

ENERGY TAX SIMULATIONS IN A FLEXIBLE CGE MODEL OF CATALONIA

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Abstract

There is a considerable body of literature that has studied whether or not an adequately designed tax swap, whereby an ecotax is levied and some other tax is reduced keeping government income constant, may achieve a so-called double dividend, that is, an increase in environmental quality and an increase in overall efficiency. Arguments in favor and against are abundant. Our position is that the issue should be empirically studied starting from an actual, non-optimal tax system structure and by way of checking the responsiveness of equilibria to revenue neutral tax regimes under alternate scenarios regarding the technological structure of the economy. We find that the most critical elasticity for achieving a double dividend is the substitution elasticity between labor and capital whereas the elasticity that would generate the highest carbon dioxide emissions reduction is the energy goods substitution elasticity.

Keywords: Applied General Equilibrium, Tax Reform, Tax Substitution, Double Dividend, CO₂ emissions.

JEL classification: C68, D58, H22, Q48

1. Introduction

The model we present in this article is a technologically flexible computable general equilibrium (CGE) model. By technologically flexible we mean that the model offers a wide variety of parameter and behavioral specification possibilities on its production side. The purpose is to have the modeling machinery ready for broad sensitivity analysis. It is sometimes argued that CGE models, and any general equilibrium model for that matter, are black-box models in the sense that their simulation results are difficult to trace to specific causation factors. When all markets depend on all markets, indeed, explanations are sometimes not easy to come by. We disagree, however, with this defeating position. In the first place, economic intuition of the partial equilibrium type does work quite often to give coherent explanations for most of the CGE simulation results. All it takes is some mental discipline and rigor to separate direct effects from indirect ones. It is not always easy but it is almost always possible. In the second place, when all else fails, sensitivity analysis may come in handy. By selectively modifying parameters and rerunning simulations, we perform something akin to an empirical topological deformation of the equilibrium set, therefore salient features can be better identified and the underlying complex interdependency effects may be better revealed. Also, as it has been correctly pointed out by Whalley [1987], CGE models, in opposing contrast to econometric models, have a strong economic structure but a feeble statistical basis; simulation results, therefore, provide “insights” rather than “forecasts”. Even if this were to be the case, there is nothing wrong with “insights” being somehow “validated” and one way to proceed along this line is by having models with built-in flexibility and modularity. All in all, the more options in parameter selection and parameter behavior, the more appraisable the results, the better they can be understood and explained.

Empirical general equilibrium models have evolved along several alternate paths. One distinction is linear versus nonlinear models. In the first category we find basic and extended input-output and SAM models. Originally, input-output models focused their “general equilibrium” on the production side of the economy with particular interest in detecting and revealing indirect interdependencies among production sectors. SAM models are natural extensions of the simple input-output Leontief model in which additional layers of interdependency are added, particularly by complementing the initial feedback between final demand and production with additional feedbacks from production to factor incomes and from these back to final demand. This procedure closes the circular flow of income and hence the “general equilibrium” of SAM models is quite more comprehensive than that of simple linear production models. SAM models, however, share the same restrictive property that affect input-output models, namely, the independence between the quantity side and the price side of the economy. Equilibrium quantities can be determined without any knowledge of prices and, vice versa, equilibrium prices can be determined without any knowledge of quantities. This is the so-called classical dichotomy between prices and quantities of linear models. This dichotomy is a modeling convenience since it allows for quick implementation, fast computation, and easy interpretation of results. Disregarding the market interaction between prices and quantities, however, is a substantial limitation of the linear approach. The implicit assumption is one of rigidity in behavior since agents’ decisions are not price responsive. This global linearity assumption is without doubt an unnecessary restriction and nonlinear models of the Walrasian type have been filling up most of the modeling needs once computing costs have been reduced to affordable levels. Applied Walrasian models have adapted the neoclassical paradigm to deal with the presence of non-typical agents in standard general equilibrium models, namely, the government and the foreign sector. This has led to a divergence, in practice, between tax and trade models. The best known examples of tax

models are probably those of Ballard et al. [1985] and Shoven & Whalley [1992]. Trade models are best described in De Melo et al. [1983]. Despite some alleged differences, all these models share nonetheless the basic principle of general equilibrium analysis in that agents are seen as rational optimizers formulating individual demand and supply functions. These, in turn, give rise to market demand and market supply functions whose coordination (equilibrium) is achieved by the price mechanism. Differences, if any, are not of substance but rather of emphasis. Tax models pay special attention to the role of the government in developed economies and incorporate a detailed description of its spending and tax policies. Trade models focus, on the other hand, in developing economies and study the links between external sector policies and development strategies.

This paper's model belongs to the tax model tradition and its goal is to explore the effects of energy tax policies on the double dividend debate in the presence of increasing technological flexibility. The double dividend hypothesis states that tax reforms can be enacted so that without increasing total tax collections a better environmental quality (less carbon dioxide emissions, say) and a better economic indicator (a welfare improvement or an unemployment reduction, for instance) can both be achieved simultaneously. Whether or not revenue neutral tax reforms targeting two different goals can be successful depends upon whether the initial tax system has been optimally designed. If so, by definition, no tweaking of the tax rates will manage to achieve an efficiency gain. In real world economies, however, the tax system is far from being optimally designed and some room for a dual target improvement may indeed exist. This has been pointed out in the tax reform literature by Atkinson & Stiglitz [1980], Ahmad & Stern [1984] and more recently by Leung et al. [1999] but, unfortunately, has mostly been disregarded in the double dividend debate. By extending Ahmad & Stern [1984] analysis to a general equilibrium setting, one can compute for each tax category—and within a category, for each tax rate—its marginal welfare loss. As long as

two tax categories have different marginal welfare losses, a small tax swap could enhance efficiency. These marginal welfare loss computations, however, will depend on the technological and behavioral structure that describes the economy.

Previous work for the Spanish economy (Manresa & Sancho, 2002) identified some instances of an effective double dividend following the adoption of energy taxes levied on CO₂ emitters. It also suggested that the likelihood of observing a double dividend may increase with the degree of flexibility in the economy. We therefore go here a step further and introduce more encompassing modeling assumptions to describe the set of technological possibilities and its correspondingly increased adaptability to changing relative prices. We do this by introducing substitution possibilities at three distinct levels of the production function. First, we introduce Armington substitution governed by a CES function. Second, we introduce CES substitution in primary factors. Third, we model the intermediate input-output matrix using a fixed coefficient submatrix for non-energy inputs and a variable coefficient submatrix for energy inputs. Input-output coefficients for the energy submatrix are determined using again a CES specification. The present model is supported by a recently compiled 1994 regional Social Accounting Matrix (SAM) of Catalonia, an industrially advanced region in northeastern Spain. The article has the following organization. In section 2 we describe the model and its main characteristics. Section 3 explains the calibration procedure used to implement the model. Results are presented and discussed in section 4. Section 5 concludes.

2. Detailed presentation of the model

2.1 The Consumption side

The model contemplates one representative consumer. Although a many consumer type's version would be preferable for income distribution purposes, there currently is no available data that allows us to disaggregate the consumption information in the background Social Accounting Matrix (SAM). From the viewpoint of model development and implementation, however, the distinction is not relevant. All expressions below would apply *mutatis mutandis* to any consumer disaggregation. The representative consumer owns endowments of labor and capital that are competitively sold at market factor prices. The capital market is perfectly competitive. The labor market, however, is not fully frictionless. Due to the presence of some labor market rigidities, not all of the labor endowment can be sold at the given wage rate. There is a part of the labor endowment that is *involuntarily* idled and we term it unemployment. This happens when labor demand by firms is not enough to occupy all of the available labor endowment elastically supplied (up to the exhaustion of the endowment level where supply becomes fully rigid) at the given wage rate. Unlike models with leisure, the unoccupied labor endowment does not produce here any utility (or disutility) to the consumer. Net income m is income after all applicable income taxes at rate t are deducted from the sale of the endowments of capital \bar{K} and non-idled labor $\bar{L}(1 - u)$ plus any taxable transfers coming from the public sector in form of social transfers T_G and income from abroad T_X :

$$m = (1 - t)(w\bar{L}(1 - u) + r\bar{K} + T_G + T_X) \quad (1)$$

Here u is the unemployment rate affecting total labor endowment and thus only a fraction $(1 - u)$ of the labor endowment is sold in the market. Preferences are represented by a

standard Cobb-Douglas aggregator defined over current sectoral consumption C_j ($j=1, 2, \dots, n$) and future consumption C_f (savings). These goods are purchased at final prices p_j, p_f which are inclusive of all applicable sales or value-added taxes. The utility maximization problem can be now stated as:

$$\text{Max } U = C_f^{1-\beta} \prod_{j=1}^n C_j^{\beta_j}$$

subject to the budget constraint:

$$p_f C_f + \sum_{j=1}^n p_j C_j = m = (1-t)(w\bar{L}(1-u) + r\bar{K} + Tg + Tx) \quad (2)$$

where the coefficients of the utility function satisfy the conditions $\beta + \sum_j \beta_j = 1$ and $\beta, \beta_j \geq 0$.

The demand functions take the usual Cobb-Douglas form:

$$\begin{aligned} C_f &= \beta \cdot \frac{m}{p_f} \\ C_j &= \beta_j \cdot \frac{m}{p_j} \quad (j = 1, 2, \dots, n) \end{aligned} \quad (3)$$

Despite the static nature of the model, we need to include savings as a variable in the consumer's decision problem to respond to the empirical nature of the model and the need to account for all flows recorded in the database.

2.2 The production side

There are n production sectors in the economy, each one producing an homogeneous good which is used to satisfy intermediate demand and final domestic (private consumption,

capital accumulation, public consumption) and foreign demands (exports). All production takes place under constant returns to scale (CRS) nested technologies. The nest contemplates three different production stages. In the first stage, total gross output is obtained by means of combining domestic and imported outputs. The aggregation follows the Armington [1969] assumption that local and foreign goods are imperfect substitutes with the selected aggregator being a CES function. In the second stage of the process, domestic output is generated using two types of intermediate goods and a composite primary factor (value-added) with no substitution allowed between them. The first type of intermediate input is a composite of energy inputs. Production requires a fix amount of this composite energy per unit of domestic output, but the energy input itself is modeled as a CES aggregation of the individual energy inputs of which there are k goods. The remaining, non-energy, intermediate inputs enter the production function with fixed coefficients. Similarly, value-added is the result of combining two primary factors (labor and capital services) using again a CES aggregator.

The detailed representation of the technology is as follows. In the first stage we have the CES function:

$$Y_j = \left[(a_j^d X_j)^{\rho_j} + (a_j^m M_j)^{\rho_j} \right]^{\frac{1}{\rho_j}} \quad (j = 1, 2, \dots, n) \quad (4)$$

where Y_j stand for gross output, X_j for domestically produced output and M_j for imports.

The Armington substitution elasticity in sector j is $\sigma_j = 1/(1 - \rho_j)$. Domestic production is a Leontief function of non-energy intermediate inputs, composite energy and value-added:

$$X_j = \text{Min}\left(\frac{X_{ij}}{a_{ij}}, \frac{E_j}{e_j}, \frac{VA_j}{v_j}\right) \quad (j = 1, 2, \dots, n) \quad (5)$$

In this expression a_{ij} is the non-energy input-output technical coefficient, that is, the minimum amount of non-energy input i needed to produce a unit of domestic output j whereas e_j and v_j are the minimum amounts of energy and value-added per unit of output j . In turn, energy is a CES composite of the k sectoral energy goods with common substitution elasticity $\sigma_e = 1/(1 - \rho_e)$ and non-negative energy share parameters a_i^e :

$$E_j = \left(\sum_{i=1}^k (a_i^e X_{ij})^{\rho_e} \right)^{\frac{1}{\rho_e}} \quad (j = 1, 2, \dots, n) \quad (6)$$

In a like manner, value-added is a CES aggregation, with substitution elasticity $\sigma_v = 1/(1 - \rho_v)$, of primary factors labor L and capital K :

$$VA_j = \left[(a_l L)^{\rho_v} + (a_k K)^{\rho_v} \right]^{\frac{1}{\rho_v}} \quad (j = 1, 2, \dots, n) \quad (7)$$

Notice that we assume again that this elasticity of substitution is the same in all sectors. Given the CRS assumption, productive units will maximize profits using the cost minimizing bundles at each of the three stages. By duality the cost function for the Armington stage is the CES cost function:

$$C_j(p_j, p_j^m, Y_j) = Y_j \left[\left(\frac{p_j}{a_j^d} \right)^{(1-\sigma_j)} + \left(\frac{p_j^m}{a_j^m} \right)^{(1-\sigma_j)} \right]^{\frac{1}{(1-\sigma_j)}} \quad (8)$$

From here, and given domestic price p_j and import price p_j^m , the amounts of domestic and imported output needed to produce the output level Y_j can be obtained using Shepard's lemma:

$$\begin{aligned}\frac{\partial C_j(p_j, p_j^m, Y_j)}{\partial p_j} &= X_j(p_j, p_j^m, Y_j) \\ \frac{\partial C_j(p_j, p_j^m, Y_j)}{\partial p_j^m} &= M_j(p_j, p_j^m, Y_j)\end{aligned}\quad (9)$$

The second stage is quite simpler given its fixed coefficients structure. Inputs at this stage are given by:

$$\begin{aligned}X_{ij} &= a_{ij} X_j(p_j, p_j^m, Y_j) \\ E_j &= e_j X_j(p_j, p_j^m, Y_j) \\ VA_j &= v_j X_j(p_j, p_j^m, Y_j)\end{aligned}\quad (10)$$

Observe that non-energy intermediate inputs, energy and value-added are not directly price responsive through their technical coefficients, but they do respond to price changes indirectly through their dependency on X_j . In other words, there is no pairwise substitution among them. Finally, in the third stage we obtain the CES cost functions for energy and value-added as:

$$\begin{aligned}C_j^e(p_1^e, \dots, p_k^e, E_j) &= E_j \left[\sum_{i=1}^k \left(\frac{p_i^e}{a_i^e} \right)^{(1-\sigma_e)} \right]^{\frac{1}{(1-\sigma_e)}} \\ C_j^v(w, r, VA_j) &= VA_j \left[\left(\frac{w}{a_l} \right)^{(1-\sigma_v)} + \left(\frac{r}{a_k} \right)^{(1-\sigma_v)} \right]^{\frac{1}{(1-\sigma_v)}}\end{aligned}\quad (11)$$

where p_i^e is the price of the i -th energy good and w and r are labor and capital prices. Again, by using Shepard's lemma, homogeneity and (10) we obtain conditional demands for energy goods and for labor and capital:

$$\begin{aligned} \frac{\partial C_j^e(p_1^e, \dots, p_k^e, E_j)}{\partial p_i^e} &= X_{ij}(p_1^e, \dots, p_k^e, E_j) = X_{ij}(p_1^e, \dots, p_k^e, 1)E_j = x_{ij}(p_1^e, \dots, p_k^e) e_j X_j(p_j, p_j^m, Y_j) \\ \frac{\partial C_j^v(w, r, VA_j)}{\partial w} &= L(w, r, VA_j) = L(w, r, 1) VA_j = l(w, r) v_j X_j(p_j, p_j^m, Y_j) \\ \frac{\partial C_j^v(w, r, VA_j)}{\partial r} &= K(w, r, VA_j) = K(w, r, 1) VA_j = k(w, r) v_j X_j(p_j, p_j^m, Y_j) \end{aligned} \quad (12)$$

where $l(w, r) = L(w, r, 1)$ and $k(w, r) = K(w, r, 1)$ are variable labor and capital requirements per unit of domestic output and where $x_{ij}(p_1^e, \dots, p_k^e) = X_{ij}(p_1^e, \dots, p_k^e, 1)$ are variable input-output energy coefficients.

2.3 The government

The government, or public sector, intervenes in the economy as an spending agent and a tax collector. On the expenditure side the government uses its income to purchase goods and services C_G , to undertake public investments I_G , and to provide various social transfers to the private sector T_G . On the tax collection side we distinguish the following income categories:

DIR: income taxes

IND: output net indirect taxes

VAT: value-added taxes

TAR: tariffs

SSP: payroll taxes-firms' contribution

SSC: payroll taxes-workers' contribution

Adding up income from all tax sources yields total tax collections TAX . On the other hand, for any given set of tax rates, tax collections will depend upon the applicable tax bases. For each tax category, the tax base depends on the interaction of prices and activity levels, thus their endogenous character. This can be described by a tax revenue function TR :

$$TR = TR(p, p^m, w, r, Y) \quad (13)$$

The government budget constraint takes the form:

$$D = TAX - C_G - I_G - T_G \quad (14)$$

where D stands for the public deficit (or surplus). A slight rearrangement yields:

$$C_G + I_G + T_G = TAX - D \quad (15)$$

Under this format we clearly see the financing role that the public deficit can play. Indeed, if the deficit is negative, the government is spending more than it collects and $-D$ can be interpreted as a loan (bonds, for instance) from the private sector to the government. Since TAX is endogenous there is a degree of freedom in the government's budget constraint. Either the level of spending is fixed—and the public deficit becomes endogenous along with TAX —or the level of the deficit is fixed—and spending turns out to be endogenous along with TAX . If government policy, for instance, aims at controlling the deficit, then it makes sense to set D as exogenous.

2.4 The Labor Market

Labor demand is given by the conditional demand function for labor which in turn is obtained from Shepard's lemma:

$$L(w, r, VA_j) = L(w, r, 1) VA_j = l(w, r) v_j X_j(p_j, p_j^m, Y_j) \quad (16)$$

On the supply side we consider an stylized real wage function that incorporates a trade-off between the unemployment rate and the real wage (see Oswald [1982] for a justification). More specifically we have:

$$\frac{w}{IPC} = \left[\frac{1-u}{1-\bar{u}} \right]^{1/\beta} \quad (17)$$

where u is the unemployment rate, \bar{u} is the benchmark unemployment rate, and β is an elasticity that measures the sensibility of the wage rate to the unemployment rate. The parameter $1/\beta$ can be interpreted as a wage flexibility parameter. When $\beta = \infty$, the wage rate is totally rigid and unemployment is perfectly flexible. When $\beta = 0$, unemployment is totally rigid (and equal to the benchmark level) and the wage rate is fully flexible. This is the case when there is unemployment but it is fixed and not responsive to the real wage. In the in-between cases, $0 < \beta < \infty$, as β increases the sensibility of the wage rate to the unemployment rate decreases.

2.4 Savings and Investment

Given the static character of the models, investment and savings should be seen as the closure variables needed to complete the circular flow of income. Private savings by consumers, SAV_{priv} , are identified with their demand for future consumption and its value is

therefore determined within the utility maximization problem. Add to private savings the savings of the public sector, SAV_{pub} , and the foreign sectors, SAV_{ext} to have total savings in the economy. This global level of savings determines in turn the level of total investment demand which translates into sectoral investment demand by way of a fixed coefficients activity vector:

$$p_I(\lambda \bar{I}) = SAV_{priv} + SAV_{pub} + SAV_{ext} \quad (18)$$

where p_I is a price index for the investment goods, \bar{I} is benchmark investment, λ is the investment level (1 in the benchmark) and where $SAV_{pub} = D$ and $SAV_{ext} = \text{Imports} - \text{Exports}$.

2.5 The External Sector

Demand for imports are obtained from the Armington stage of the production function. Once the Armington cost function is determined, an application of Shepard's lemma yields all import demand functions. World import prices are given in the world market and are taken as given by domestic producers in their cost minimization problems. The Armington substitution elasticity implicitly assumes that domestic and foreign goods are imperfect substitutes. Despite the fact that domestic prices p and world prices p^m may, and in general will, be different, there is sufficient product differentiation perceived by domestic producers among domestic and imported goods so that there is a positive import demand even when domestic prices are lower than world prices.

The level of exports is assumed to be given reflecting an external decision process on how much foreign exchange to allocate to purchase our domestic goods. The composition of exports is variable, however, being sensitive to relative prices between domestic and world commodities. Export prices are set by domestic prices and we again assume enough

perceived product differentiation for exports to have a positive demand even when export prices are higher than world prices. These assumptions about imports and exports reflect well the empirical phenomenon of cross hauling and incomplete specialization whereby a given commodity may at the same time being imported and exported.

2.6 Equilibrium

The equilibrium concept is essentially Walrasian, with the above macro touch in the labor market for modeling unemployment. An equilibrium is described by a vector $q^* = (p^*, w^*, r^*)$ of prices for domestic goods and factors, a vector of gross production outputs Y^* , a level λ^* of gross capital formation, a level of the public deficit D^* , a level of tax collections TAX^* , and an unemployment rate u^* such that:

i) Markets for goods clear: total output available for each good covers intermediate demand by firms, AY^* , domestic demand for private consumption C^* , domestic demand (private and public) for gross capital formation I_{λ^*} , public consumption C_G^* , and the trade balance between exports E^* and imports M^* :

$$Y^* = AY^* + C^* + I_{\lambda^*} + C_G^* + E^* - M^* \quad (19)$$

ii) Markets for factors clear: All of the endowment is capital is demanded at the equilibrium price q^* and allocation Y^* :

$$\bar{K} = K^D(q^*, Y^*) \quad (20)$$

On the other hand, because of the presence of unemployment, only a fraction of the labor endowment is actually demanded in equilibrium:

$$\bar{L} \cdot (1 - u^*) = L^D(q^*, Y^*) \quad (21)$$

In the expressions above K^D and L^D stand for conditional factors' demand.

iii) Total tax collections coincide with total tax payments from all sources by all agents:

$$TAX^* = TR(q^*, Y^*) \quad (22)$$

iv) Total investment equals savings by all agents:

$$I_{\lambda^*} \equiv p_I^*(\lambda^* \bar{I}) = SAV_{priv} + SAV_{pub} + SAV_{ext} \quad (23)$$

with

$$SAV_{priv} = p_f^* C_f^*$$

$$SAV_{pub} = TAX^* - C_G^* - I_G^* - ST$$

$$SAV_{ext} = M^* - E^*$$

v) Because of the constant-returns-to-scale assumption, final prices satisfy the average cost rule.

3. Data and Calibration

The CGE model is implemented using a regional Social Accounting Matrix of Catalonia for 1994. Implementation proceeds through the method of calibration whereby tax rates and structural parameters are selected in such a way that the compiled database satisfies all the conditions to be a competitive equilibrium (referred to as initial or benchmark equilibrium). Calibration is a deterministic procedure that uses the restrictions derived from the first order condition of consumer's and firms' optimization problems to select behavioral parameters consistent with the empirically observed database. Given the typical number of parameters needed to implement this type of models, econometric determination of coefficients is usually unfeasible. However, some parameters can be econometrically obtained, either directly or through literature search, and their values adopted. In this case, calibration requires to adjust the remaining coefficient specification of a production or utility function to the exogenously adopted parameter value. There are three categories of parameters in the model. First, tax parameters that represent the structure of the current tax system; tax rates are calibrated to be percentage effective rates that when applied to tax bases yield observed tax collections for each tax category. Any tax fraud or tax evasion is therefore reflected in these average effective rates. Second, extraneous parameter values for specific functional forms; this is the case of the labor market elasticity or the Armington substitution elasticities. Finally, we have structural consumption and production parameters such as share and scale parameters and average propensities. As a simple example of what is essentially involved in the calibration procedure, we show in what follows how to calibrate a CES production function.

Let us consider an output Y which is obtained combining two inputs X_1 and X_2 according to the CES function:

$$Y = \theta [(a_1 X_1)^\rho + (a_2 X_2)^\rho]^{\frac{1}{\rho}} \quad (24)$$

where θ is a scale parameter, a_j is a productivity parameter and ρ is a substitution parameter related to the elasticity of substitution σ (with $\sigma = 1/(1 - \rho)$).

From the cost minimization problem, the CES cost function takes the form:

$$C(Y) = \theta^{-1} \left[\left(\frac{w_1}{a_1} \right) + \left(\frac{w_2}{a_2} \right)^\gamma \right]^{\frac{1}{\gamma}} Y \quad (25)$$

where $\gamma = \rho/(\rho - 1)$, and so $\gamma = 1 - \sigma$, and where w_j is the market price of input j . As a matter of fact, the scale parameter θ can be omitted altogether from the calibration procedure. The CES function can be written as:

$$Y = [(\theta a_1 X_1)^\rho + (\theta a_2 X_2)^\rho]^{\frac{1}{\rho}} \quad (26)$$

Therefore by making $\theta a_j = \beta_j$ in (26), or directly taking $\theta = 1$, we can simplify and without loss of generality we can write:

$$Y = [(a_1 X_1)^\rho + (a_2 X_2)^\rho]^{\frac{1}{\rho}} \quad (27)$$

with the cost function now being:

$$C(Y) = \left[\left(\frac{w_1}{a_1} \right)^\gamma + \left(\frac{w_2}{a_2} \right)^\gamma \right]^{\frac{1}{\gamma}} Y \quad (28)$$

If desired, however, the scale parameter θ can be made explicit once the modified productivity parameters are known. Given the substitution elasticity σ , the calibration problem consists in determining the productivity parameters a_j which are consistent with the given elasticity and the observed data in the SAM. From the cost function (28) we use Shepard's lemma to obtain the conditional demand functions for inputs. For input j we would find:

$$\frac{\partial C(Y)}{\partial w_j} = X_j = \frac{1}{\gamma} \left[\left(\frac{w_1}{a_1} \right)^\gamma + \left(\frac{w_2}{a_2} \right)^\gamma \right]^{\frac{1}{\gamma}-1} \gamma \left(\frac{w_j}{a_j} \right)^{\gamma-1} \frac{1}{a_j} Y \quad (29)$$

Using (28) and homogeneity we obtain:

$$C(1)^{-\gamma} = \left[\left(\frac{w_1}{a_1} \right)^\gamma + \left(\frac{w_2}{a_2} \right)^\gamma \right]^{-1} \quad (30)$$

Combining with (29) we can write:

$$a_j^\gamma = \frac{C(Y)}{X_j} w_j^{\gamma-1} C(1)^{-\gamma} \quad (31)$$

By an appropriate selection of units (31) reduces to:

$$a_j = \left(\frac{Y}{X_j} \right)^{\frac{1}{\gamma}} = \left(\frac{\sum_{i=1}^2 X_i}{X_j} \right)^{\frac{1}{\gamma}} \quad (32)$$

Since we know γ (from the substitution elasticity σ) and X_j (from the SAM database) we have all of the ingredients to determine the calibrated productivity parameters a_j .

The remaining parameters are obtained as follows. The Cobb-Douglas utility coefficients are derived from the consumption and savings expenditure shares reported in the SAM. The initial input-output technical coefficients are obtained as average cost propensities from registered intermediate data flows in the SAM. For the input-output non-energy submatrix they remain fixed throughout whereas energy coefficients are responsive to energy prices and are derived from CES cost functions using the derivative property as explained above. The sensitivity β of the real wage to the unemployment rate is taken from the estimates of Andrés et al. [1990] for the Spanish economy and adopted as the regional value. There are no available region specific estimates for the Armington substitution elasticities. Welsch [2001], however, estimates Armington elasticities for four countries in the European Union (Germany, France, Italy and Great Britain). We take average elasticities from this study as our initial values. There is good enough evidence that the value-added substitution elasticity takes a value less than unitary as the review in Ballard et al. [1985] and more recently Chirinko [2002] point out. Since there does not seem to be reliable estimates of the elasticity of substitution among energy inputs we will adopt a range of values. The reference value is taken to be the average substitution between domestic and foreign energy inputs in Welsch [2001] a value which is probably slightly lower than the in-country elasticity. Given the start-up set of parameters, we proceed to conduct sensitivity analysis to appraise the role of increased substitution possibilities on CO₂ emissions and welfare indicators.

Emissions coefficients for carbon dioxide have been obtained from estimates calculated by the Department of the Environment of the regional government. Since the original coefficients are expressed in physical units they need to be converted into model-ready units. These are in turn adjusted so that activity levels in the original

equilibrium reproduce total estimated non-transgenic emissions in the region. With the use of these reformulated coefficients we can link observed economic activity levels with estimated CO₂ emissions. We distinguish emissions that originate in production activities from the use of energy polluting inputs and emissions that originate from domestic final demand.

4. Simulations

We consider the adoption of an indirect output tax on energy goods along with an increase in the current excise tax on petrol. Two tax bundles are considered. The first one contemplates a new 10 percent tax on energy goods plus a 15 percent increase in the petrol tax rate. The second bundle just doubles these rates to 20 and 30 percent, respectively. In both cases payroll taxes are reduced to keep total tax collections at the initial level. Thus the income size of the government is kept constant. The spending size of the government is also kept fixed as far as demand for public consumption is concerned. Its value depends, however, on endogenous prices. Similarly non-employment related social transfers are fixed in quantity but adjusted in value using a consumers price index. Transfers to compensate for unemployment are indexed to unemployment levels. Any change in the public deficit is therefore due to endogenous adjustments to unemployment and value indexing adjustments. The first simulation is a reference no-frills scenario where no substitution is allowed on the production side. This particular version of the CGE model can therefore be seen as a hybrid Leontief-Walras model. On the one hand, all production coefficients are fixed and not let to be price responsive—this is the Leontief side; on the other hand, each market has a well defined demand and supply function and the full circular flow of income is accounted for—this is the Walras side. In this version, all adjustments induced by the new tax policy on the production side of the economy take place through prices. We then proceed to relax stepwise the non-substitution conditions, rerun the simulations and compare the new results

with the no-frills simulation. A summary of the numerical results is presented in Tables 1-3. More detailed results and graphics are relegated to an appendix. Table 1 compares the initial run with four simulations that used reference substitution elasticities all under the first energy tax bundle. Table 2 does the same with the second energy tax policy. Finally, Table 3 retakes the first tax package under a new scenario regarding substitution possibilities. Now all positive substitution elasticities are doubled allowing for flatter isoquants and higher adaptive response to energy tax induced changing relative prices.

Table 1 shows that as far as efficiency is concern the substitution elasticity between labor and capital is the most critical parameter. Only when labor and capital are substitute inputs a welfare improvement, an unemployment fall and a carbon dioxide emissions reduction is observed—a “triple” dividend situation. In all the other cases, the new energy tax policy exacerbates preexisting tax distortions. In all scenarios the increased cost of energy goods leads to reductions in emissions that reflect firms and consumers choosing less energy intensive goods.

The effects on emissions seem to be more stable on the final demand side than in the production side but this could be due to the specific consumption formulation adopted. As expected, production associated emissions see the most reduction when energy inputs substitution is allowed. In this case firms can take advantage of lower isoquant curvatures to select less costly and less energy intensive energy bundles. When the tax rates are doubled, results are less than doubled (Table 2) in emissions reductions suggesting that tax policies may enter some decreasing returns interval. Interestingly enough, welfare losses more than double when we double tax rates whereas welfare gains, when they occur, do not increase as fast as tax rates do. This reflects the nonlinear nature of the CGE model that we use.

When positive elasticities are doubled (Table 3), again primary factors substitution yields the only welfare improvement which is more than double than that reported in Table 1.

The green dividend, however, is now lower than before and even CO₂ production emissions increase due to the increased production levels. In this case the output effects (real GDP would increase over 1 percent point and unemployment would decrease about 3 percent points) dominates the energy substitution effects. The efficiency effects in the other cases do not show marked changes. A higher Armington elasticity tends to reduce welfare losses whereas a higher energy inputs substitution tends to increase it but in both cases the actual figures are quite small and very close to those of Table 1. The effect on emissions is, however, more noticeable, mainly on production emissions and quite more marked when energy elasticities are doubled than when Armington elasticities are. The last columns in all three tables show the simulation results when all substitution elasticities are simultaneously considered. These simulations reflect results for the reference set of parameters under the two tax policies (tables 1 and 2) and to the initial tax package under two substitution structures (tables 1 and 3). In all three cases an efficiency and an employment dividend is observed, along with the expected reduction in emissions. It is interesting to notice that the doubling of the energy tax rates, and the corresponding revenue neutral reduction in the payroll tax rates, gives rise to a positive stimulus in both employment and welfare. On efficiency grounds alone, this observation suggests that the distorting impact of the payroll tax in Spain has not been fully assessed by fiscal policy makers. The tax gradient indicates that additional welfare improvements ensuing further revenue neutral tax swaps may be possible. Furthermore, these welfare improvements could even be fostered under a more flexible substitution structure between labor and capital with only a very small penalty in terms of demand emissions which, on the other hand, are more than compensated by larger reductions in production emissions that overall yield larger reductions in carbon dioxide (from 3.489 percent in table 1 to 3.845 percent in table 3).

Table 1: 10% carbon tax + 15% increase in petrol tax	No substitution	Armington substitution	Primary Factors substitution	Energy inputs substitution	All substitution allowed
Unemployment % (base=21.20)	21,11	21,07	20,00	21,13	20,04
Real GDP (base=100)	99,85	99,85	100,56	99,83	100,25
Equivalent Variation/GDP %	-0,365	-0,354	0,375	-0,383	0,326
% Increase Production emissions	-1,202	-1,429	-0,482	-1,938	-1,489
% Increase Demand emissions	-16,505	-16,498	-15,720	-16,516	-15,770
% Increase Total emissions	-3,345	-3,540	-2,616	-3,980	-3,489

Table 2: 20% carbon tax + 30% increase in petrol tax	No substitution	Armington substitution	Primary Factors substitution	Energy inputs substitution	All substitution allowed
Unemployment % (base=21.20)	21,06	20,97	18,98	21,09	19,07
Real GDP (base=100)	98,70	99,54	100,85	98,66	100,16
Equivalent Variation/GDP %	-0,804	-0,782	0,576	-0,842	0,466
% Increase Production emissions	-2,230	-2,675	-0,915	-3,656	-2,879
% Increase Demand emissions	-29,741	-29,695	-28,479	-29,747	-28,541
% Increase Total emissions	-6,083	-6,460	-4,779	-7,310	-6,474

Table 3: 10% carbon tax + 15% increase in petrol tax + double substitution	No substitution	Armington substitution	Primary Factors substitution	Energy inputs substitution	All substitution allowed
Unemployment % (base=21.20)	21,11	21,02	19,09	21,15	19,26
Real GDP (base=100)	99,85	99,86	101,16	99,81	100,82
Equivalent Variation/GDP %	-0,365	-0,342	0,990	-0,402	0,820
% Increase Production emissions	-1,202	-1,678	0,111	-2,669	-1,987
% Increase Demand emissions	-16,505	-16,491	-15,073	-16,528	-15,247
% Increase Total emissions	-3,345	-3,753	-2,016	-4,610	-3,845

5. Concluding remarks

The present analysis makes a case for tax energy policies as an effective mechanism to promote efficiency gains and a better environment as measured by reduced carbon dioxide emissions. These policies involve a tax substitution whereby the new taxes are compensated with revenue neutral reductions of the payroll tax. The income size of the government is therefore kept constant to avoid mixing the results with those that could be due to size effects. Results have been tested for sensitivity under different substitution elasticity configurations. We find that the elasticity of substitution between labor and capital is the most critical parameter for achieving both efficiency gains and emissions reductions but at a cost. Indeed, emissions reductions fall when compared to the initial no frills simulation. Increased substitution among energy inputs promotes greater carbon dioxide reductions than increased Armington substitution vis a vis the no frills simulation. Since in both of these cases the induced tax distortion cost is very close to that of the initial simulation, we conclude that higher technological substitution possibilities would work to enhance the environmental beneficial impact of the energy tax policies. How to implement more flexible substitution possibilities is however another matter altogether. The Armington elasticity depends, for instance, on the degree of openness of the economy to foreign trade. More fluid substitution between labor and capital in a considerably regulated labor market, as the Spanish labor market is, may be easier said than done due to its built-in socioeconomic rigidity. As for energy inputs substitution, a distinction should be made between short run and long run substitution since alternate feasible access to some less polluting energy sources, like hydroelectric or nuclear power, may require a considerable investment effort.

The analysis shows, on the positive side, that under a plausible structure of the elasticities of substitution in production, revenue neutral tax policies may work in reducing

inefficiencies and CO₂ emissions when interdependency and general equilibrium effects are taken into account in a microconsistent way.

5. References

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Appendix

Base tax policy + Scaling of Armington elasticities				
Elasticity Scale	% Reduction in production emissions	% Reduction in demand emissions	Welfare Loss over GDP	Unemployment rate
0,00	1,2016	16,5045	-0,3648	21,11
0,25	1,2586	16,5030	-0,3620	21,10
0,50	1,3155	16,5015	-0,3591	21,09
0,75	1,3724	16,4999	-0,3563	21,08
1,00	1,4291	16,4983	-0,3535	21,07
1,25	1,4903	16,4965	-0,3505	21,06
1,50	1,5582	16,4945	-0,3473	21,04
1,75	1,5989	16,4933	-0,3454	21,04
2,00	1,6779	16,4909	-0,3417	21,02

Base Tax Policy + Value-added substitution elasticity				
Elasticity	% Reduction in production emissions	% Reduction in demand emissions	Welfare Loss over GDP	Unemployment rate
0,00	1,2016	16,5045	-0,3648	21,11
0,25	0,9459	16,2263	-0,1027	20,72
0,50	0,7063	15,9652	0,1438	20,35
0,75	0,4818	15,7203	0,3553	20,00
1,00	0,3165	15,5399	0,5461	19,75
1,25	0,0740	15,2751	0,7973	19,37
1,50	-0,1113	15,0725	0,9896	19,09
1,75	-0,2855	14,8819	1,1708	18,82
2,00	-0,4495	14,7023	1,3417	18,57

Base Tax Policy + Energy substitution elasticity				
Elasticity	% Reduction in production emissions	% Reduction in demand emissions	Welfare Loss over GDP	Unemployment rate
0,00	1,2016	16,5045	-0,3648	21,11
0,25	1,9378	16,5162	-0,3832	21,13
0,50	2,6685	16,5279	-0,4015	21,15
0,75	3,3938	16,5395	-0,4197	21,16
1,00	4,1201	16,5510	-0,4380	21,18
1,25	4,8279	16,5626	-0,4557	21,19
1,50	5,5364	16,5741	-0,4735	21,21
1,75	6,2404	16,5856	-0,4912	21,23
2,00	6,9385	16,5970	-0,5087	21,24