Matrix, it has started from 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 (see section 4). They are grouped in 27, trying to achieve the highest possible level of disaggregation in the energy sectors or intensive in the use of energy inputs. This matrix is completed with information from the INE of its National Accounts through the Accounts of institutional sectors. The description of economic activities comprising the sectors is shown in Table 1.

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

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 will be done. The elasticity values used 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 the end-consumer goods (σ_{BC}): 1

• Elasticities related to production:

- Between intermediate inputs and value added (σ_{I}): 0
- Between labor and capital (σ_{LK}): values for sectors ranging from 0.20 to 1.68
- Domestic and imported goods (or Armington elasticities): the values for the sectors are between 0.90 and 4.05
- Goods with national destination and exports (or elasticity of transformation): 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 of 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.

Simulations made with the model consist in the productivity improvement of the inputs related to energy. Specifically, they simulate the reduction in the use of five energy intermediate inputs (collectively and individually) per unit of output produced.

The five intermediate inputs are those corresponding to the sectors of (1) Mining of coal, (2) Extraction of crude petroleum and natural gas, uranium and thorium, (3) Manufacture of coke, refined petroleum products and nuclear fuel, (4) Production and distribution of electrical energy, and (5) Production and gas distribution.

5. Results

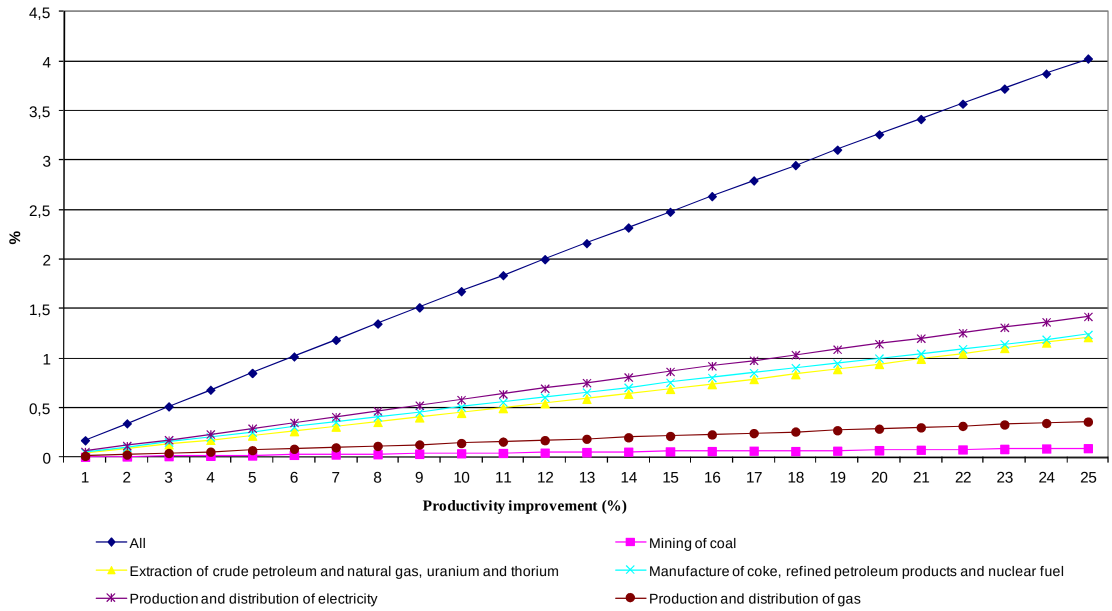
5.1. Macroeconomic results

The macroeconomic variables analyzed are welfare, employment, unemployment rate, real income of labor and capital. The simulation consists of improvements in input productivity, with savings ranging from 1% to 25% of that input for the same unit of output. Obviously, this last figure of a 25% improvement in productivity is unrealistic in most cases, but collecting the range between 1 and 25% can be appreciated more clearly the evolution of the different macroeconomic variables.

As explained above, the results are collected in cases where the efficiency improvement takes place in one of the five energy inputs, and the case "All" comprising a simultaneous improvement of these five inputs.

A first approach is by measuring changes in welfare for the whole country (excluding the public sector), measured by an indicator of equivalent variations. These results are shown in Figure 1, 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 occur the improvements in productivity: the most positive effects are generated by the productivity gains in the electricity sector, while the lowest would be driven by improvements in the use of coal.

Figure 1. Change in welfare (in %)



The origin of the welfare gains in this model comes from the operation of markets of production factors. While in the case of capital factor is assumed full employment, in the case of labor factor we have an unemployment situation, characteristic of the Spanish market. This allows involuntary unemployment can be reduced to the expansion that involves the improvement in productivity. Although this issue is studied in the section of microeconomics results, at macroeconomic level there was an increase in employment (Figure 2) and a decrease in the unemployment rate

(Figure 3). We do not have to forget that the labor market representation includes the existence of leisure, a factor that influences the supply of this factor.

Figure 2. Change in employment (in %)

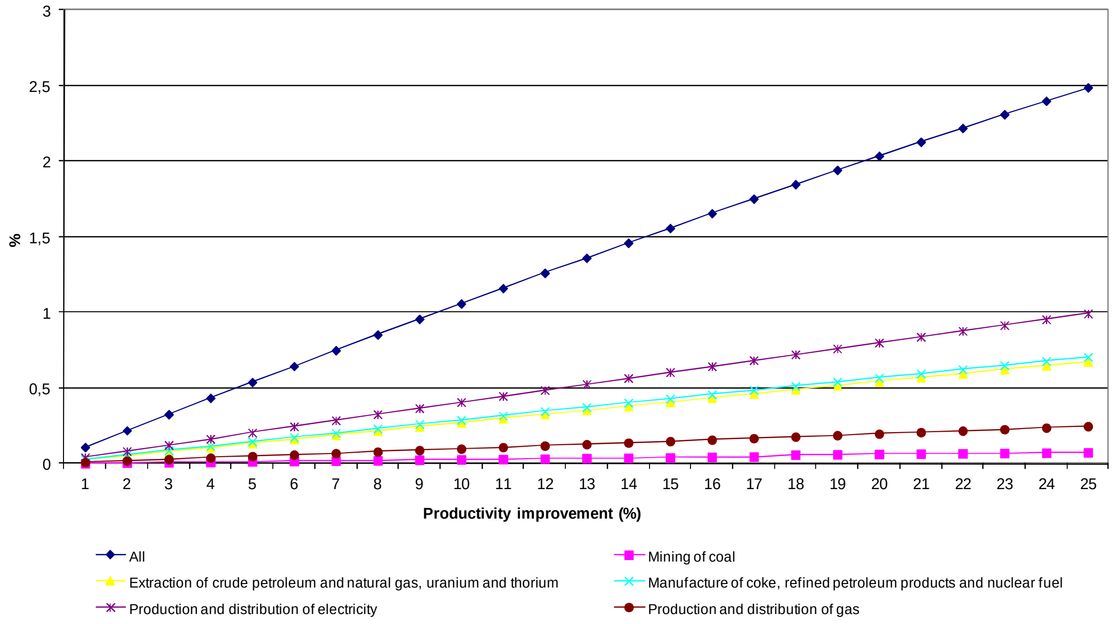
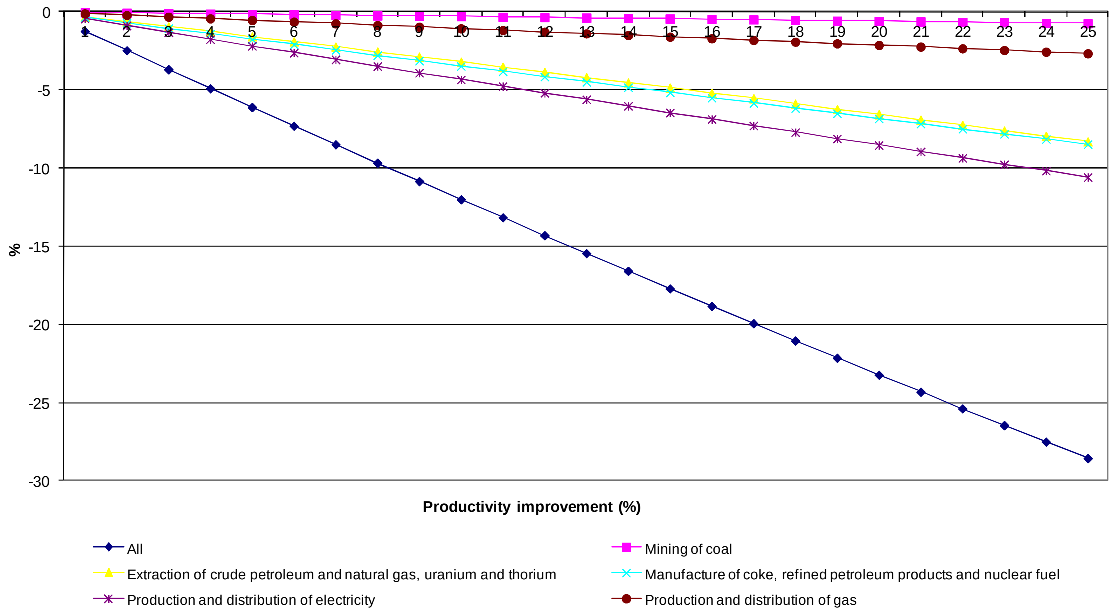


Figure 3. Change in unemployment rate (in %)



It can be seen the similar behavior that the improvements in productivity of each type of energy as generator of employment. Improvements in electricity (coal) are those that generate higher (lower) effect on employment generation. For its part, the reduction in the unemployment rate includes symmetrical effects to the employment variable, showing a similar variation in relative terms.

The higher employment, along with the real incomes improvement of the two factors (Figures 4 and 5) are the generators of GDP growth and welfare. Both workers and capital owners are improving their real income. 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. This lower relative improvement of wage of labor factor is also motivated because labor supply is elastic and there is the possibility of unemployment, while the endowment of capital is fixed and it is assumed full employment, which implies a supply function of vertical capital. An economic expansion, therefore, would lead to a further increase of capital rent in relation to the increase in labor wage.

In relation to changes in factor rents, note that the evolution of wages is particularly favorable in scenarios that involve efficiency improvements in electricity, petroleum and derivatives. 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 sector of "Extraction of crude petroleum and natural gas, uranium and thorium" which shows a comparatively higher increase.

Figure 4. Change in real wage (in %)

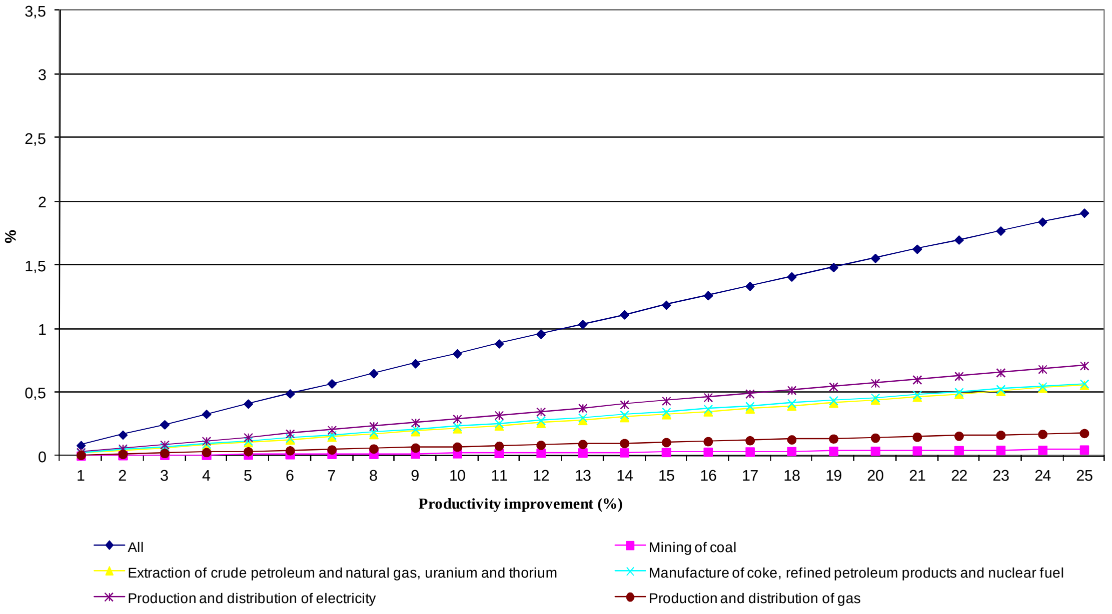
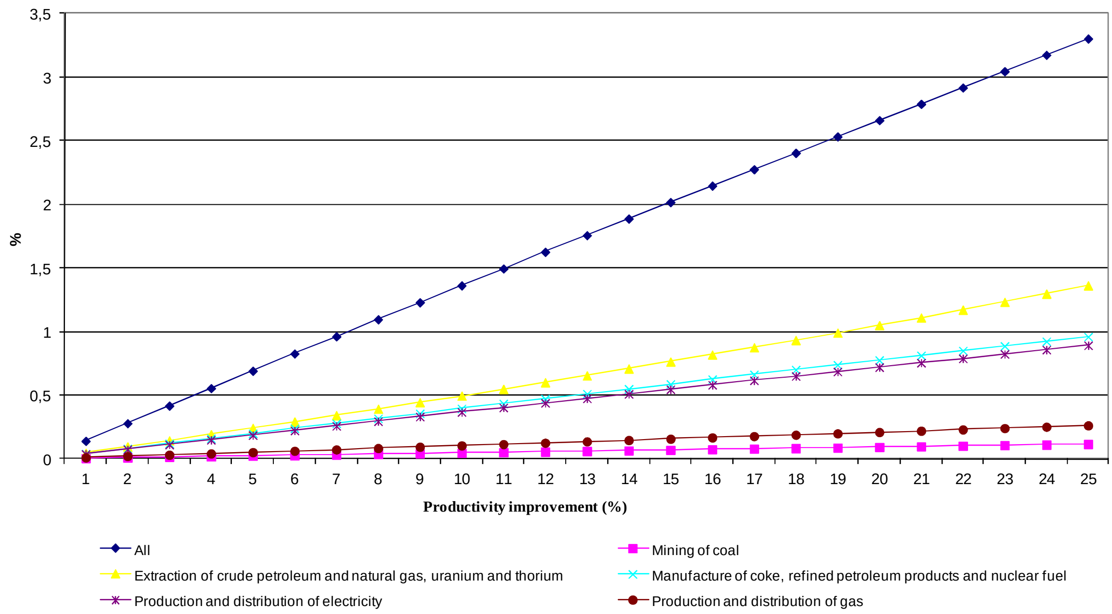


Figure 5. Change in real rent of capital (in %)



5.2. Microencomic results

At the micro level are presented solely for the scenario in which all energy inputs show a 5% improvement in its efficiency (scenarios *All* in the previous section).

Table 2 provides numerical results that shown several characteristics. First, we can 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 petroleum (measured in physical units). But the reduction is not equal to 5% of improvement in energy efficiency that we have considered which serves to underscore the general equilibrium framework adopted in this paper. Thus, the last row of Table 2 shows that the reduction in the consumption of electricity would be 4.62%. I.e. in this case, our results show a "rebound effect" of 7.6% in the use of this energy (35.8% in the case of oil). In the case of coal and gas we found negative rebound effects with 5% reductions in both energy consumptions (8.63% and 5.69% respectively). By contrast, in the case of petroleum rebound effects are greater than 100%, showing an increase in the quantity consumed of 1.83% (note also the necessary increase of 19.23% of crude imports predicted by the model in row import for column 2). In this case, where all potential savings from the efficiency improvement are offset, is known in the literature as "backfire effect".

Table 2. Sectorial changes in the use of intermediate energy inputs, final consumption, exports, imports, output and price level with a 5% improvement in the productivity of energy inputs (% change of physical units)

	Mining of coal	Extraction of crude petroleum and natural gas, uranium and thorium	Manufacture of coke, refined petroleum products and nuclear fuel	Production and distribution of electricity	Production and distribution of gas	lABOR	CAPITAL	OUTPUT	REAL PRICE
AGRIC	-5,69		-5,69	-5,69	-5,69	-0,68	-0,74	-0,73	0,18
EXTCOAL	-13,20			-13,20	-13,20	-8,63	-8,68	-8,63	-0,43
EXTOIL		-8,05	-8,05	-8,05	-8,05	-3,20	-3,26	-3,21	-0,65
EXTMIN	-4,61		-4,61	-4,61	-4,61	0,43	0,37	0,41	-0,83
REFINO	-3,24	-3,24	-3,24	-3,24	-3,24	2,12	1,76	1,85	-5,21
ELEC	-9,39		-9,39	-9,39	-9,39	-4,35	-4,69	-4,62	-3,19
GAS	-10,40	-10,40		-10,40	-10,40	-5,44	-5,77	-5,69	-3,20
AGUA			-4,52	-4,52		0,62	0,26	0,51	-0,09
ALIM			-4,83	-4,83	-4,83	0,29	-0,02	0,18	-0,01
TEXT			-5,38	-5,38	-5,38	-0,32	-0,67	-0,40	-0,20
QUIM	-2,91		-2,91	-2,91	-2,91	2,36	2,00	2,20	-1,18
CAUC			-5,19	-5,19	-5,19	-0,10	-0,45	-0,20	-0,51
CEMEN			-4,61	-4,61	-4,61	0,62	0,26	0,41	-0,47
VIDR			-5,15	-5,15	-5,15	-0,05	-0,40	-0,15	-0,41
CERAM			-4,74	-4,74	-4,74	0,36	0,00	0,27	-0,38
MINER			-4,53	-4,53	-4,53	0,63	0,28	0,50	-0,47
METALU	-5,46		-5,46	-5,46	-5,46	-0,30	-0,65	-0,48	-0,59
METAL			-5,29	-5,29	-5,29	-0,20	-0,55	-0,30	-0,23
EQUIPO	-5,73		-5,73	-5,73	-5,73	-0,67	-1,02	-0,77	-0,29
MATTRANS			-5,82	-5,82	-5,82	-0,75	-1,10	-0,86	-0,14
PAPEL			-5,00	-5,00	-5,00	0,13	-0,22	0,00	-0,15
MADERA			-5,15	-5,15	-5,15	-0,07	-0,42	-0,16	-0,13
CONSTR			-4,42	-4,42		0,79	0,31	0,61	0,14
COMERC			-4,47	-4,47	-4,47	0,79	0,32	0,56	0,18
TRANSPOR	-4,34	-4,34	-4,34	-4,34	-4,34	0,92	0,44	0,70	-0,84
SERVMERC	-4,70	-4,70	-4,70	-4,70	-4,70	0,52	0,17	0,32	0,31
SERVNOMERC			-4,26	-4,26	-4,26	0,81	0,45	0,77	0,16
CONSUMO PRIVADO FINAL	0,04		7,54	6,09	1,27				
EXPORTACIÓN	0,18	0,12	9,56	0,63	0,31				
IMPORTACIÓN	1,08	19,23	7,36	0,27	0,00				
TOTAL	-8,63	-3,21	1,85	-4,62	-5,69	0,54	0,00		

By sectors, the structure Leontief in the intermediate inputs of production functions determines the changes in the use of different energy inputs are equal at the sector level.

However Table 2 shows the significant differences between sectors with respect to the magnitude of the impact of energy efficiency improvement in final consumption of energy, and ultimately, the rebound effect.

Likewise, there is a difference between energy use as intermediate inputs and final consumption. Most of the rebound effect and the backfire effect detected is determined by the behavior of private final consumption. There is a substantial increase in the consumption of petroleum products and electricity, and to a lesser extent gas (except oil not consumed directly and coal, whose share of final consumption is marginal). That is, the rent effect generates an increase of energy consumption by households: the improvement of labor and capital rents (see previous section) determines an increased final consumption.

With respect to changes in the output, these are largely determined by the use of factors. The model uses the assumption of free mobility of labor and capital across sectors, but not internationally.

Since capital has a fixed endowment, any increase in the use of capital in a sector is accompanied by a decline in the use of capital in one or more sectors. This restriction is less rigid to labor, given the existence of unemployment and leisure. 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 4 and 5 it is shown the relative increase in capital rent relative to wages, and Table 2 confirms that this leads to a further decline (or smaller increase) in use of capital relative to labor for each sector.

Finally, changes in real prices are measured relative to a price index like the CPI. Therefore, there will be a series of sectorial prices that are below the price level of the index, while for other sectors the actual prices are above the weighted average. As expected, the last column of Table 2 shows that sectorial prices are more down for the energy sectors, the result of declining demand for its products (derived from the efficiency improvement in the use of energy inputs for the remaining sectors).

6. Conclusions and discussion

Since the present paper is an ongoing investigation, the results are still preliminary and may experience changes as a result of potential refinements offered by the model and we are incorporating. In particular, the production functions. These are specified with the same nesting for all sectors (see appendix), with differences in some of its elasticities of substitution. We are working on sectorial differentiation not only in terms of elasticities, but also nesting. In addition, the utility function is also changing, trying to reflect in greater detail the substitutability between goods that involve energy consumption in the final consumer.

Another relevant point is that it is needed to check the robustness of the results and their sensitivity to the elasticity of substitution and other exogenous parameters of the model. This work is to be done systematically. Therefore, the implications arising from these very preliminary results should be viewed with caution.

However, the present results in general terms indicate that an efficiency improvement of 5% in the use of all energy inputs would have the following effects:

- A decline in the total consumption of electricity, gas and coal (positive rebound effect for electricity and negative for gas and coal).

- An increase in consumption of petroleum products and the resulting increase in oil imports (backfire effect).

- A significant increase in the amount of energy as the end use.

- An increase in the GDP of the economy around 0.5% and a reduction in the unemployment rate of around 5%.

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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:

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

(A20)

in which tax revenues come from several sources:

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

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

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

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

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

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

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:

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

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

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