Maria Llop (Spain), Laia Pié (Spain)

Capturing the multisectorial effects of environmental policies: a linear price model for Catalonia

Abstract

The aim of this paper is to evaluate the economic impact of implementing different policies that would make it possible to reduce CO_2 equivalent emissions in Catalonia. Specifically, the authors analyze the effects of a tax on both intermediate consumption and final consumption, a tax on intermediate consumption, a tax on final consumption, and a tax on total production. The model used is a price version of the social accounting matrix (SAM) modelization that shows the cost impacts and the price mechanisms of the different simulations analyzed. The empirical application is for the Catalan economy and uses economic and environmental data for the year of 2001. The best policy analyzed, both for the environment and for society in general, is the third scenario, consisting of the application of a tax on final consumption. This is a measure which combines a considerable degree of price stability, a significant reduction in CO_2 equivalent emissions, and also reduces private real income in a small value compared with the other policies analyzed.

Keywords: SAM price model, CO_2 equivalent emissions, environmental policies.
JEL Classification: C67, C69, Q53, Q59.

Introduction

Modern societies have for years been characterized by the general thought that a high level of welfare should be compatible with a high level of environmental protection, and that it should be possible to sustain the demand for natural resources and at the same time absorb pollution and the negative impacts on the capacities of the planet. The economic model currently in force in the industrialized countries, combined with the increasing population of the developing countries and the population's desire to attain a higher level of welfare, has frequently led to an inappropriate consumption of natural resources, causing serious problems for the environment. With regard to all of these questions, the principal problem we now have to face is that of climate change.

Finding a solution to mitigate the effects of climate change requires many different strategies, both in the medium term and in the long term, in a sustained way and in accordance with the requirements of each sector of activity, since finding appropriate solutions and putting them into practice is a very complicated task. Very few of the solutions proposed so far have prospered, with the result that the consequences of the problem are sometimes underestimated or that the problem is pushed into the background by other subjects that come under the media spotlight, such as the economic crisis.

If we do not find an effective remedy to the problem, the consequences may be very negative for humanity. It is, therefore, of vital importance to conceive viable policies and measures to react to the situation within an appropriate time-frame and to view them as a continuous interactive process. Only if we manage to put in place effective policies to reduce greenhouse emissions we will be able to improve the quality of the air and quality of life in general. What is more, such policies would enable us to save energy and to improve the quality and reliability of our infrastructures, and also to give companies a higher degree of competitiveness and a greater potential to export goods and services with a high technological content, without inflicting so much damage on the natural environment.

In the 2008-2012 period, the European Union (EU) has to reduce the aforementioned emissions by 8%. It was agreed that Spain would not increase greenhouse gas emissions beyond 15%. In Catalonia, in accordance with the Catalan Convention for Climatic Change, a reduction of 5.33 million tons of greenhouse gas emissions has been planned for the 2008-2012 period (Department of the Environment, 2008).

At the end of 2008, the European Union signed a climate change agreement and pledged to reduce the Union's greenhouse gas emissions by 20% before 2020[1]. Moreover, this agreement also stipulated that 20% of the energy used had to come from renewable sources, and that energy efficiency had to be improved by 20%[2]. In the case of Spain, 20% of the energy consumed will have to come from renewable sources by 2020 (8.7% in 2005). Moreover, 10% of emissions will have to be reduced in sectors not covered by the Emission Trading Scheme in relation

[1] Each country has "its" compulsory national objective established in relation to their emission levels in 2005. Central European countries, still in the economic recovery stage, may increase their emissions, but with certain restrictions. The wealthy EU countries, in contrast, will have to reduce their emissions. No country may reduce its emissions by more than 20%, nor increase them by more than 25%.

[2] The EU also established a specific objective for bio fuels, which should represent at least 10% of the total fuel and diesel oil consumption in transport.

to levels in 2005 (reference year). Sectors covered by the ETS must reduce their emissions by 21% in 2020, also taking 2005 as the reference year.

In the Stern Review (2006), one of the basic elements proposed to control greenhouse gas emissions efficiently, and which currently involves less sacrifice, is to set a price on carbon by means of taxes, trade or regulation. Secondly, the Review proposes promoting technology policies, support for innovation and the deployment of low carbon technologies have been considered. And finally, it proposes that barriers to technological change can be eliminated in order to adopt clean technologies, promote energy efficiency and make people aware of possibilities for action in the face of climate change.

If we analyze the theoretical literature on public economy, where the environment is considered to be public property, and pollution a negative externality, we find the double dividend hypothesis put forth by David Pearce in 1991. The main idea of this hypothesis is to improve the environment by means of pollution taxes that reduce polluting emissions and, at the same time, improve the tax system in the form of greater private welfare, hence, the name "double dividend"[1]. The double dividend hypothesis consists, therefore, of exploring under which conditions we would have improvements in tax efficiency and in the environment. The hypothesis of the double dividend has generated substantial literature in both the theoretical and empirical fields. Some surveys on this literature can be found in works by Goulder (1995), Bovenberg (1999), Bosello, Carraro and Galeotti (2001), Gago, Labandeira and Rodríguez (2004), Schöb (2005) and Manresa and Sancho (2007).

There are several studies that use computable general equilibrium models to assess the impact of different environmental policies. One of the first studies is the one by Bovenberg and De Mooij (1994) and was followed by many others with similar analytical aims, such as Goulder (1992) for the USA, Böhringer, Pahlke and Rutherford (1997) for Germany, and Pireddu and Dufournand (1996) for Italy. At the Spanish level, Labandeira and Rodríguez (2004) studied the impact of an environmental tax on carbon dioxide emissions. Faehn et al. (2009) analyzed aspects of fiscality and environment using a general equilibrium model with imperfect competition. Manresa and Sancho (2007) analyzed the impact of recycling ecotaxes towards lower labor taxes in Spain. At the regional level, André et. al. (2005) and González and Dellink (2006) assessed the impact of an environmental tax reform on the economies of Andalusia and the Basque Country, respectively.

In this paper, we use a linear multisectorial model based on a social accounting matrix (SAM) to analyze the economic impact on Catalonia of the implementation of policies that would reduce CO_2 emissions. The model used is a price version of the SAM modelization that shows the cost impacts and the price mechanisms of the different simulations analyzed.

In recent years, SAMs have become extremely useful tools for the economic analysis. SAM models have mostly been used to examine the process of income generation through circular flow of income. This kind of approach involves quantity-oriented models and measures the changes in the income levels of the endogenous accounts caused by exogenous inflows received[2]. However, a social accounting matrix can also involve cost transmission models that capture the responses of the endogenous prices to the exogenous shocks received. Essentially, the SAM price model is an extension of Leontief's traditional approach, endogenously defining production prices and those of other endogenous components, such as production factors and consumers.

Surprisingly, in what we know, there are only two papers that apply the price methodology to a SAM database. One is realized by Roland-Holst and Sancho (1995) in which it was developed and intersectorial price model using a SAM that captures the interdependence among activities, households, and factors and provides a complete set of accounting prices. The other article was realized by Llop (2011), where the author presented a multisectorial model of prices based on the SAM framework. The aim was to focus on establishing the role of the price of capital in the cost transmission process and the price formation mechanism.

If we focus on the literature of atmospheric pollution and environmental regulations, there are few papers that the use input-output price model applied to environmental issues. Llop (2008) used a price model to analyze the economic impacts of alternative water policies on the Spanish production system. Llop and Pié (2008) proposed an input-output price model to analyze the economic effects on the Catalan economy caused by alternative policies implemented on the energy activities of the regional production system. More recently, Hong-Tao Liu et al. (2009) used the input-output price model to evaluate how alternative energy policies impact on Chinese production prices, consumption prices, and real income of rural and urban households through the mechanism of indirect energy consumption.

The model used in this paper illustrates different economic impacts on regional variables of alternative

[1] See, for example, Manresa and Sancho (2007) and Rodríguez (2002).

[2] See Stone (1978) or Pyatt and Round (1979) for an analysis of the SAM quantity models.

policy measures that can reduce greenhouse emissions. In fact, policy makers have a set of possible economic and environmental policies that may help to comply with the 20%-20%-20% plan signed by the European Union in 2008. Taking into account this interesting direction of the European environmental policy, the present paper is an intent of simulate some aspects that can be in line with the European directives.

The rest of the paper is organized as follows. Section 1 describes the SAM price model. Section 2 shows the empirical results of the different simulations for Catalonia. The paper ends with a conclusion Section.

1. The SAM price model

1.1. Definition. The SAM price model, like the quantity approach, is based on the accounting identities reflected in a social accounting matrix. A SAM contains all the economic transactions and monetary flows between economic agents during a period of time, generally a year[1]. It presents the accounts in rows and columns in a square matrix. Each cell simultaneously represents the monetary income (in rows) and the payments or expenditure (in columns) of agents and institutions. The equilibrium between income and expenditure means that the total value of each row must be the same as the total value of the corresponding column. Economically, this implies that total saving is the same as total investment, that expenditure is the same as income, and that demand is the same as supply.

Table 1. Simple structure of a SAM

	Production	Factors	Households	Rest	Total
Production	T_{11}	0	T_{13}	T_{14}	Y_1
Factors	T_{21}	0	0	T_{24}	Y_2
Households	0	T_{32}	T_{33}	T_{34}	Y_3
Rest	T_{41}	T_{42}	T_{43}	T_{44}	Y_4
Total	Y_1	Y_2	Y_3	Y_4	

Source: Roland-Holst and Sancho (1995).

Table 1 presents a simplified representation of a SAM with four classes or groups of accounts, namely, production, factors, households, and a consolidated account of the remaining sectors (government, capital and foreign agents' accounts). In the first row of Table 1, matrix T_{11} contains the intermediate transactions, matrix T_{13} contains households' sectorial consumption and matrix T_{14} contains the other destinations of production (exports, public expenditure and sectorial investment). Matrix T_{21} contains the sectorial value added and matrix T_{24} shows factorial income from abroad and the public transfers to factors. Matrix T_{32} contains the factorial income of consumers, matrix T_{33} contains the transactions between consumers and matrix T_{34} shows the private income from abroad. Finally, the last row shows the transactions corresponding to the rest of the accounts (the government, capital and the foreign agent).

To transform the structure in Table 1 into a price model, we assume that income and payments structure is constant. In addition, we divide the SAM accounts into endogenous and exogenous accounts, using the same criteria that in Roland-Holst and Sancho (1995), which consisted of endogenously incorporating the accounts of the productive activities, factors of production (capital and labour) and households.

Let A_{ij} denote the matrix of normalized column coefficients, calculated by dividing the transaction in the SAM by the corresponding column sum (Y_i), and let p_i denote a price index for group i's activity. Reading down the columns of the SAM, we obtain the SAM price model:

$$\begin{aligned} p_1 &= p_1 A_{11} + p_2 A_{21} + \overline{p}_4 A_{41}, \\ p_2 &= p_3 A_{32} + \overline{p}_4 A_{42}, \\ p_3 &= p_1 A_{13} + p_3 A_{33} + \overline{p}_4 A_{43}. \end{aligned} \tag{1}$$

So, matrix A of structural coefficients has the following structure:

$$A = \begin{bmatrix} A_{11} & 0 & A_{13} \\ A_{21} & 0 & 0 \\ 0 & A_{32} & A_{33} \end{bmatrix}.$$

Let $p = (p_1, p_2, p_3)$ be the row vector of prices for the endogenous accounts of the SAM. We can also define exogenous costs (i.e., factor payments, taxes, import costs) with the equation:

$$v = \overline{p}_4 A_4, \tag{2}$$

where A_4 is the submatrix of the SAM composed by A_{41}, A_{42}, and A_{43}, with the equation:

$$A_4 = \begin{bmatrix} A_{41} & A_{42} & A_{43} \end{bmatrix}.$$

If we transform equation (1) to matrix notation:

$$p = pA + v = v(I - A)^{-1} = vM, \tag{3}$$

[1] See, for example, Pyatt (1988).

where v is a row vector of exogenous costs and $M = (I-A)^{-1}$ is the matrix of SAM price multipliers.

For an identical classification of the exogenous and endogenous components, it is important to know that M is also the multiplier matrix in the quantity model:

$$Y = AY + x = \left(I - A\right)^{-1} x = Mx. \quad (4)$$

However, according to the model we chose, matrix M is interpreted in one or another way. In the SAM price model it is interpreted through the columns; in the quantity model it can be interpreted through the rows.

1.2. Emissions and environmental policies. The SAM model can be extended to account for the environmental pollution associated with production and consumption activities, which are considered endogenous in the definition of the model. This extension integrates the economic and ecological relations that take place in environmental pollution and is a useful instrument of environmental analysis.

Let B be the matrix of greenhouse gas emissions per unit of endogenous income. In this matrix, each element (b_{kj}) is the amount of gas type k (in physical units) per monetary unit of endogenous income in account j. That is:

$$B = E(\hat{Y})^{-1}, \quad (5)$$

where E is a matrix of total greenhouse emissions made by the endogenous accounts of the model (i.e., activities of production, factors and consumers)[1], and $\hat{Y}$ is the diagonal matrix of the elements of vector Y of endogenous income. Following equation (5), we can obtain the amount of pollutant emissions as:

$$E = B\hat{Y}, \quad (6)$$

which means that there is a linear and fixed relation between emissions and endogenous income.

To calculate the new level of emissions in the simulations, we can assume that in each endogenous account the monetary value of endogenous income is kept constant. That is:

$$p\hat{Y} = p^S \hat{Y}^S, \quad (7)$$

where p is the row vector of benchmark prices and $\hat{Y}$ is the diagonal matrix of the value of endogenous income in the benchmark. Similarly, p^s is the row vector of prices in the simulations and $\hat{Y}^S$ is the diagonal matrix of the value of endogenous income in the simulations. Taking into account that the benchmark prices are unitary, we can obtain the vector of new endogenous income as follows:

$$Y^S = (p^S)^{-1}\hat{Y}. \quad (8)$$

The new emissions associated to the simulations (E^s) are calculated through the combination of equations (6) and (8):

$$E^S = B\hat{Y}^S. \quad (9)$$

The simulation analysis involves alternative interventions to reduce the pollutant emissions of the economy. All the policies implemented are defined in accordance to the relative importance of the emissions caused by each economic agent. That is, the level of taxation will be applied in relation to the emissions of each account. To accomplish with this objective, we define the row vector g of dimension $(1\times j)$ that shows the relative index of emissions in each endogenous account as follows:

$$g = \frac{e'E}{e'E\bar{e}}, \quad (10)$$

where e' is a unitary row vector with dimension $(1\times k)$, E is the matrix of sectorial emissions of pollutants and $\bar{e}$ is a unitary column vector of dimension $(j\times 1)$[2].

The simulations are applied individually according to the sectorial relative contribution to emissions by sectors and consumers[3]. That is, the level of taxation is defined in a row vector t $(1\times j)$, calculated as follows:

$$t = \tau g, \quad (11)$$

where τ is a scalar that shows the level of taxation established. Depending on the simulation, t will be an intermediate tax or a final production tax.

The definition of measures that affect the individual agents differently seems to be more efficient than a general intervention that affects agents equally. If agents exert different damages to environment, it is necessary to treat them individually to accomplish the environmental objectives with the minimum negative effects on economic activity.

1.3. Private real income and public revenues. We can also obtain an approximation of the influence that

[1] In this paper, we have rescaled all the gas emissions to show tonnes of CO_2 equivalent.

[2] Note that the calculation of g involves the addition of all the gas emissions of each endogenous account through the product $e'E$. This addition is possible because all the gas emissions are measured in tonnes of CO_2 equivalent.

[3] The SAMEA for the Catalan economy shows emissions for both sectors of production and private agents.

each setting exerts on the consumers' real income. In particular, the changes in private real income (ΔI) are calculated using the following expression:

$$\Delta I = \sum_{j=1}^{27} p_j C_j - \sum_{j=1}^{27} p^S{}_j C_j = \sum_{j=1}^{27} \left(p_j - p^S{}_j\right) C_j, \quad (12)$$

where j = 1, 2,..., 27 are the sectors of production, $p^S{}_j$ is the price of good j after the simulations, p_j is the price of j in the benchmark, and C_j is the consumption of j in the benchmark. A positive difference represents a better situation in terms of consumer real income, and a negative difference represents a worse situation. This comparison gives us an estimation of the variations in real income of the consumers after the different simulations[1].

When a tax on sectorial production is applied, public revenues (R) are calculated as:

$$R = \sum_{j=1}^{27} \tau g P_j Y_j = \sum_{j=1}^{27} t P_j Y_j. \quad (13)$$

If the tax is defined on final consumption, public revenues are equal to:

$$R = \sum_{j=1}^{27} \tau g P_j C_j = \sum_{j=1}^{27} t P_j C_j. \quad (14)$$

Finally, the tax on intermediate consumption gives the following revenues:

$$R = \sum_{i=1}^{27} \tau g P_i T_{ij} = \sum_{i=1}^{27} t P_i T_{ij}. \quad (15)$$

2. Empirical results

In the empirical application, we used a national accounting matrix with environmental accounts (NAMEA) for the Catalan economy with 2001 data. A NAMEA contains the information reflected in a SAM and its links to the environment, that is, it includes both economic and environmental information of an economy. A SAM does not include environmental variables such as polluting emissions, waters or soil, and hazardous waste, the use of natural resources, or environmental quality. A NAMEA extends the SAM framework with environmental information in order to describe how economic activities affect the environment.

Our database is applied to atmospheric emissions and it is constructed by adding columns related to the greenhouse gases. The information in the account on atmospheric emissions includes the discharges of pollutants generated by sectors and consumption. This database originally included the emissions of ten pollutants. In this paper, we used only the four emissions that show greenhouse pollution in the regional economy. The four gases we analyzed are those that must follow the guidelines of the Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), nitrogen monoxide (N_2O) and sulphur hexafluoride (SF_6). The original units of these four emissions have been rescaled so they are all expressed in the same units, which are carbon dioxide equivalents (CO_2 eq.).

2.1. The relative emissions. Table 2 shows the relative index of emissions for each endogenous account, following expression (10) of the model. This calculation enables us to understand the relative importance of each agent in the amount of regional greenhouse pollution.

Households cause the highest contribution to total CO_2 equivalent emissions in Catalonia, since they produce 20.560% of the total greenhouse emissions. Other sectors that also have a significant role are other non-metallic mineral products (sector 11), with 18.439% of the total, and transport and communications (sector 20), with 14.953%. We can also highlight agriculture (sector 1), which produces 12.188% of the total, as well as the energy sectors (sector 3 and sector 4), the chemical sector (sector 9) and the other services, social and personal services (sector 26), which produce 10.440%, 5.368%, 6.067% and 5.319% of total emissions, respectively. Finally, it should be highlighted that the remaining sectors produce quantities which are less than 1% of the total.

Table 2. Relative index of emissions (g)

		(%)
1	Agriculture	12.188%
2	Fishing	0.182%
3	Energy, minerals, coke, petroleum and fuels	10.440%
4	Electrical energy, gas and water	5.368%
5	Food	1.014%
6	Textile	0.567%
7	Manufacture of wood and cork	0.136%
8	Paper	0.733%
9	Chemistry	6.067%
10	Rubber and plastic products	0.261%
11	Other non-metallic mineral products	18.439%
12	Metal	0.992%
13	Machinery	0.160%
14	Electrical equipment, electronics and optics	0.249%
15	Automobiles	0.342%
16	Other industries	0.215%
17	Construction	0.264%
18	Commerce	0.521%
19	Hotel management	0.188%
20	Transport and communications	14.953%
21	Financial intermediation	0.054%
22	Real estate activities, entrepreneurial services	0.384%
23	Public services	0.109%

[1] Changes in consumers' real income is not a "perfect" indicator of consumers' welfare, but it can be used as an approximation to the effects of the new policy scenarios on private agents.

Table 2 (cont.). Relative index of emissions (g)

		(%)
24	Education	0.065%
25	Sanitary, veterinary activities, social services	0.230%
26	Other services, social and personal services	5.319%
27	Homes that employ domestic staff	0.000%
	Labor	0.000%
	Capital	0.000%
	Households	20.560%

The results of Table 2 suggest that air emissions are concentrated in a few sectors of production which, together with households, are responsible of the major part of total pollution. This fact may mean that pollution abatement policies must be individually defined and individually applied to generate a minimum distortion on the economic activity and on the productive system.

2.2. The price effects. The price model assumes that the structure of income and payments is constant. The first decision in the model consists in separating the SAM accounts into endogenous accounts and exogenous accounts. In order to make this distinction, we apply the same criterion used by Roland-Holst and Sancho (1995), i.e., we apply the traditional criterion of the SAM-based quantity model, which consists of endogenously assimilating the accounts of production activities, factors of production (capital and labor) and the private agents of the economy.

In our model, simulations first took the form of the introduction of a 20% tax on intermediate consumption and final consumption. Subsequently, a 20% tax was applied to intermediate consumption. Additionally, we analyzed the introduction of a 20% tax on final consumption. Finally, we calculated the impact of a 20% tax on total production[1]. The values in matrix *M* reflect both the absolute variation and the percentage variation in prices, because the calibration takes all benchmark prices equal to unity.

Table 3 shows the changes in production prices after the various simulations. The first column in Table 3 shows how production prices evolve when we introduce a 20% tax on both intermediate consumption and final consumption. The introduction of this tax leads to a general increase in production prices. The most noteworthy case is that of transport and communications (sector 20), in which prices increase by 1.876%, but in general all the production prices increase. Construction (sector 17) with 1.568%, other non-metallic mineral products (sector 11) with 1.414%, electrical energy, gas and water (sector 4) with 1.364% and commerce (sector 18) with 1.363% are also sensitive to the introduction of the new taxation.

Table 3. Changes in prices (%)

		Situation 1	Situation 2	Situation 3	Situation 4
1	Agriculture	0.726%	0.690%	0.223%	3.972%
2	Fishing	0.475%	0.473%	0.124%	0.636%
3	Energy, minerals, coke, petroleum and fuels	0.760%	0.890%	0.068%	3.577%
4	Electrical energy, gas and water	1.364%	1.488%	0.229%	3.050%
5	Food	1.328%	1.449%	0.221%	1.909%
6	Textile	0.883%	0.875%	0.235%	1.241%
7	Manufacture of wood and cork	0.836%	0.841%	0.209%	1.075%
8	Paper	0.839%	0.810%	0.244%	1.227%
9	Chemistry	1.003%	1.074%	0.188%	2.775%
10	Rubber and plastic products	0.975%	1.002%	0.225%	1.278%
11	Other non-metallic mineral products	1.414%	1.537%	0.242%	6.399%
12	Metal	0.599%	0.562%	0.190%	0.994%
13	Machinery	0.546%	0.505%	0.180%	0.718%
14	Electrical equipment, electronics and optics	0.531%	0.505%	0.162%	0.722%
15	Automobiles	0.691%	0.682%	0.186%	0.944%
16	Other industries	0.832%	0.821%	0.225%	1.088%
17	Construction	1.568%	1.588%	0.384%	2.014%
18	Commerce	1.363%	1.295%	0.418%	1.823%
19	Hotel management	1.154%	1.044%	0.405%	1.482%
20	Transport and communications	1.876%	2.023%	0.337%	6.089%
21	Financial intermediation	0.907%	0.742%	0.396%	1.139%
22	Real estate activities, entrepreneurial services	1.011%	0.886%	0.384%	1.352%
23	Public services	1.058%	0.928%	0.400%	1.340%

[1] We analyze a 20% tax in line with other studies that have simulated similar numerical changes to the benchmark reference equilibrium (for instance, Faehn et al (2009) analyzed the effects of a 25% tax). On the other hand, the qualitative results of our simulations do not change in case of applying other numerical simulations.

24	Education	0.958%	0.729%	0.472%	1.206%
25	Sanitary, veterinary activities, social services	1.060%	0.904%	0.426%	1.375%
26	Other services, social and personal services	1.095%	0.999%	0.377%	2.699%
27	Homes that employ domestic staff	0.860%	0.598%	0.480%	1.069%
	Labor	1.045%	0.727%	0.583%	1.298%
	Capital	1.045%	0.727%	0.583%	1.298%
	Households	1.045%	0.727%	0.583%	1.298%

Notes: Situation 1: Introduction of a 20% tax on intermediate consumption and final consumption. Situation 2: Introduction of a 20% tax on intermediate consumption. Situation 3: Introduction of a 20% tax on final consumption. Situation 4: Introduction of a 20% tax on total production.

In the second simulation, a 20% tax on intermediate consumption is applied. This simulation gives rise to a general increase in production prices, although the increase is slightly smaller than that found in situation 1. Specifically, it can be seen that transport and communications (sector 20) experiences an increase (2.023%) that is larger than that found in the other sectors. In construction (sector 17), however, price increases by 1.588%. Other non-metallic mineral products (sector 11), undergoes a price increase of 1.537%; electrical energy, gas and water (sector 4) of 1.488%; food (sector 5) of 1.449%, and commerce (sector 18) of 1.295%[1].

In the third situation, we apply a 20% tax on final consumption, which also gives rise to a general increase in production prices, although much smaller than that obtained in the other scenarios. In this simulation, factors of production (capital and labor) and households show the highest price increases, with a value of 0.583%. The results are again characterized by a wide range of sectorial variation, and homes that employ domestic staff (sector 27) with a price increase of 0.480%, education (sector 24) with 0.472%, sanitary and veterinary activities; social services (sector 25) with 0.426%, commerce (sector 18) with 0.418%, hotel management (sector 19) with 0.405% and public services (sector 23) with 0.400% are the sectors most affected by the application of a tax on final consumption. Through this simulation we can observe that when a tax is applied to final consumption, the factors of production and the sectors of production that are linked to private consumption are those which are most affected by price changes.

Finally, the fourth simulation shows the effects of a 20% tax on total production. Compared with the other scenarios, this situation gives the largest increase in production prices. The sectors undergoing the biggest increases are other non-metallic mineral products (sector 11) with 6.399%, transport and communications (sector 20) with 6.089%, agriculture (sector 1) with 3.972% and energy products, minerals, coke, petroleum and fuels (sector 3) with 3.577%. By contrast, metal (sector 12) with 0.994%, manufacture of transport material (sector 15) with 0.944%, electrical equipment, electronics and optics (sector 14) with 0.722%, machinery (sector 13) with 0.718%, and fishing (sector 2) with 0.636% are sectors which undergo a lower rate of price increase.

The conclusion that we can draw from Table 3 is that different policies have different effects on regional prices. Depending on where we apply a tax, a larger or smaller increase in prices will be obtained. These empirical results thus show different scenarios which may be used by policy makers to reduce the CO_2 equivalent emissions and, at the same time, improve the environmental efficiency of Catalan production system.

3.3. Effects on emissions, public revenues and private income. We can complete the analysis by calculating some aggregated indicators which will help us to better understand the economic impact of the different scenarios. These indicators are shown in Table 4.

Table 4. Changes in aggregated variables

	Situation 1	Situation 2	Situation 3	Situation 4
Emissions (%)	-8.71%	-1.82%	-7.22%	-5,81%
Emission elasticity index (%)	-8.326%	-2.498%	-12.384%	-4.472%
Public revenue: *R* (thousands of euros)	1,135,316	1,047,394	393,390	2,535,824
Changes in real income: ΔI (thousands of euros)	-1,162,755	-808,802	- 648,445	-1,444,005

Notes: Situation 1: Introduction of a 20% tax on intermediate consumption and final consumption. Situation 2: Introduction of a 20% tax on intermediate consumption. Situation 3: Introduction of a 20% tax on final consumption. Situation 4: Introduction of a 20% tax on total production.

[1] Apart from these sectors, others also experience significant, but smaller, increases. The sectors concerned are hotel management (sector 19), with a price increase of 1.044%, and rubber and plastic products (sector 10) with 1.002%.

We calculated the elasticity of the emissions, since this enables us to observe the changes undergone in the CO_2 equivalent emissions in relation to changes in prices. This indicator appears in Table 4 as the emission elasticity index, and it was calculated as the total percentage variation in CO_2 equivalent emissions divided by the total percentage variation in consumer prices. If we apply a 20% tax on intermediate and final consumption, the emission elasticity is -8.326%. On the other hand, when the tax is limited to intermediate consumption, the emission elasticity is of -2.498%. In the third simulation, the elasticity is -12.384% being the scenario in which there is the greatest degree of sensibility of the CO_2 equivalent emissions to changes in consumption prices. Finally, by applying a 20% tax on total production the elasticity is -4.472%. Thus, the different policy measures analyzed show different sensibility of the emissions to price increases. This is an interesting evidence for policy responsibles, especially if they want to get lower emissions avoiding price inflation.

Meanwhile, the impact on public revenues of applying a 20% tax on intermediate and final consumption is 1,135,316 thousand euros. A 20% tax on intermediate consumption is associated with public revenues of 1,047,394 thousand euros. The scenario of the smallest public revenues is when a 20% tax is applied to final consumption, with 393,390 thousand euros. Finally, a 20% tax on total production of the Catalan economy generates the highest level of public revenues, since the value amounts 2,535,824 thousand euros.

Depending on which policy scenario is chosen, the effects on private real income are very different in quantitative terms. Situation 3 affects less private real income (-648,445) because prices increase in a small percentage. On the other hand, a tax on total production reduces private real income by 1,444,005 thousand euros. This scenario produces the largest negative effect on private welfare given that the price impacts are the largest of all the policies analyzed.

Our results suggest that different measures cause different effects on emissions, public revenues and private real income. The best situation for the environment is the simulation one (a 20% tax on both intermediate consumption and final consumption) as it generates the highest reduction in emissions. However, this situation is not a good policy for the consumers as it causes a significant reduction in private real income. On the other hand, the situation 3 (a 20% tax on final consumption) is a good situation for the environment, for the consumer and, in addition, it generates the lowest inflation.

Conclusions

In this paper we have used a price model, to evaluate the economic impact of implementing different policies that would make it possible to reduce CO_2 equivalent emissions. The SAM price model used is essentially an extension of the traditional approach proposed by Leontief, defining endogenously production prices and the prices of other components such as factors of production and households.

Various simulations were carried out. The first took the form of the introduction of a 20% tax on intermediate consumption and final consumption, leading to an overall increase in prices, which in turn gives rise to a negative effect on private welfare. This is, however, the simulation that results in the greatest reduction in the level of CO_2 equivalent emissions.

We subsequently applied a 20% tax on intermediate consumption, resulting in a limited increase in prices and a considerably limited reduction in CO_2 equivalent emissions, in comparison with the preceding simulation. The amount of tax revenue collected is also slightly lower than in the previous simulation, although the level of private real income is considerably higher.

The following simulation consisted of introducing a 20% tax on final consumption, which reduces emission levels and gives rise to a price increase that is considerably lower than in the other simulations. This is also the scenario which results in the highest level of private real income, although the amount of tax revenue collected is smaller. On the other hand, in absolute values, in this scenario, there is the highest elasticity of emissions to changes in consumers' prices.

Finally, we calculated the impact of a 20% tax on total production, which gives rise to a higher increase in prices and a significant reduction in CO_2 equivalent emissions. This is, however, the scenario with the worst level of private real income although, on the other hand, it results in the highest level of tax revenue.

The information obtained from this study shows the relationship existing between the economy and the generation of emissions. Among the various policies analyzed, the best, both for the environment and for society in general, is the third scenario, consisting of the application of a 20% tax on final consumption. This is a measure which combines a considerable degree of price stability, a significant reduction in CO_2 equivalent emissions, but also reduces private real income in a small value compared with the other policies analyzed.

Our results can be used to find solutions for fighting against climate change, since policy makers can use

this information to design appropriate policies to reduce CO_2 equivalent emissions. Although it may at first seem that some measures are not very favourable for households and for certain production activities, in the long term they would in fact be extremely beneficial for the Catalan economy and society at large.

Finally, we should take into account that the SAM-based price model, as the Leontief approach, assumes a completely rigid price formulation that impedes the substitution between the components that define the price levels and, consequently, this method provides up-biased estimations of the price effects. We must bear in mind, however, that the absence of cost substitution is an acceptable assumption in the short run analysis when there is limited ability to react to price changes. This absence also seems an appropriate simplification for economies with institutional rigidities, where prices are automatically indexed according to the prices of production or the cost-of-living indices.

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