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Multisectorial Models Applied to the Environment: An Analysis for Catalonia

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MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT: AN ANALYSIS FOR CATALONIA

Ph.D. Dissertation

Ph.D. Advisor:

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Departament d'Economia

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Maria Llop Llop, professora titular d'universitat del Departament d'Economia de la Universitat Rovira i Virgili,

CERTIFICO:

Que el treball titulat "Multisectorial models applied to the environment: an analysis for Catalonia" que presenta Laia Pié Dols per a l'obtenció del títol de Doctora, ha estat realitzat sota la meva direcció al Departament d'Economia d'aquesta universitat i que acompleix els requeriments per poder optar a la Menció Europea.

Reus, 10 de novembre de 2009.

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*To my mother who
made me believe that
dreams may come true*

*To Andreu for being
always there for me*

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Acknowledgments

Looking back, I realize just how quickly the years have gone by. When I think of how I came to enter the university world, the first things that pass through my mind are my memories of the very first day I arrived here. Little did I imagine at the time that this would be my home for so many years, and still less that it would give me the opportunity to learn what it takes to become a good teacher or a good researcher. If I had to thank all those who have given me support during this long and gratifying process I would probably need to write another thesis, for there is a long list of people who, while asking for nothing at all in return, have helped me to realize one of my greatest dreams.

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and workshops and my stay at the Research School of the Faculty of Economics and Business of the University of Groningen (SOM).

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ISBN:978-84-693-0717-5/DL:T-442-2010

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Completing this thesis has allowed me to meet many people, and has also enabled me to discover just how much I love the world of research, and how much I still have to learn, for producing this thesis is only the start of a long and continuing apprenticeship.

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Contents

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MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
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List of Tables

UNIVERSITAT ROVIRA I VIRGILI
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Prologue

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"This paper is an attempt to apply the theory of general equilibrium to an empirical study of interrelations among the different parts of a national economy" (...). This research, like any other attempt at realistic analysis, represents a compromise between the unrestricted generalities of purely theoretical reasoning and the practical limitations of empirical fact finding" (...) "Despite the remarkable increase in the volume of primary statistical data, the proverbial boxes of theoretical assumptions are in this respect as empty as ever."

(Leontief, 1941)

Modern societies have for years been characterized by an ever-increasing requirement 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 this same 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.

It should be remembered that emissions of carbon dioxide and of other greenhouse effect gases occur naturally and are an essential pre-condition for life on Earth, since they retain in our atmosphere the heat from the Sun. The artificial emissions produced by humans add carbon dioxide to the atmosphere and thus lead to greater global warming. This is the phenomenon known as climate change.

Finding a solution to mitigate the effects of climate change requires many different strategies, both in the medium term and in a long-term basis, in a sustained way and in accordance with the requirements of each sector of activity or economic system, 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

ISBN:978-84-693-0717-5/DL:T-442-2010

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. The magnitude of the problem is, however, only too real, and if we do not find an effective remedy the consequences may be disastrous 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 emissions of greenhouse effect gases we will be able to improve the quality of the air and the quality of life in general, both for humans and for all other species living on the planet. 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.

The objective of this doctoral thesis is to apply different multisectorial models available to analyse the impact that would had on the Catalan economy as a result of the introduction of policies designed to reduce emissions of greenhouse effect and save energy, and also at the same time, to improve the environmental competitiveness of both individual companies and the economy as a whole. For the purposes of this thesis I have analysed the six greenhouse gases that are regulated by the Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). The range of exercises that I put into practice in this thesis enables us to examine the usefulness of the models applied, and allows to analyse questions that are of great importance for the future environmental and economic conditions of Catalan society.

Chapter one contains a brief introduction to computable general equilibrium models, describing the different phases that make up the construction of any applied general equilibrium model, and the advantages and limitations of this type of models. I also give an introduction to the

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subject of computable general equilibrium models applied to the environment. Models using the structure of social accounting matrices can be classed into two overall groups. The first group consists of the so-called linear models, and the second includes computable general equilibrium models. In this chapter I shall undertake an extensive review of the literature dealing both with linear models and with computable general equilibrium models applied to the environment. Although in this thesis I have not constructed an applied general equilibrium model, I considered it of interest to review exhaustively the literature concerning this methodology, since in the immediate future I propose to construct a model of this type.

In *chapter two* I construct a social and environmental accounting matrix for Catalonia for the year 2001 (referred to below as NAMEA01), which will be used as the numerical basis for all subsequent analyses. A NAMEA (National Accounting Matrix using Environmental Accounts) is simply a double-entry table in which the rows contain the origins of the economic resources and the columns show the uses that economic agents give to the resources concerned. In a NAMEA, this information is linked to the environmental consequences of economic activity such as pollution and the use of natural resources. A NAMEA, therefore, enables to visualize the network of direct interconnections found in the economy and in society, i.e. between branches of activity and institutional sectors, and between the former and the environment. When constructing this matrix, I define the economic structure of Catalonia in terms of economic, social and environmental aspects.

C*hapter three* presents a linear model of emission multipliers using the NAMEA for the Catalan economy. Like income multipliers, emission multipliers can be divided into own effects, open effects and circular effects. This decomposition shows the various channels of income generation and how they affect regional greenhouse pollution. On the other hand, in the same chapher I analyse the impact of a 10% reduction in total greenhouse emissions on emission multipliers. This reduction percentage would bring the Catalan economy into compliance with the maximum emissions level

ISBN:978-84-693-0717-5/DL:T-442-2010

allowed by the Kyoto Protocol, which urges the reduction of greenhouse gas emissions. In my analysis, the reduction in emissions is modelled using different economic scenarios. Specifically, I simulate a reduction in regional emissions accompanied by a reduction in production as well as factorial and private income. I also simulate a reduction in regional emissions accompanied by increasing levels of production and factorial and private income.

In *chapter four* I analyse the economic impact of alternative policies implemented on the energy activities of the Catalan production system. Specifically, I analyse the effects of a tax on intermediate energy uses, a reduction in intermediate energy demand, and a tax on intermediate uses combined with a reduction in intermediate energy demand. The methodology involves two versions of the input-output price model: a competitive price formulation and a mark-up price formulation. These two versions behave unevenly, since they differ in their hypotheses about how production prices are established. The competitive formulation is a setting in which production prices are equal to the average cost of production. The mark-up formulation is a setting in which production prices lead to a fixed capital rent. The input-output price framework will make it possible to evaluate how the alternative measures modify production prices, consumption prices, private real income, and intermediate energy uses.

In *chapter five*, I use the model proposed by Roland-Holst and Sancho (1995) to assess the economic and social impact of the implementation of different policies to reduce CO_2 emissions and improve, at the same time, the environmental competitiveness of enterprises and the private welfare in Catalonia. The information obtained from this analysis will allow us to see the existing relationship between the economy and the generation of emissions. Alternativelly, I also apply a second model, which is an extension of the exogenous determination of production in the input-output quantity model (Miller and Blair, 1985) to a SAM database. This approach allows to complete the results because it shows the level of total income of the endogenous accounts needed to reduce emissions in an exogenously determined quantity. The two models used allow to illustrate

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different economic impacts on regional variables of alternative policy measures that can reduce greenhouse emissions.

Finally, in *chapter six* I shall outline the principal conclusions of this doctoral thesis. Despite the fact that each chapter includes its specific conclusions, the overall results of the study contribute to showing how different economic activities affect environmental problems from different perspectives. To conclude this chapter I shall show some future lines of research that have opened up as a result of this study.

Some previous results have been presented in various international and national conferences such as the II Jornadas Españolas de Análisis Input-output in Zaragoza (2007), the Internacional Conference on Energy and Environmental Modeling in Moscow (2007) and the III Jornadas Espanolas de Análisis Input-output in Albacete (2009). Moreover, some results of these chapthers have been also published in international journals and book chapters jointly with Maria Llop. Chapther 4 was published in Energy Policy[1] and some outcomes of chapther 3 were published in the book "The Kyoto Protocol: Economic Assessments, Implementation Mechanisms and Policy Implications".[2]

With a view to facilitating the reading of this thesis, each chapter will be treated on an individual basis in relation to the others. This means that each chapter will begin with an introduction and will end with the main conclusions that are reached on the basis of its content. The relevant bibliographical references and appendices, if any, will also be added at the end of each chapter. The numbering of tables and of footnotes will likewise be independent for each chapter.

[1] "Input-Output Analysis of Alternative Policies Implemented on the Energy Activities: An Application for Catalonia", *Energy Policy*, 36(5), pp. 1642-1648, 2008.
[2] "Modelling a Reduction in Greenhouse Gas Emissions in the Catalan Economy: The NAMEA Approach" in Vasser, C.P. (ed.), *The Kyoto Protocol: Economic Assessments, Implementation Mechanisms and Policy Implications*, Nova Science Publishers, 2009.

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Chapter 1

Introduction to Computable General Equilibrium Models Applied to the Environment

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1.1. Introduction to Computable General Equilibrium Models

The historical evolution of the economy is characterised by the development of a set of analytical instruments which have helped economists to improve knowledge about the economic relationships between companies, public institutions, consumers and foreign agents. All these questions are normally analyzed using partial equilibrium models. Partial equilibrium, however, only takes into account the direct effects that exist in a specific economic environment, and does not take into account the indirect effects which have a chain of impacts on the economy.

In recent decades, Computable General Equilibrium Models (CGE models) have become an effective instrument for analyzing public interventions and changes in economic scenarios. This kind of investigation involves, on the one hand, an extensive representation of the economic system that includes all the agents and their optimised decisions and, on the other hand, a complete and systematic representation of the way in which agents interrelates.

CGE models use the theory of general equilibrium, based on the Walrasian system of integration and interdependence between agents and markets, to analyse different economic measures or changes in economic scenarios. Therefore, we can define a CGE model as an empirical representation of an economy.[3] In this representation, all the markets are interrelated and the prices of goods, services and primary factors guarantee that the economy is balanced.

The origin of general equilibrium models can be found in *Pure Economic Policies* by Leon Walras (1874).[4] Walras' study looked at the joint interdependencies between agents and economic institutions and led to important changes in the analytic framework that has been used ever since. Neoclassical general equilibrium was rigorously elaborated both by Arrow and Hahn (1971) and Debreu (1959), the latter being rigorously

[3] According to Shoven and Whalley (1984): "a CGE model represents the evolution from the structure of the Walrasian general equilibrium, which represents the economy in abstract form, towards a more realistic model of the same."
[4] Walras belonged to the marginal utility or neoclassical school.

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mathematic in his attempts to describe economic systems precisely, whilst also trying to prove the existence of optimum Pareto equilibriums in a competitive setting.

The Input-Output model developed by Leontief (1941) is the first general equilibrium model to accurately compile the effects of economic interdependency between productive sectors. However, this model has two well-known weaknesses: the absence of substitution between factors and the null role of the final demand in defining the prices of the economy.

The Walrasian theory of general equilibrium was a purely theoretical exercise which for many years was difficult to apply to economic reality. However, a century later it had become a valuable instrument for applied work. In the 1960s, the first steps were taken to find solutions for the general equilibrium. Thanks to these first steps, computerised algorithms can nowadays obtain results that allow researchers to evaluate the economic relations and the new scenarios that affect economies.

The first practical effort to unite theory and reality was made by Johansen (1960), who developed the first computable general equilibrium model. This author presented a system of general equilibrium equations that would be resolved on alignment. The simulations consisted of making a marginal change to one of the exogenous variables of the equations. Since then, new models have tried to capture different and multiple aspects of reality, whose unification into one sole model does not always provide consistency from a theoretical point of view. This characteristic distances Johansen’s methodology from the neoclassic tradition.[5] Within the tradition of Johansen’s model, we can quote the Australian model ORANI[6] and the Michigan model of world trade.[7] We can also identify a large number of models designed to analyse economic development problems and taxation in countries of relative poverty (Aldeman and Robinson, 1978).

[5] This explains why some authors consider these models to be less orthodox within the method of general equilibrium (see Willenbockel (1994)).
[6] See, for example, Dixon et al. (1982) and Dixon et al. (1992).
[7] See, for example, Deardorff and Stern (1986).

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Later on, Harberger (1962) developed a model with two productive sectors to analyse the effect of taxation on societies, using information from the American economy for the year 1950.

At the end of the 1960s and the beginning of the 1970s, computerised algorithms were developed which, under certain conditions, permitted the localization of vectors of equilibrium prices.

The accessibility of computation methods has led to an extensive literature dedicated to analyzing different economic problems. General equilibrium techniques have been applied to different fields of economic analysis. Amongst others, these include the analysis of fiscal policies,[8] commercial policies,[9] the environment,[10] education,[11] immigration,[12] regional economies,[13] population movement,[14] agricultural policies,[15] European integration,[16] and even problems such as the economic development and the stabilisation of poorer countries.[17]

In CGE modelling there are multiple ways of representing an economy, and this in turn greatly determines the models' final characteristics. The structure and design of the model is established according to the problem that the investigator wants to analyse. The institutional classification of the economic system, the behaviour of the

[8] See Harberger (1962), Shoven and Whalley (1972), and Piggot and Whalley (1977) for Great Britain; Ballard, Fullerton, Shoven and Whalley (1985) for the USA; Kehoe and Serra-Puche (1983) for México; Keller (1980) for Holland; and Piggot (1980) for Australia.
[9] See Deardorf and Stern (1986) and Whalley (1985a, 1985b) for analysis of the evolution of the GATT.
[10] See Bovenberg and Van de Ploeg (1998) for analysis of environmental questions; Devarajan (1998) for analysis of natural recourses; and Bergman (1988) for analysis of energy policies.
[11] See Ferri (1998) for a model for analyzing public spending on education.
[12] See Ferri, Gómez and Martín (2001) for an analysis of the effects of increasing immigration in the Spanish economy.
[13] Amongst others, Cardenete (2000) analyses the effects of the 1999 tax reform in Andalusia, and Llop (2001) analyses the effects of the reductions in employer contributions to social security under different hypotheses of incidence in the Catalan economy.
[14] See Kehoe and Noyola (1991).
[15] See Keyzer and van Veen (1994) for analysis of food polices; Parikh (1994), for analysis of the public distribution system of an agricultural policy in India, according to which the government offers some primary aid at lower prices than the market; and Golden and Kundsen (1992), for analysis of the effects of the free trade of commerce in agriculture.
[16] See Mercenier and Srivivasan (1994), Mercenier (1995), Polo and Sancho (1993) and Gómez (1998).
[17] See Dick et al. (1984), Dacaluwe and Martens (1998), and Bandara (1991) for analysis of developing countries.

ISBN:978-84-693-0717-5/DL:T-442-2010

different agents, and the technologies of the productive sphere are crucial aspects in determining the characteristics of applied general equilibrium models.

1.2. Design of a Computable General Equilibrium Model

A computable general equilibrium model starts with a theoretical set that is intended to be a simplified representation of the economy under study.[18] Firstly, the researcher has to identify the problem he wants study. This is a crucial aspect of the model, because it determines the nature and the degree of disaggregation that should be used when representating the economy's agents and institutions. A model must be chosen that can respond to the economic problem that one wants to analyse.

Secondly, it is necessary to design the analytical context in which the economic behaviour of consumers and the producers is to be identified. The consumers possess some initial endowments (of goods and factors of production), and a set of preferences which allow the demand functions for each good and each factor to be obtained. The demand of the market is obtained by adding together individual demands, and is continuous, non-negative and complies with Walras' law.[19] Furthermore, market demands are homogeneous of grade zero, and this implies that only relative prices are significant. Therefore, the level of absolute prices has no impact on the resulting equilibrium.

On the production side, the technology shows constant returns to scale,[20] and producers choose those quantities of inputs and factors of production that ensure the maximum level of benefits. On the other hand, the equilibrium must guarantee the equality between demand and supply. In other words, the equilibrium is characterised by a set of relative prices

[18] See Kehoe (1996).
[19] Walras' law says that for any set of prices, the total value of consumers' expenditures equals revenues.
[20] This is the normal representation of technology. However, the literature of CGE models shows increased returns to scale in some sectors and companies as well as imperfect competition. An example is Bonano (1990).

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

and levels of production in each industry for which the demand is equal to supply in all markets (including the surplus, if there exists any kind of free good). With constant returns to scale, the maximum benefit implies that the only possible solution is the one that gives null benefits to companies.

In addition to identifying the consumers and the producers, CGE models also incorporate the public agent. This agent transfers income to the consumers and the companies, and sees to public expenditure. Government wants maximize their utility, but is faced with an income restriction. This agent also collects taxes, which are the main source of public income, and may have a public deficit which, in this case, is financed by the other economic agents.

Finally, CGE models incorporate the relations with the foreign agents. As there are many ways to define the external relations of the economy, computable general equilibrium models can differ widely depending on the foreign agents involved.

Once the theoretical model and its basic characteristics have been defined, the functional forms of each part of the model have to be chosen. Usually, the choice of functional forms depends on how the statistics in the model are to be used. Functions like Cobb-Douglas, Constant Elastic Substitution (CES), Leontief, Translog, or Lineal Expenditure Systems (LES) are frequently used because the parameters involved can be easily obtained compared with other more flexible and general analytical expressions.

Once the structure of the model has been determined, it is necessary to specify the parameters (or exogenous variables) which will permit it to be functional. These parameters can be obtained using both econometric estimations and a calibration procedure.[21] To calibrate the parameters, it is necessary to have a database that consistently reflects all the flows of goods, services and income between the agents during a stated period. This

[21] According to Mansur and Whalley (1984): "Calibration is the method for supposed functional forms, with a fixed parametric value, unknown in form, so that the system of equations reproduces a database as a solution for general equilibrium".

ISBN:978-84-693-0717-5/DL:T-442-2010

database is a social accounting matrix or SAM.[22] The information that a SAM contains comes from different sources, for example national accounts, an Input-Output matrix, economic surveys, etc.

Those who defend econometric analysis have criticised the calibration procedure because there is no statistical test that proves the reliability of the parameters.[23] The principal argument on which the criticism rests is that calibration assumes that the economic reality reflected in a SAM corresponds to equilibrium in the economy. Despite these methodological problems, calibration has many advantages and this explains why calibration is the most commonly used method in computable general equilibrium models.[24] However, there is no theoretical reason not to use econometric estimates of parameters,[25] although one of the motives for not using them is because, taking into account the number of variables to be estimated, more information is needed than is available. Nevertheless, there are small scale general equilibrium models which use statistical estimation.

Once the functional parameters are obtained, the model can be represented as a system of equations where the variables to be determined (i.e. the endogenous variables) are the prices of goods, services, and factors, the levels of activity of the different sectors, as well as other relevant variables. After obtaining the values of the exogenous parameters, the system is resolved by using a computer program such as MPS/GE, GEMODAL, GEMPACK or GAMS.[26] From here, an initial solution is obtained,

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[22] There are CGE models that do not use any SAM to calibrate their parameters because they use macroeconomic data from statistical sources. However, this is not the normal practice in applied general equilibrium.

[23] See Hansen and Heckman (1996) for an argument about this theme.

[24] In Whalley's work (1991) we can find the principal advantages of calibration, which are the following:

- The number of parameters of a computable general equilibrium model necessitates a great number of observations in order to use estimation methods.
- The difficulty in treating value, and its separation in observations of prices and quantities make it difficult to estimate the parameters econometrically.
- The dimension of CGE models implies that the construction of reference equilibrium datasets is by no means trivial; hence the research could not be viable if the construction of time series is needed.

[25] See Jorgenson (1984).

[26] The GAMS program was developed by the World Bank in cooperation with institutional academies in North America.

ISBN:978-84-693-0717-5/DL:T-442-2010

which is considered the starting point for the entire analysis. This initial equilibrium solution, or benchmark solution, can be compared with new situations analysed in the model.

The simulations consist of changes to some of the exogenous variables of the initial equilibrium. This procedure is an experiment in comparative statics, whose sole objective is to analyse the consequences of adopting economic measures without having to put such measures into practice.

It is very important to interpretate the results and analyze their robustness. Robustness means, on the one hand, whether the variables are sensitive to small variations in some of the parameters of the model, and on the other hand, if the variables are sensitive to certain specifications of some functional forms.[27] This is important because it informs about important aspects of the economy that could influence the results, which in turn could lead to new investigations or focus attention on those aspects of the economy towards which the model is aimed.

Finally, the model must be contrasted with reality.[28] Cox and Harris (1985) and Brown and Stern (1989) highlighted the errors in the predictions of the computable general equilibrium models built for the NAFTA constitution. Contrasting the results is an important phase of computable general equilibrium because it allows us to understand the degree of trust we should place in a given model.

Finally, when analyzing robustness we have to take into account that a CGE model is built from a series of suppositions that, if not reproduced in the economy, will invalidate the results.

[27] See Harrison and Vinod (1992).

[28] Kehoe, Polo and Sancho (1995) analysed the model made to study the introduction of VAT in Spain (Kehoe, Manresa, Noyola, Polo and Sancho (1988)). In general, the original simulation was good for predicting industrial prices, levels of production, remuneration of the factors of production and principal components of production, even though the predictions of the prices of goods was not very good.

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

1.3. Advantages and Limitations of General Equilibrium Models

The principal advantage of CGE models is that they constitute a clear bridge between theoretical analysis and its application in policy analysis. We can also find the other following advantages:

- They allow the incorporation of multiple markets (goods, factors, foreign markets, etc.).
- They allow non-lineal problems to be resolved and, as a result, generate non-lineal cost structures.
- They allow different policy simulations to be executed.
- They allow prices in the economy to be obtained in an endogenous form as a result of free play between supply and demand.
- They can incorporate imperfect competition in some markets and in some sectors.
- They can incorporate the characteristics of a country or group of countries in a realistic way.

Nevertheless, one of the most important limitations of applied general equilibrium is that its static theoretic nature prevents the dynamic aspects of the economic reality from being properly dealt with. In addition to this limitation, we can find other problems such as:

- The large quantity of statistical sources needed to construct the SAM.
- The absence of statistical tests which confirm the quality of the specifications included in the model. This means that we can not use econometric procedures to test the model because the general equilibrium models are calibrated from the database of a definite year.

Apart from all these limitations, some of them repairable and others simply resulting from insufficient resources, CGE models are important

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

instruments in economic planning, as their advantages outweigh their disadvantages. In fact, CGE analysis allows to improve the knowledge of economic relations and the effects that public measures have on agents and institutions. All of this is extremely valuable for policy purposes.

1.4. Computable General Equilibrium Applied to the Environment

Nowadays, there is constant economic growth in the industrialized countries, together with an increasing population in the developing countries. This can increase the demand for resources and the negative impacts of economic activity, and is the reason why developing countries have recently expressed concerns about obtaining higher and more equitable economic growth whilst at the same time reducing the associated environmental damage.

Modelling an economy with all its interrelations, agents and sectors has always been complex. For this reason, economic, social and environmental policies have usually been studied separately in a partial equilibrium context. However, we must bear in mind that many of the measures that affect, for example, the environment, also have an impact on variables such as economic growth, poverty, employment, and income distribution. Therefore, in order to understand the effects of macroeconomic policies on the environment, or the effect of either environmental protection or social policies on macroeconomic variables, we need to use models capable of capturing the complex interrelations existing between the different sectors and agents of the economy.

The environment plays an important role in society because, on the one hand, it is the provider of natural resources, such as production system inputs, and on the other hand, it is the final destination of the residuals generated by production and consumption. Therefore, economic activity influences the environment by the consuming natural resources and generating pollution.

ISBN:978-84-693-0717-5/DL:T-442-2010

There has been much debate in recent times regarding the relation between economic activity and the environment and the measures that need to be taken. This debate was first opened during the late 1970s[29] when the societies start to become more socially aware and when some economists realised that it makes no sense to analyse separately the relation between the environment and economic growth.

But it was not until the mid 1980s when politicians began to be aware of the need to introduce new ways of dealing with the environment. In particular, in 1987, the report of the World Commission on the Environment and Development (WCED or Brundtland Commission) defined Sustainable Development (hereafter SD) as "development, which meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). In practice, this definition means that in a developing society, the economic,[30] environmental[31] and social[32] goals should all be met simultaneously, both in the present and for "future generations".[33] In June 1992, the Rio Earth Summit[34] concluded that "the right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations" (UNCED).[35]

The "Rio+5 Summit" was held in 1997 and was mainly aimed at analyzing the execution of "Programme 21", which had been approved at the summit held in 1992. In order to evaluate the conferences held in 1992 and 1997, the United Nations organized a further summit that was held in Johannesburg in 2002. This summit dealt with, among others, the following issues:

[29] The debate about the need to balance economic growth and environmental impacts came to the fore in 1972 when the Club of Rome released its publication "Limits to Growth".
[30] The economic goals take into account the need for economic growth, more equity and greater efficiency. Thus, the old notion of economic growth used up to that point was overturned.
[31] The environmental goals included raising concern for ecosystems, biodiversity, assimilation capacity, and other global issues.
[32] The social goals include issues of participation, social mobility, cultural identity and institutional development among others.
[33] See Pearce and Turner (1990).
[34] "Programme 21" was adopted.
[35] United Nations Conference on Environment and Development.

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

- Eradicating poverty and raising welfare,
- Sustainable production and consumption,
- Sustainable management of natural resources,
- Water,
- Energy,
- Health.

The main issue addressed by the conference was how to change the world to ensure long term preservation of life and guarantee the sustainability of the Earth. Since then, the debate about development has continued with varying degrees of controversy as people have tried to incorporate different economic and environmental variables.

Over the years, newer methodologies have been developed which have allowed ecological variables to be included in the traditional economic analyses by improving the existing statistical sources. Some fields in which people have tried to integrate economic activity and the environment are: national accounting, the input-output framework and computable general equilibrium models.

Computable general equilibrium models use a database that consistently reflects (during a period of reference) all the flows of goods, services and income between the agents of the model. This database is known as social accounting matrix (SAM). However, this matrix does not include the environmental variables such as emission of pollutants to the air, water or soil, dangerous residuals, natural resources, environmental quality, and so on. Hence, the logical thing to do would be to add environmental data to the SAM.

On the one hand economic activities make use of natural resources, and on the other they generate emissions. Despite this, the national accounts systems do not take into account that the environmental data may be related with the mechanisms that determine the circular flow of income.

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

Some experts have proposed the creation of an integrated system of environmental-economic accounting that allows the evaluation of policies designed to attain sustainable development. There are also authors that argue that environmental degradation should appear as a discount factor in the national accounts system. This would permit countries' economic growth to be accurately estimated.[36] Furthermore, a common procedure in CGE models is to relate pollution to production (outputs), or to the use of certain intermediate goods. Although it is better to associate each type of pollution with a particular input, both the level of economic disaggregation and the need to simplify the model can sometimes make this impossible.[37] Despite all this, there is still no standarized, formal environmental accounting system.

There is growing interest in developing computable general equilibrium models by including environmental variables. Nowadays people wish to be able to evaluate the environmental externalities of economic policies and their effects on prices and quantities. They also want to determine the economic and social structure of environmental policies and the direct and indirect impacts that a given policy has on the three spheres of sustainable development (i.e. economic growth, equity and environmental sustainability). All these concerns make it necessary to use a broader analytical framework which reflects all the interrelations existing in an economy. Computable general equilibrium models can do this because they take into account all the relations between agents and markets.

1.5. Main Contributions of Computable General Equilibrium Models Applied to the Environment

General equilibrium models can be classified in two main groups. The first is made up of linear SAM models. Like the input-output model, SAM models use a matrix of technical coefficients, but they incorporate a greater degree

[36] See Dasgupta and Mäler (1991).
[37] A good introduction to the relations between environment, economy and CGE models can be found in Bergman (1991).

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

of endogeneity. Furthermore, this first group of models has important restrictions such as the exogeneity of prices and the linear behaviour of economic agents.

The second group of models includes CGE models. This group provides more complex models with agent behaviour hypotheses that are less restrictive and which use a set of simultaneous equations to reflect economy's conditions of equilibrium.

1.5.1. Linear SAM Models

The linear models allow us to evaluate how the economic activity of the different agents affects the relations of the circular flow of income. These relations include the interdependence within the productive sphere, the final demand, and the income distribution operations.

SAM models calculate the countable or extended multipliers that quantify the global effects, in terms of increased income, produced by the set-up of the economic system from the instruments of income that have an exogenous character. By analyzing these extended multipliers, it is possible to determine the extent to which sectors affect economic activity.

The SAM model is similar to the input-output model, but with one significant difference: in the process of income creation, the extended multipliers incorporate not only the production relations, but also the income distribution and final demand relations.

This methodology was pioneered by Stone (1978) and Pyatt and Round (1979), who showed the relations between production, income and demand in a social accounting matrix of the Sri Lankan economy. Since then, many more studies have been carried out. Defourny and Thorbecke (1984) proposed adding structural path analysis to the traditional multipliers. This consisted of determining not only the influence of the multiplier effects on the different sectors of the economy, but also the transmission channels between these sectors.

ISBN:978-84-693-0717-5/DL:T-442-2010

SAM methodology has significantly extended the multisectoral framework of the input-output table by including the interrelations between production activities, production factors and institutions. This extension has allowed a circular flow perspective when analyzing the income generation process. The SAM method has been used to analyze both national and regional economies and it has substantially improved knowledge regarding the transmission of the income effects.

Among the literature regarding linear SAM models, only a few studies apply a social accounting matrix to the environment. Among these studies, Keuning (1992, 1993 and 1994) proposed a national accounting matrix that would include environmental accounts (that is, an environmentally extended SAM system).[38] In this matrix, which would include both economic variables and pollution information, economic variables would be expressed in monetary terms and environmental ones in physical terms. Pollution originating from production, consumption or import activities would appear in an emissions account.[39]

On the other hand, Xie (1995) constructed an environmental SAM for China that took into consideration polluting emissions (liquid waste, solid waste and suspended dust). The SAM analyzed payments to avoid emissions, taxes paid for emissions, subsidies for controlling emissions, and industrial environmental investment (waste treatment plants and control teams). These activities were differentiated according to production type, which resulted in a consistent database with which to initially calibrate a model with dejection activities. This SAM was therefore able to use real data on dejection costs to evaluate environmental policies.

The first pilot National Accounting Matrix including Environmental Accounts (NAMEA) developed for the Netherlands (De Haan and Keuning, 1996) was an attempt to embed indicators for economic and environmental

[38] The work is based on the input-output approach of Leontief (1970). Leontief´s (1970) analysis of the physical economy can be regarded as the first prototype NAMEA since both systems are characterized by a hybrid structure including both physical and monetary data (De Haan, 2001).
[39] These environment satellite systems have been extended from the pilot version presented in De Haan et al. (1993).

ISBN:978-84-693-0717-5/DL:T-442-2010

performance into one information system. The first NAMEA showed the environmental stress of production and consumption in a format consistent with the economic figures in the national accounts by adding environmental accounts expressed in physical units to the national accounts matrix.

Keuning, Dalen and De Haan (1999) described an aggregated NAMEA which they used to compare the contribution of economic activities to economic indicators with the contribution of economic activities to environmental themes. They also described how economic activities contribute cumulatively to economic and environmental indicators (thus taking into account the relations between the production activities) and described a number of recent applications and extensions of the NAMEA in the Netherlands. Keuning and Steenge (1999) presented a description of the structure and methodology of construction of a NAMEA.

De Haan (1999) presented a comparison of databases with economic and environmental information for the economies of Sweden, Germany, United Kingdom, Japan and Holland. In the same year, Ike (1999) described a NAMEA for Japan which provided 1) a comprehensive and consistent picture of the interrelationship between the economy and the natural environment, 2) a basis on which cost-benefit analysis could be applied and 3) the necessary information for policy planning. This NAMEA showed environmental pressures not only from domestic pollutant emissions, but also from transboundary flows from the rest of East Asia. It also focused on pollutant emissions in East Asia in relation to future growth potential.

Vaze (1999) explained how environmental accounts carried out in the UK were calculated. Results from the pilot accounts were reproduced in a NAMEA framework, which allowed them to be compared with the NAMEAs calculated by other countries.

Xie and Saltzman (2000) constructed a numerical version of the environmentally extended SAM using Chinese data from 1990. Multiplier and structural-path analyses were applied to this database to assess the environmental impacts of pollution-related economic policies. Xie (2000) then extended the SAM to capture the relationships among economic

ISBN:978-84-693-0717-5/DL:T-442-2010

activities, pollution abatement activities, and pollution emissions. The author presented a numerical example of the environmentally extended social accounting matrix (ESAM) using Chinese data from 1990. Multiplier and structural path analyses were applied to the ESAM to assess the environmental impacts of pollution-related economic policies. The results showed that an ESAM can be a useful tool for environmental policy analysis.

De Hann and Keuning (2001) showed how environmental issues can be incorporated into macroeconomic accounting and analysis when they constructed a National Accounting Matrix including Environmental Accounts (NAMEA) for the Netherlands. The paper first discussed a number of conceptual issues on the harmonisation of environmental statistics and national accounts. Specific attention was given to consistently accounting for the pollution generated by production and consumption activities and to the importance of aggregated environmental indicators.

Manresa and Sancho (2004) conducted the first integrated economic and environmental analysis for Catalonia, taking 1987 as the base year. The paper analysed the sectorial power intensity of the Catalan economy using a regional SAM that differentiated between the polluting emissions originating from production and those originating from final consumption. The authors observed that the energy sectors themselves were the largest consumers of energy sources.

Rodríguez, Llanes and Cardenete (2007) showed that a SAM including environmental accounts can be used for economic and environmental efficiency analysis. They used Spanish data for the year 2000 and applied it to water resources and greenhouse gas emissions. The matrix was used as a database for a multisectoral model of economic and environmental performance, which made it possible to calculate the domestic multipliers and their break down into direct, indirect and induced effects. These multipliers were used to evaluate the economic and environmental efficiency of the Spanish economy. The study demonstrated that there is no causal interrelation between those sectors with greater backward economic linkages and those with greater environmental deterioration.

ISBN:978-84-693-0717-5/DL:T-442-2010

Flores and Sánchez (2007) analysed and assessed the most important environmental impacts on the economy of Aragon by relating the main economic activities to resource consumption and pollution levels. To carry out this analysis, they first constructed a social accounting matrix including environmental accounts (SAMEA) for Aragon for 1999. In particular, water resources and several types of aquatic and atmospheric pollution were incorporated into this SAMEA. An open Leontief model was constructed on the basis of these matrices. This model enabled water and pollution to be linked with final demands and revealed the role these demands play in the use of water resources and the generation of pollution.

Finally, Cardenete, Fuentes and Polo (2008) presented estimates of energy intensities and CO_2 emissions for Andalusia's economy in 2000. Energy intensities of productive sectors were calculated in several scenarios using a SAM model. Emissions were estimated with an input-output model, breaking down emissions into those due to intermediate and final uses. The results indicated there were important variations in energy intensities across sectors as well as substantial changes when consumption and investment were endogenous.

Undoubtedly, SAM methods are very valuable when accounting for the environmental consequences of economic activity. Thus, improving both databases and linear models will allow the joint analysis of the circular income effects and the associated environmental loads. In the coming years, therefore, linear SAM applications to environment will be a rich area of economic and ecological research.

1.5.2. Computable General Equilibrium Models

One of the main advantages of computable general equilibrium models is their capacity to explain the different consequences of the activities of a particular sector or of the whole economy, when there is some change in the economic scenarios.

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

We can divide the computable general equilibrium models into static models and dynamic models. The static models focus on analyzing in great detail the interrelations that take place within the economy during a given period of time. The dynamic models focus on adjusting the economic variables to new scenarios. We must remember that the dynamic models of general equilibrium not only have conceptual difficulties, related to the existence and unity of equilibrium, but also practical difficulties, related to the availability of data. In consequence, dynamic models cannot reflect the economy to such a level of detail as can static ones. In the remainder of this chapter, I will focus on static models.

Recently, researchers have become increasingly interested in developing computable general equilibrium models that include environmental variables. The reason for this is the increasing desire to be able to evaluate the environmental effects caused by both economic activity and the economic policies implemented by modern societies to mitigate the effects on the environment.

The first environmental CGE models, which appeared at the end of the eighties, were put forward by Forsund and Strom (1988) and Dufournaud et al. (1988). Since then, there have been many applications and the literature of environmental CGE has developed a very extensive set of models. A review of the literature shows that CGE models have been applied to several environmental issues, some of which are described below.

a) Carbon

Globally, 60,000 million tons of CO_2 are produced and sent into the atmosphere every year, 80% coming from the use of petroleum, coal and gas. To combat the global warming caused by these gases, several international conferences (Toronto 1988, Cairo 1990, Rio 1992, Berlin 1995, Kyoto 1997[40] and Johannesburg 2002) have called for a significant reduction in the combustion of fossil fuels.

[40] This led to the "Kyoto Protocol" (1997).

ISBN:978-84-693-0717-5/DL:T-442-2010

One of the aims of the Kyoto Protocol in 1997 was to reduce the dependency of the global economy on fossil fuels (i.e. petroleum, gas, and coal) whose impact on the environment has altered the climate and, with it, the biosphere and biodiversity. To reduce this dependency, the European Union forcefully advocated taxes on coal emissions as an effective instrument to reduce global carbon dioxide emissions.

Different studies have used general equilibrium models to analyse how imposing a tax on coal affects an economy or a productive sector. For example, Whalley and Wigle (1991) discussed how different countries may fare (because of international incidence effects) under certain carbon-tax schemes adopted over the next few years as part of effort to limit global build-up of carbon dioxide and other greenhouse gases. This work provided no evaluation of the severity or otherwise of the greenhouse effect, but instead made the assumption that there will be a policy response to the risk of significant global warming over the next few decades. Tax on carbon use could be a component of such a response.

On the other hand, Boyd et al. (1995) adopted a computable general equilibrium modelling approach to evaluate the cost impact of carbon taxation. They considered a scenario where the government keeps the carbon tax revenue so that its revenues increase, and also assumed that the revenue would be increased with a non-distorting lump-sum tax. They showed that even for their public finance assumptions; the net benefits were explicitly monetized. Their contribution to the literature is to add an explicit monetization of the environmental benefit to provide a broader analysis of the net benefits of carbon taxation.

Following on from this, Böhringer and Rutherford (1997) used a static general equilibrium model designed to investigate the economic implications of sectoral exemptions from environmental regulation with specific reference to carbon taxation. The model was calibrated with 1990 data for West Germany. In the same year, Parry et al. (1997) applied a CGE model to the USA, in which the costs of reducing USA emissions by 10% were more than three times higher under a grandfathered permit system than

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

with a carbon tax, due to the inability to recycle income. This result is in line with Goulder et al. (1998), who used a computable general equilibrium model to study various methods of allocating NO_x permits in the USA. A rate-based strategy of permits allocated in proportion to output was more costly than a limit-based strategy of crude grandfathering where there are no second-best interactions with other taxes, because the rate-based strategy does not lead to a fall in output from high-polluting industries. However, this output effect had large second-best implications where there are labour taxes. In this case, Goulder et al. showed that it was preferable to use a rate-based system, which gave higher employment and tax revenues.

Gottinger (1998) employed a computable general equilibrium model, developed in the context of energy–economy–environmental models, to simulate the impacts on the EU economy of major internal and multilateral policy instruments, including the taxation of greenhouse gas emissions (GHGs).

More recently, Edwards and Hutton (2001) used a computable general equilibrium model to evaluate methods of allocating permits within the UK. Auctioning is broadly similar to a carbon tax, with revenues recycled to reduce other distortions. They examined the various internal economic instruments by which a country can control carbon emissions. These include: a carbon tax, a fully-auctioned permit system, and systems of allocating tradable permits to certain energy users. Hao-Yen Yang (2001) investigated the joint effects of trade and environmental policies on the Taiwanese economy. The estimates were derived from a five-household, 18-sector computable general equilibrium model calibrated with a 1995 social accounting matrix.[41] The empirical results based on Taiwanese data showed that tariff elimination can significantly reduce the costs of carbon emission control and possibly set welfare reductions due to implementation of a carbon tax.

[41] The computable general equilibrium model used is neoclassical, with perfect competition and static behaviour which follows closely that of Dervis et al. (1982).

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

In the same vein, Babiker et al. (2003) presented a large-scale computable general equilibrium model of the world economy with distortionary taxation. They used this model to evaluate policies to reduce carbon emissions. The results demonstrated that the interplay between carbon policies and pre-existing taxes can differ markedly across countries. Böhringer et al. (2003) investigated whether environmental tax reform-cum-joint implementation provides employment and overall efficiency gains compared with a stand-alone environmental tax reform. They addressed this question within the framework of a large-scale general equilibrium model for Germany and India, in which Germany carries out the joint implementation with the Indian electricity sector. Their main finding was that joint implementation largely offsets the adverse effects of carbon emission constraints on the German economy. The joint implementation significantly lowered the level of carbon taxes and thus reduced the total costs of abatement as well as the negative effects on labour demand. In addition, the joint implementation triggered demand for direct investment in energy efficient power plants in Germany. This had a positive effect on employment and provided additional income for Germany. For India, the joint implementation equipped its electricity industry with scarce capital goods which led to more efficient power production, lower electricity prices for the economy and substantial welfare gains.

In contrast, Dissou (2005) used a static and multi-sector general equilibrium model to analyse and compare the cost effectiveness of a performance standard system and a carbon permit scheme to reduce CO_2 emissions in Canada. The simulation results suggested that this instrument could reduce emissions with almost the same productive efficiency as a permit-trading system. As it did not raise the price of commodities compared to the price of labour, it introduced fewer distortions in labour supply decisions. The results also suggested that the performance system standard could be better than a permit-trading system at preventing carbon leakage.

Scrimgeour et al. (2005) used a computable general equilibrium (CGE) model to address some of the important questions related to

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

environmental taxation, in particular carbon, energy and petroleum taxes. The model is developed within a theoretical structure that focuses on the energy sector and allows for substitution between various sources of energy and between energy and capital. The preliminary simulation results showed the impact of alternative carbon, energy and petroleum taxes on the New Zealand economy and the competitiveness of industry sectors including energy intensive industries.

Oladosu and Rose (2007) used a regional computable general equilibrium model to examine the cost-side income distribution impacts of a carbon tax in the Susquehanna River Basin Region of the United States.[42] They found the aggregated impacts of a carbon tax on the Susquehanna River Basin economy are likely to be negative. However, unlike many previous studies, they found that the carbon tax is mildly progressive when measured in terms of income bracket changes, per capita equivalent variation, and Gini coefficient changes based on expenditure patterns.

Finally, Faehn et al. (2009) analysed the impact of carbon policy on unemployment in Spain and whether recycling the public revenues earned from permit auctions can alleviate this problem. They used a computable general equilibrium model that includes unemployment in the markets for unskilled and skilled labour. They found that introducing carbon permits does not aggravate Spanish unemployment.

b) Climate Change

The excessive use of fossil fuels in human activities and the immoderate destruction of forests have led to the accumulation of greenhouse gases, especially carbon dioxide (CO_2), which in turn has contributed to the increase in the atmospheric temperature.

[42] The Susquehanna River Basin (SRB) is located in south central New York State, nearly all of central Pennsylvania, and a small portion of north central Maryland. Sixty eight counties in these three states form an economic trading area that roughly covers the SRB. The total population of the region is about 8 million and Gross Regional Product about $200 million. The Susquehanna River flows 444 miles from Lake Otsego near Cooperstown in New York into the Chesapeake Bay and drains 27,500 square miles. The SRB accounts for 43% of the Chesapeake Bay's drainage area and 60% of it is forest. The Susquehanna River is the longest commercially non-navigable river in North America.

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

The "United Nations Framework Convention on Climate Change" was created and signed at the Rio Summit in 1992. Under the terms of this convention, the developed countries, responsible for approximately 60% of the world's annual carbon dioxide emissions, promised to reduce their greenhouse gas emissions to 1990 levels by 2010. Despite the advances made by this Convention, it became evident that a stricter agreement was necessary. For this reason, a legally binding protocol was reached in Kyoto in 1997 whereby the developed countries promised to reduce their collective emissions of six greenhouse gases by 5.2% between 2008 and 2012, taking 1990 levels as the point of reference.[43] This agreement is known as the "Kyoto Protocol" and took effect on 16th February 2005, after ratification by Russia.

Different studies have used computable general equilibrium models to analyze climate change, the effects of greenhouse gases, the Kyoto Protocol and decreases in carbon dioxide emissions. For example, Gottinger (1998) used a new class of computable general equilibrium models based on energy-economy-environmental models (Gottinger and Barnes, 1993)[44] to simulate how internal and multilateral instruments for regulating greenhouse gases emissions would affect the European Union's economy.

Ian Sue Wing (2006) used a computable general equilibrium model to analyze climate change. He incorporated information regarding electricity generating technology into a CGE model of the US to identify the electric power sector's margins of technological adjustment to taxes on CO_2 emissions, and the impacts of these margins on aggregate economic variables. The simulation results demonstrated that the malleability of capacity is an important determinant of energy technological substitution and is a key driver in assessing the costs of policies designed to mitigate climate change.

[43] These six gases are: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFC), perfluorocarbons (PFC) and sulphur hexafluoride.
[44] The computable general equilibrium model developed by Gottinger (1998) in the course of related work forms a new class of computable general equilibrium model because it incorporates market-based regulatory instruments for the internal and multilateral regulation of pollution.

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

In contrast, Zhu et al. (2006) used a comparative-static general equilibrium model to examine the impacts of margins of technological adjustment to taxes on CO_2 emissions under different economic scenarios. Two regions (the EU and the CEECs[45]) and three categories of goods and services (agricultural goods, industrial goods, and services) were included. The model was calibrated with 1998 data and was subsequently used to study the effects of free trade, factor mobility and environmental constraints on production and international trade in the light of EU enlargement. They showed that in this specific context, free trade is beneficial to economic welfare and does not necessarily increase emissions of greenhouse gases. Factor mobility also increases economic welfare, but in the case of fixed production technology it may harm the environment through greater emissions of greenhouse gases.

Finally, Wissema and Dellink (2007) used a computable general equilibrium model with specific information regarding taxation and energy use. The model was developed to quantify the impact of implementing energy taxation to reduce carbon dioxide emissions in Ireland. This paper confirmed that a carbon energy tax leads to greater emission reductions than an equivalent uniform energy tax. The latter had a stronger negative impact on the less polluting energy sectors, whereas the carbon tax greatly stimulated the use of renewable energy and reduced the use of peat and coal.

c) Combustion Plants

The European Parliament and the European Council adopted a new directive on air emission limits for certain pollutants from large combustion plants (Large Combustion Plants Directive (LCPD 2001/80/EC[46])) on 27 November 2001 (European Commission, 2001). This Directive requires the existing large combustion sources to conform with stricter controls of SO_2, NO_x and particle emissions by 2008. In addition, plants with capacity over 500 MWt will need to meet very strict NO_x emission standards by 2016.

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[45] Central and Eastern European Countries.
[46] European Commission.

ISBN:978-84-693-0717-5/DL:T-442-2010

As far as we know, computable general equilibrium models have been used to analyze this situation in only one study, which looks at the energy sector in Poland. The Polish energy sector differs from that of other EU Member States and Candidate Countries in many respects. Electricity and heat generation in Poland relies heavily on domestic coal and lignite, which make up 97% of the fuel mix. This means that environmental protection costs form a large part of the costs of electricity generation. Electricity demand is forecasted to increase during the next 10–20 years, with the share of coal in the fuel mix gradually decreasing. Taking this situation into account, Kiuila and Sleszynski (2003) used a static computable general equilibrium model to measure how the indirect market feedbacks can influence the macroeconomic and structural impacts of the environmental protection costs borne by the power sector. They analyzed the economic impact of complying with the large combustion plants directive from two different perspectives: the power-sector perspective and the market-wide perspective. First, they modelled the power-sector perspective, which showed that compliance appeared to be associated only with costs. This scenario is an indicator for lobby groups. Second, they modelled the market-wide perspective, which showed that the abatement expenditure by the power sector became revenue for other sectors. This served as a general interest indicator. Kiuila and Sleszynski's study is the first analysis of the final structural and economic impact of the new Large Combustion Plants Directive in Poland and it is the first simulation of the final structural incidence of this Directive in Europe.

d) Energy

Interest in the energy sector has dramatically increased since the first oil crisis in the early 1970s. This gave impetus to the development of different models for analyzing energy policy. Some of these models concentrated mainly on the energy demand, the supply options, and the technologies involved, whereas others investigated the interaction between energy and economy.

ISBN:978-84-693-0717-5/DL:T-442-2010

In recent decades, different energy policy options have been analyzed using many computable general equilibrium models, ranging from the early Hudson and Jorgenson (1974)[47] model to more recent contributions such as that of Böhringer and Löschel (2006).[48] Bhattacharyya (1996)[49] provided an excellent survey of CGE models for energy studies, most of them used to analyze climate change policy. Weyant (2004) gave a more recent overview.[50]

The first application of a CGE model to energy studies was the Hudson and Jorgenson (1974) model in the wake of the first oil crisis. In this model, a price responsive interindustry production structure was combined with a long-run model of aggregate demand, which marked a significant methodological advance. The model was used to forecast the energy demand for the period 1975 to 2000, and analysed the effects of tax policies on energy use. Manne and Richels (1977) closely followed the Hudson-Jorgenson model, but their approach was quite different. They used a detailed description of energy technologies and an aggregated representation for the rest of the economy.

These pioneering papers stimulated others to use economy-wide models for energy studies. As a consequence, other energy-economy models based on CGE tradition appeared in the 1980s. Although the

[47] This paper presented a new approach to the quantitative analysis of US energy policy by integrating an econometric model with an input-output analysis. It incorporated a new methodology for assessing the impact of economic policy on both demand and supply of energy within a complete econometric model of the US economy. The model was first used to project economic activity and energy use for the period 1975-2000 under the assumption that there was no change in energy policy. The model was then employed to design a tax program for stimulating energy conservation and reducing dependence on imported sources of energy. The overall conclusion of the analysis of tax policy was that substantial reductions in energy use could be achieved without major economic cost.

[48] This paper investigated the use of general equilibrium for measuring the impacts of policy interference on policy-relevant economic, environmental, and social (institutional) indicators. They found that operational CGE models used for energy–economy–environment analyses had a good coverage of central economic indicators. In 2007, Scrieciu wrote a critique based on Böhringer and Löschel (2006).

[49] This paper surveyed the literature on general equilibrium models applied to energy studies, and reported their special features, their evolution through time and their limitations.

[50] This paper provided the impetus for the Energy Modeling Forum (EMF) study on technology and climate change policy, an overview of the design of the study and some aggregate model comparison results. The model comparison results focused on aggregate projections of economic growth, energy use, carbon emissions, fuel choice, and carbon taxes required to control carbon emissions.

ISBN:978-84-693-0717-5/DL:T-442-2010

structure and focus of these models differ widely, the general emphasis on interactions between the energy and non-energy sectors has always been preserved.

Sampaio de Souza (1984) used a CGE model to make an economic assessment of the early stages of Proalcool.[51] He studied the income distribution process between rural and urban sectors and the effects of Proalcool on food production.

Computable general equilibrium models have been shown to be a powerful tool for policy analysis. Various models based on general equilibrium theory have been developed to capture the energy-economy interaction in developing countries. Devarajan (1988), who surveyed the energy CGE models and their applications, pointed out two weaknesses in most of the energy-economy models applied to developing countries: first, their rough treatment of the economy, apart from the energy sector, weakens the feedback effects from the rest of economy in any policy simulation; second, their tenuous connection with the theory of international trade.

Years later, Haji Hatibu Haji Semboja (1994) used a computable general equilibrium model to evaluate how the Kenyan economy was affected by the second oil price crisis and the resulting energy tax policies. The simulations showed that a dramatic change in energy prices and the consequent changes in domestic energy consumption generated sequential feedbacks in the production process and affected economic structures. The terms of trade deteriorated, the balance of payments deficit increased, and national income fell. Energy import tariffs and sales taxes were effective policy instruments in controlling energy consumption and increasing government revenue. Both energy policies had net negative effects on other economic activities similar to those observed during the oil price crisis.

[51] The importance of the sugarcane agroindustry in Brazil has led to a great number of economic studies on biomass energy, mainly after the implementation of the Brazilian Alcohol Program (Proalcool) in 1975.

ISBN:978-84-693-0717-5/DL:T-442-2010

Naqvi (1998) constructed a computable general equilibrium model of the Pakistan economy in which some major extensions to a standard neoclassical model had been made to capture the interlinkages between economy, energy and equity. The model was designed mainly for policy oriented short-term studies, in particular, of the energy sector. An illustrative application of the model showed that it provides detailed information which is useful for analyzing policy issues.

Grepperud and Rasmussen (2004) used a computable general equilibrium model for Norway to explore how energy efficiency improvements can have economic consequences that offset potential savings resulting from using more efficient technologies (rebound effects). Two types of energy efficiency improvement (electricity and oil) were introduced into various sectors of the economy. Their results suggested significant and surprising differences across the sectors regarding both energy use and the build-up of greenhouse gases. Rebound effects were found to be quite significant for manufacturing sectors because long-term energy consumption undergoes minor reductions or increases in response to efficiency improvements. In other sectors, rebound effects appeared to be weak or almost absent.

Scaramucci et al. (2006) used a computable general equilibrium model to estimate the economic impact of constraining the supply of electric energy in Brazil. They also investigated the possible penetration of electricity generated from sugarcane bagasse. On the other hand, Hanley et al. (2006) analyzed the consequences that significant improvements in the productivity of power resources in Scotland would have on the environment. They found that an improvement in energy efficiency eventually increases energy consumption and pollution over time, since the positive output and substitution effects associated with lower energy prices outweigh the direct efficiency effect.

Otto et al. (2007) developed a computable general equilibrium model that explicitly captures connections between energy, the economy and the rate and direction of technical change. They showed the importance of

ISBN:978-84-693-0717-5/DL:T-442-2010

feedback in technical change, the substitution possibilities between final goods, and the general-equilibrium effects for energy bias in technical change. If the feedback effect is strong, or the substitution elasticity large, or both, the model tends to show the development of technologies for producing non-energy intensive goods.

Allan et al. (2007) used an economy–energy–environment computable general equilibrium model for the UK to measure the impact of a 5% across-the-board improvement in energy efficiency in all production sectors. They identified rebound effects of between 30–50%, but no backfire (i.e. no increase in energy use). However, these results are sensitive to the assumed structure of the labour market, key production elasticities, the time period under consideration, and the mechanism through which increased government revenues are recycled back to the economy.

Finally, Hanley et al. (2009) used CGE model to explore the impact of improvements in energy efficiency both theoretically and empirically using a flexible, energy–economy–environment. They argued that predicting the environmental impacts of significant improvements in energy efficiency requires a general equilibrium approach.

Researchers' interest is currently focused on environmental issues in general and the energy sector in particular. Undoubtedly, in the coming years this growing interest will lead to many more studies using computable general equilibrium techniques.

e) Environmental Policy

Environmental pollution is now a serious problem in many developing countries where it continues to increase and aggravate environmental problems such as deforestation, soil erosion, and desertification. These problems severely threaten sustainable development and have caused a great deal of concern at all levels, from the general public to national governments and international agencies. The threat of serious environmental degradation has led the governments of many developing

ISBN:978-84-693-0717-5/DL:T-442-2010

countries to introduce environmental policies and regulations. The most popular environmental policies include pollution taxes, environmental impact assessments, pollution subsidies, and pollution emission permits.

In the last few years, computable general equilibrium techniques have started to be applied to environmental policy analysis.[52] An example of this can be found in the study by Boyd and Uri (1991).[53] They used a computable general equilibrium model composed of 12 producing sectors, 13 consuming sectors, 6 household categories classified by income, a foreign sector, and a government. They then presented two alternative pollution abatement strategies and used the CGE model to evaluate the effects of these strategies on production, consumption, and consumer welfare. They found first that, irrespective of the type of strategy directed at improving environmental quality, both output and consumption declined, as did household utility. Thus, there was a quantifiable trade-off between economic activity and the quality of the environment. That is, the aggregated loss in production and economic welfare (measured by consumption expenditures and utility) was lower under a policy that stresses reliance on alternative fuels (brought about by taxation) than under one that requires the installation of pollution abatement devices (i.e. regulation).

On the other hand, Ballard and Medema (1993) employed a computable general equilibrium model of the US economy, in which certain types of pollution externalities were explicitly included. They analyzed these issues with a 19-sector CGE model based on 1983 US data. The simulation results indicated that when additional government expenditure is financed by Pigouvian taxes,[54] the marginal cost of public funds is substantially below

[52] See, for example, Boyd and Uri (1991), Glomsrod et al. (1992), Conrad and Schroder (1993), Blitzer et al. (1992), Lee and Roland-Holst (1993), Robinson et al. (1993), Lewis (1993), Azis (1993), Beghin et al. (1997), Copeland and Taylor (1994), Persson (1994), Dowlatabadi et al. (1994), Nestor and Pasurka (1995), Yeldan and Roe (1994), Gruver and Zeager (1994), and Espinosa and Smith (1994).
[53] The analysis in this paper compared the relative effectiveness of two different methods for meeting the Bush Administration's goals outlined in the Clean Air Plan.
[54] A Pigouvian tax is a tax on pollution. A firm can avoid this tax either by reducing output or by pollution abatement. This contrasts with, for example, Sandmo (1975), who created a model in which the only way pollution can be reduced is through an output-reducing commodity tax. For practical reasons, marketable licenses to pollution may be preferred to

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

one. Labour, sales and output taxes also affect the output of the polluting industries and thus have indirect Pigouvian effects which tend to reduce the associated marginal costs of public funds.

Devarajan (1993) noted that the lack of property rights was an important factor in the environmental degradation of many developing countries and suggested possible ways of incorporating the misuse of property rights into environmental CGE models for these countries. Espinosa and Smith (1994) reported a computable general equilibrium model for measuring the environmental consequences of international trade policy. Their model used existing non-market valuation estimates with specific consumer preferences and feedback effects on market demands. Persson (1994) formulated a situation of undefined and well-defined property rights in a computable general equilibrium model of deforestation in Costa Rica.

On the other hand, Xie and Saltzman (2000) used the computable general equilibrium approach to develop an integrated economic and environmental model to analyze environmental policies in developing countries. The model incorporated various environmental components into a standard CGE framework, including pollution taxes, subsidies, and cleaning activities. The model was applied to China to evaluate the effectiveness of Chinese environmental policies on pollution control and their impacts on the Chinese economy.

Felder and Schleiniger (2002) analyzed the trade off between efficiency and the political feasibility of several CO_2 tax and reimbursement schemes, using a computable general equilibrium model for Switzerland. The simulation results indicated that a policy combining a uniform CO_2 tax with differentiated labour subsidies preventing intersectoral redistribution is a better solution for the trade-off than the current tax schemes in various countries.

Pigouvian taxes. Ballard and Medema used Pigouvian taxes here because they can be easily incorporated into the model.

ISBN:978-84-693-0717-5/DL:T-442-2010

On the other hand, Gómez and Kverndokk (2002) analyzed aspects of fiscality and environment using a general equilibrium model with imperfect competence. This model was novel because it incorporated a representation of labour market based on the reserve wages and search costs. The productive structure studied a disegregation of sixteen productive sectors involving only one representative consumer. The simulation analyzed how substituting social values with taxation affects polluting emissions in a scenario where there is constant public income.

In contrast, O'Ryan et al. (2005) used the static computable general equilibrium model (ECOGEM-Chile) to analyse the economy wide impacts of several environmental, social and combined policies applied to the Chilean economy. They simulated: 1) three environmental policies that imposed different taxes on PM10, SO_2 and NO_2 emissions, respectively; 2) the tax on PM10 in a context of high unemployment; and 3) a social policy that increased government transfers to households. They also simultaneously simulated the environmental tax on PM10 and the social transfer policy of a mixed social-environmental policy package. The results used real disposable income by quintiles as proxy and showed that environmental tax policies may have negative social effects. As a result, the ECOGEM-Chile model was useful for systematically and holistically analyzing different economy wide policies and their impact on the Chilean economy.

Learmonth et al. (2007) used a multi-period economic-environmental computable general equilibrium model to analyse local sustainability policy issues. Their focus was the small, open, and labour constrained regional economy of Jersey. They employed CGE model simulations to track the impact of changes in population on a number of energy-consumption and pollution indicators. This involved using a recursive dynamic framework with alternative hypotheses regarding the economic conditions during the time period under consideration. They found that household consumption was the key factor governing the environmental impact of economic disturbances. Consequently, they also examined how sensitive the simulation results were to different assumptions affecting the wage

ISBN:978-84-693-0717-5/DL:T-442-2010

elasticities of labour demand and supply, as well as the speed with which household income adjusted to shifts in labour supply.

Finally, De Miguel et al. (2009) developed a static CGE model for the Extremadurian economy to analyse the effects that have been caused by the introduction of the tax on retail sales of some fuels in a regional economy. In this model, a hypothetical regional tax rate, to finance environmental policies, is considered. The simulation showed household welfare losses, decreasing activity levels and generalised price reductions, except in production sectors more directly linked to the oil products sector. In addition, they also observed that this hypothetical additional regional fuel tax rate would reinforce the effects produced by the national tax rate.

f) Pollution Permits

There is little literature regarding the numerical analysis of alternative designs of tradable pollution permits. Using analytical and numerical static general equilibrium models with pre-existing distortions, Parry et al. (1999) assessed the efficiency impacts of two policies designed to reduce US CO_2 emissions: a tax and a grandfathered quota. They found that tax interactions with pre-existing distortions significantly raised the efficiency cost of CO_2 abatement and that the impact was particularly large for the grandfathered quota, which did not increase government revenue.

Similar results can be found in Parry and Williams (1999) and Goulder et al. (1999). These two analyses also looked at performance standards that restrict the emissions rate per unit of output and that resemble the output-based allocation method considered in the present study. They found that with pre-existing distortions, an idealized performance standard which sets the most cost-effective standard was more costly than an emissions tax but less costly than a grandfathered quota.

g) Sustainability Impacts

Environmental challenges in transportation have repeatedly occurred throughout history; for example in London in the 1870s there was concern

ISBN:978-84-693-0717-5/DL:T-442-2010

that the growing population would lead to greater use of horse drawn transport, which in turn would lead to the city being overwhelmed by horse manure (an earlier form of transport derived pollutant).[55] Environmental concerns regarding the transport system have increased significantly since the 1970s. Transport is now responsible for at least a quarter of global primary energy use and for a similar amount of CO_2 emissions.[56]

Nugent et al. (2002) used an environmentally extended computable general equilibrium model (EECGE) for India to demonstrate that simple policy changes can be made which would raise distributional equity, environmental sustainability, and growth-increasing efficiency all at the same time. The results support the hypothesis that sustainable development is generally possible only when there is a thorough integration of economic, distributional, and environmental policies that can collectively "win" in achieving economic growth, equity, and environmental objectives at the same time.

Finally, Steininger et al. (2007) used a computable general equilibrium approach model when they studied private transport and provided a detailed empirical analysis for Austria. Regarding the social dimension, it has often been argued that poorer households (and commuters) would have to bear a disproportionate share of the road pricing burden. However, they found the opposite, that is, there was a stronger negative policy impact on richer households, and on a small group of intensive car users. Recycling revenue ameliorated the negative social and economic effects of road pricing, without reversing the desired positive environmental effects. They systematically addressed distributional impacts within a quantitative framework because these are most important when gauging political feasibility.

[55] The impact of this on daily life is captured in an example quoted by Weightman and Humphries (1985): "But with all the horse traffic, there was an awful amount of dirt on the streets, some of them were in a dreadful state. There were crossing sweepers, rather oldish men, and if one gave them a coin they would be very pleased to sweep a path across the street in front of one".
[56] See, for example, Berechman (2002).

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

h) Double Dividend

If we analyse 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 consumer well-being; hence the name "double dividend".[57] The double dividend hypothesis consists, therefore, of exploring under which conditions this trade-off might not exist, in which case 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 energy and environmental policies. This is because they lead, in many cases, to quantitative analytical frameworks that estimate the effects of a certain tax policy on variations in CO_2 emissions, as well as other pollution factors, the economic cost associated with this policy, and the economic and social benefits stemming from such public interventions. One of the first studies by Bovenberg and De Mooij (1994) 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, we can mention the papers by Labandeira and Rodríguez (2004), who studied the impact of an environmental tax on carbon dioxide emissions. On the other hand, Manresa and Sancho (2005) constructed an environmental CGE model for Spain. The general equilibrium framework was used to analyze the existence of the double dividend in the

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

ISBN:978-84-693-0717-5/DL:T-442-2010

Spanish economy. The model looked at a detailed representation of the productive structure, and incorporated twenty-two branches of activity, ten of which correspond to the power sectors. The simulation consisted of introducing an environmental tax on the intermediate and final use of energy goods. Under a revenue neutral assumption, they evaluated the real income and employment impact of lowering payroll taxes. The results of this analysis confirmed the possibility of introducing an environmental tax to the economy and simultaneously increasing the number of jobs and reducing the polluting emissions.

Manresa and Sancho (2007), analysed the impact of recycling ecotaxes towards lower labor taxes in Spain. At the regional level, works by André, Cardenete and Velázquez (2005) and by González and Dellink (2006) assessed the impact of an environmental tax reform on the economies of Andalusia and the Basque Country, respectively.

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UNIVERSITAT ROVIRA I VIRGILI
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MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
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Chapter 2

The National Accounting Matrix with Environmental Accounts for Catalonia, 2001

UNIVERSITAT ROVIRA I VIRGILI
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2.1. Introduction

A social accounting matrix (or SAM) can be generically defined as a database that shows all the transactions between the agents of a specific economic system and the interrelation between income distribution, consumer patterns and production structure. A SAM, then, uses a complete representation of the circular flow of income to explain how income is obtained and how the expense of all the economic agents is generated. It provides considerable numerical information which, in conjunction with its accounting framework, can make it a very useful tool.

The origin of social accounting matrices can be traced back to the pioneering papers of Stone (1978) and Pyatt and Round (1979). Subsequently, Pyatt and Round (1985), Pyatt (1988) or Keuning and Ruijter (1988) systemized the structure and the accounting chart of the SAM.

From the end of the seventies and during the eighties, a great number of SAMs were constructed for many countries, but it was not until 1993 that they appeared grouped together more specifically and extensively by the United Nations System of National Accounts (SNA), and in 1995 by the European System of Integrated National Accounts (ESA).[58]

The first social accounting matrix was constructed for Spain by Kehoe, Manresa, Polo and Sancho (1988) for the year 1980. It was developed to calibrate the parameters of a general equilibrium model that analysed the effects of introducing VAT in the Spanish tax system.

Uriel (1990) developed a SAM for the Spanish economy of 1980 which was an alternative to the one developed by Kehoe et al. (1988). This database was the basis for the subsequent Spanish social accounting matrix

[58] The SAM is explained in Chapter 20 of SNA 93, and in Chapter 8 of ESA 95. The ESA defines the social accounting matrix (epigraph 8.134) as "the presentation of ESA accounts in a matrix which explains in detail the links between an origin-destination table and sectoral accounts"; this epigraph also points out that "the SAM attempts to focus on the role of people in the economy, by means of the itemization of household and labour market sectors".

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for 1990, published in 1997.[59] This matrix was developed by both the National Statistics Institute and the Institute of Economic Research of Valencia (Uriel et al., 1997). Some authors have made some modifications to its structure. Gómez (2001), for example, extended the information by disaggregating some of its accounts. Fernández and Polo (2001), make a new modification of the 1990 matrix (altering some accounting balances and dividing some aggregated accounts).

Subsequently, Uriel, Ferri and Moltó (2005) estimated a new social accounting matrix for Spain, which updated the previous one published by the National Statistics Institute. The general shape of the new social accounting matrix was similar to that of 1990 to facilitate an inter-temporal analysis, but the classification of households and factors was varied.

Finally, Cardenete and Sancho (2006) developed a social accounting matrix of the Spanish economy for 1995. This SAM used purchase prices instead of basic prices and disaggregated the tax figures to a greater extent.

For the Spanish regions, Manresa and Sancho (1997) constructed the first SAM for the Catalan economy for the year 1987 in an attempt to assess environmental impacts on production and consumption activities. Subsequently, Llop and Manresa (1999) presented two SAMs for Catalonia for 1990 and 1994. And finally, Pérez and Polo (2007) developed a SAM for Catalonia to estimate the energy intensity of the Catalan economy in 2001.

If we focus on the region of Andalusia, Curbelo (1986) presented a social accounting matrix for 1980. This matrix was used to study the regional economy in terms of growth and equity, based on a linear SAM model. It was also used by Isla (1999) to carry out an extensive linear multiplier analysis. Years later, Cardenete (1998) developed a social

[59] According to De Miguel (2003): "This matrix is different with respect to the one carried out by Kehoe et al. (1988); one of the most noteworthy differences is that, following the general trend, it is a square matrix; moreover, a more detailed procedure of some transactions is carried out in this matrix and, on the other hand, it has greater institutional detail. Some examples of this are the disaggregation of the capital account, the incorporation of accounts for companies, the incorporation of two levels of goods and services, or a more detailed processing for operations in which the foreign sector intervenes".

ISBN:978-84-693-0717-5/DL:T-442-2010

accounting matrix for 1990. Subsequently, Cardenete (2000) obtained a matrix for 1995 which was used as a database to carry out a linear multiplier exercise and to develop a general equilibrium model with which to analyse the effects of tax reform on Personal Income Tax. And finally, Moniche (2000) constructed a matrix which stands out because of its high degree of disaggregation. Cardenete and Moniche (2001) constructed a social accounting matrix of the economy of Andalusia for 1995 (SAMAND-95) using data from Regional Accounts and the Input-Output Framework of Andalusia for 1995. They presented flows between various economic agents. Cardenete, Fuentes and Polo (2007) constructed a social accounting matrix with purchasing prices for Andalusia for the year 2000. On the other hand, Mainar and Flores (2005), in order to study the basic features of the Aragon economy, constructed of a social accounting matrix for Aragon (1999). Cazcarro and Sánchez (2007) constructed a social accounting matrix for the province of Teruel for 1999, which they used to distinguish the economic structure of this province from the whole region of Aragon.

Rubio (1995) presented an application for Castilla-Leon for 1995.[60] For the economy of Extremadura, De Miguel, Manresa and Ramajo (1998) constructed a simple social accounting matrix and presented a linear model of SAM production and employment multipliers.

Ramos, Fernández and Presno (2001) constructed a social accounting matrix for the economy of Asturias for 1995 and Argüelles and Benavides (2003) presented a SAM for the economy of Asturias with data from the regional accounts for the year 1995.

Fernández-Macho, Gallastegui and González (2006) showed a social accounting matrix for Galicia. Finally, Cámara and Marcos (2007) presented a social accounting matrix for the Community of Madrid with statistical data for the year 2000.

[60] It should be taken into account that this matrix is incomplete since it only presents the sub-matrix needed to calculate the linear SAM multipliers.

ISBN:978-84-693-0717-5/DL:T-442-2010

A national accounting matrix with environmental accounts (NAMEA) is simply a double-entry table in which the rows reflect the origin of the resources available to the economy, and the columns reflect the uses made of these resources by the economic agents. Furthermore, the total of each row must coincide with the total of the corresponding column in the same account. Thus, a NAMEA extends the SAM with environmental information in order to describe how economic activities cause negative or positive effects on the environment.

Economic activities use natural resources and generate pollutant emissions, which mean that economic and environmental information need to be analysed jointly. For this to be done, in 1993 the United Nations published its System of National Accounts (United Nations, 1993). For the first time, this handbook formulated an accounting framework for assessing national accounts and environmental statistics, which determined how economic and environmental information was to be integrated but did not define a comprehensive method for doing so. In 1998, this integrated system was revised and published in a handbook (United Nations, 2003).[61] The common framework described for economic and environmental information enabled the environment's contribution to the economy and the economy's impact on the environment to be consistently analysed.

In addition to the efforts by the United Nations to integrate economic and environmental accounts, several studies have analysed the interaction of economic and environmental information.[62] Studies on incorporating pollution emissions and environmental impacts into the social accounting matrix framework were first made in the 1990s.[63] For example, Keuning (1992, 1993 and 1994) proposed a national accounting matrix that would include environmental accounts (that is, an environmentally extended SAM

[61] The *United Nations Handbook of National Accounting: Integrated Environmental and Economic Accounting* was jointly revised by the United Nations, the European Commission, the International Monetary Fund, the Organisation for Economic Cooperation and Development, and the World Bank. Much of the work was done by the London Group on Environmental and Natural Resource Accounting through a review process that started in 1998.
[62] See, for example, Ahmad et al. (1989) and Lutz (1993).
[63] Chapters 4 and 6 of the System for Integrated Environmental and Economic Accounting (United Nations, 2003) explicitly call for associated environmental flows to be included in a SAM.

ISBN:978-84-693-0717-5/DL:T-442-2010

system).[64] It would include both economic variables and pollution information, and economic variables would be expressed in monetary terms and environmental ones in physical terms. Pollution originating from production, consumption or import activities would appear in an emissions account.[65]

Xie (1995) constructed an environmental SAM for China that took into consideration polluting emissions (liquid waste, solid waste and suspended dust). The SAM considered the dejection activities of different sectors, payments to avoid emissions, taxes paid for emissions, subsidies for controlling emissions, and industrial environmental investment (waste treatment plants and control teams). These activities were differentiated by production type, and resulted in a consistent database with which initially to calibrate a model with dejection activities. This SAM was therefore able to use real data on dejection costs to evaluate environmental policies.

The first pilot National Accounting Matrix that included Environmental Accounts (NAMEA) developed for the Netherlands (De Haan and Keuning, 1996) was an attempt to embed indicators for economic and environmental performance into one information system. The first NAMEA showed the environmental stress of production and consumption in a consistent format with the economic figures in the national accounts, by extending the national accounts matrix with environmental accounts expressed in physical units.

Keuning, Dalen and De Haan (1999) described an aggregated NAMEA which they used to compare the contribution of economic activities to economic indicators with the contribution of economic activities to environmental themes. They also described how economic activities contribute cumulatively to economic and environmental indicators (thus taking into account the relations between the production activities) and

[64] The origin of their work is the input-output approach of Leontief (1970). Leontief´s (1970) analysis of the physical economy can be regarded as the first prototype NAMEA since both systems are characterized by a hybrid structure including both physical as well monetary data" (De Haan (2001)).
[65] These environment satellite systems have been extended from the pilot version presented in De Haan et al. (1993).

described a number of recent applications and extensions of the NAMEA in the Netherlands. Keuning and Steenge (1999) described the structure and methodology of construction of a NAMEA.

De Haan (1999) presented a comparison of databases with economic and environmental information for the economies of Sweden, Germany, United Kingdom, Japan and Holland. In the same year, Ike (1999) described a NAMEA for Japan which provided a comprehensive and consistent picture of the interrelationship between the economy and the natural environment, a basis for applying cost-benefit analysis and the necessary information for policy planning. It not only gave environmental pressures from domestic pollutant emissions and transboundary flows from the rest of East Asia, but also focused on pollutant emissions in East Asia in relation to future growth potential.[66]

Vaze (1999) described the background to the work carried out on environmental accounts in the UK and explained how these accounts were calculated. Results from the pilot accounts were reproduced in a NAMEA framework, so that they could be compared with the NAMEAs constructed by other countries.

Xie and Saltzman (2000) constructed a numerical version of the environmentally extended SAM using Chinese data from 1990. Multiplier and structural-path analyses were applied to this database to assess environmental impacts of pollution-related economic policies. Xie (2000) then extended the SAM to capture the relationships among economic activities, pollution abatement activities, and pollution emissions. The author presented a numerical example of the environmentally extended social accounting matrix (ESAM) using Chinese data from 1990. The multiplier and structural path analyses were applied to the ESAM to assess the environmental impacts of pollution-related economic policies. The results showed that an ESAM can be a useful tool for environmental policy analysis.

[66] In this paper, the global warming effects of the six gases listed in the Kyoto Protocol were discussed.

ISBN:978-84-693-0717-5/DL:T-442-2010

De Hann and Keuning (2001) showed how environmental issues can be incorporated into macroeconomic accounting by constructing and using a National Accounting Matrix that includes Environmental Accounts (NAMEA) for the Netherlands. The paper firstly elaborated a number of conceptual issues on the harmonisation of environmental statistics and national accounts. Specific attention was given to the consistent allocation of pollution to production and consumption activities and the importance of aggregated environmental indicators.

The rest of the chapter is organised as follows. The next section describes the structure of a SAM. Section 2.3 describes the structure of a NAMEA. Section 2.4 presents the SAM for Catalonia and section 2.5 presents the NAMEA for Catalonia. The chapter ends with a conclusions section.

2.2. Structure of a SAM

A SAM can be defined generically as a database that shows all transactions made between the agents of a specific economic system and the interrelation between income distribution, consumer patterns and production structure. It reflects how income is obtained and how all economic agents spend their money by representing the full circular flow of income. Databases of this sort provide a considerable amount of numerical information, which makes them very useful for economic modelling.

The information in a SAM comes from various sources, including national accounts, input-output matrices and economic surveys. It has the following characteristics:

a. It reflects the circular flow of income.

b. It complies with Walras' law for all accounts.

c. It allows transparent identification of structural socioeconomic relations.

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

d. It forms the basis of computable general equilibrium models, as it is flexible, extensive and includes demographic, social and environmental indicators.

e. It is a bridge between microeconomics and macroeconomics, because it disaggregates productive activities, factors of production and institutions.[67]

A SAM reflects all the economic transactions and monetary flows between economic agents during a period of time, generally a year.[68] 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.

[67] See Pyatt and Round (1979).
[68] See, for example, Pyatt (1988).

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

Table 2.1. Structure of a SAM

			Firms	**Labour**	**Capital**	**Consumption**	**Public Sector**	**Saving-Investment**	**Foreign Sector**	**Total**
DOMESTIC ECONOMY	**PRODUCTION**	**Firms**	A	0	0	C	G	I	X	**Total uses**
		Labour	W	0	0	0	0	0	0	**Total earned income**
		Capital	Π	0	0	0	0	0	0	**Total profit income**
	INSTITUTIONS	**Consumption**	0	W	Π	0	0	0	0	**Total private income**
		Public Sector	T_1	0	0	T_2	0	0	0	**Total public revenue**
		Saving-Investment	0	0	0	S	D	0	$-F$	**Total saving**
REST OF THE WORLD		**Foreign Sector**	M	0	0	0	0	0	0	**Foreign payments**
TOTAL			**Total resources**	**Total earned income**	**Total profit income**	**Total private expenditure**	**Total public expenditure**	**Total investment**	**Income from foreign sources**	

Source: Manresa and Sancho (1997).

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

Table 2.1 presents a simplified representation of a SAM. In the first row, A is intermediate consumption, C is private consumption, I is gross capital investment, G is public expenditure, and X is sectorial exports. Additionally, W is the payment of earned income, Π is gross operating surplus or profit income, S is private saving, D is public sector deficit, F is trade balance, T_1 are net taxes on production, T_2 are direct taxes and, finally, M are sectorial imports of equivalent products.

The matrix representation shown in table 2.1 has major advantages. It makes it possible to show, in a single register, the payments and income between two units participating in a transaction. It also shows the origin and destination of transactions in a way that is easy to understand. Finally, it makes it possible to directly obtain the gross domestic product (*GDP*) of an economy by applying the following calculations:

$$GDP = C + G + I + X - M \quad \text{(expenditure)}, \tag{2.1}$$

$$GDP = W + \Pi + T_1 \quad \text{(income)}, \tag{2.2}$$

showing the gross domestic product of the economy in terms of expenditure and income, respectively.

2.3. Structure of a NAMEA

A NAMEA contains the information reflected in a SAM and its links to the environment. It includes both the 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.

ISBN:978-84-693-0717-5/DL:T-442-2010

A NAMEA can be represented as a set of matrices containing data from national accounts (SAM) and environmental accounts.[69] The SAM expresses the flows associated with the economic sphere in monetary units; in other words, it shows how flows are related to production and consumption activities, and subsequent income distribution and redistribution. In contrast, environmental accounts are represented in flow matrices expressed in physical units, which in turn are broken down into submatrices that show flows of natural resources used as inputs by the productive system, flows of atmospheric emissions, etc. The environmental data included in NAMEA databases are not unique, as they may concern atmospheric emissions, waste, woodland surface area, active ingredients of subsoil, use of energy and consumption of natural resources. They may also include energy balances and product flows.[70]

Table 2.2 shows the structure of a NAMEA database that represents only pollutant emissions. The table shows six greenhouse gases, but could perfectly show other emissions. Note that the units of measurements are not unique and depend on the type of gas. In our example, they are tons, kilotons, and kilograms. In the environmental account of table 2.2, the first row contains the column vectors E^p that show the emissions of each gas made by sectors of production. Similarly, E^c are column vectors of physical emissions made by private agents, and E^m are the emissions due to the external relations of the economy.

[69] Environmental accounts are linked to the measurement of environmental problems such as air pollution, water pollution and waste generation; they describe the pressures and flows that economic activity exerts on the environment (emissions), use of physical natural resources (environmental inputs) and steps taken by society to reduce or eliminate such pressures (recycling, reuse or depuration). Thus, environmental accounts are statistical data matrices with relations to certain environmental aspects, assessed in monetary terms and/or physical units; the only requirement is that the information take into account the established definitions and classification standards from economic statistics.
[70] Methods involving material and energy balance sheets have been developed for the physical accounting of product flows and have already been applied in some countries. These methods use physical input-output tables, extractions of environmental resources, the transformation of these materials within the economy, and waste generation from production and consumption activities (excluding transformations that occur in the natural environment). For example, see Stahmer et al. (1997) and Strassert (2000).

ISBN:978-84-693-0717-5/DL:T-442-2010

Table 2.2. Structure of a NAMEA with emissions accounts

			DOMESTIC ECONOMY						Foreign Sector	TOTAL	EMISSIONS[71]
			Firms	Labour	Capital	Consumption	Public Sector	Saving-Investment			
DOMESTIC ECONOMY	PRODUCTION	Firms	*A*	*0*	*0*	*C*	*G*	*I*	*X*	**Total uses**	E^P
		Labour	*W*	*0*	*0*	*0*	*0*	*0*	*0*	**Total earned income**	0
		Capital	Π	*0*	*0*	*0*	*0*	*0*	*0*	**Total profit income**	0
	INSTITUTIONS	Consumption	*0*	*W*	Π	*0*	*0*	*0*	*0*	**Total private income**	E^C
		Public Sector	T_1	*0*	*0*	T_2	*0*	*0*	*0*	**Total public revenue**	0
		Saving-Investment	*0*	*0*	*0*	*S*	*D*	*0*	*-F*	**Total saving**	0
REST OF THE WORLD		Foreign Sector	*M*	*0*	*0*	*0*	*0*	*0*	*0*	**Foreign payments**	E^m
TOTAL			**Total resources**	**Total earned income**	**Total profit income**	**Total private expenditure**	**Total public expenditure**	**Total investment**	**Income from foreign sources**		

Source: Alcántara (2003).

71 These emissiones are: CH_4 (t), CO_2 (kt), N_2O (t), SF_6 (kg), HFC (kg) and PFC (kg).

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

The database in table 2.2 makes it possible to integrate information about monetary flows derived from regional or national accounting with physical measurements of the atmospheric emissions of six greenhouse gases. It shows the interconnections between economic and environmental accounts, and gives clear insight into the relation between activities with a major economic influence and those which cause major harm to the environment.

2.4. The SAM for Catalonia

Certain statistical information is essential for constructing a SAM. This information includes the relations of the productive system (i.e. an input-output table) and the operations of income distribution between factors and institutions (i.e. the national or regional accounts of the economy).

Constructing a regional SAM often involves statistical difficulties in obtaining certain variables because complete homogenous sources are often not available. Sometimes the information only partially covers what is needed, or simply does not exist. Solving these problems requires indirect calculations and assumptions for the regional variables not provided by the statistical information.

The statistical sources used to construct the Catalan SAM database are:

- ***The Input-Output Table of Catalonia in 2001*** **(IDESCAT, 2007).**[72] The input-output framework captures the economic relations between the activities and their main economic operations: production, intermediate consumption, private consumption, investment, and exports.

[72] The European System of National and Regional Accounts of 1995 (SEC-95) was used as the methodological reference for constructing the input-output table of Catalonia. The SEC-95 is a suitable countable framework to make a systematic and detailed description of an economy as a whole, its components and its relations with other economies.

ISBN:978-84-693-0717-5/DL:T-442-2010

- ***The Regional Accounting of Spain* (INE, 2001).** This source provides the main economic relations between Spain and the Catalan economy.

The input-output table of Catalonia is an extended use table at basic prices. However, the 1995 European System of National and Regional Accounts recommends that the input-output framework should include the following information:

- A make matrix or supply matrix, in which a generic element (i, j) represents the amount of commodity j produced by industry i.
- A use matrix, in which a generic element (i, j) represents the amount of commodity i produced by industry j.
- A symmetric matrix, in which a generic element (i, j) represents the amount of industrial output or commodity i required by industry or commodity j.

Despite European recomendations, the Catalan institute of statistics (IDESCAT) developed only an extended use table because it believed that developing a symmetric table involves huge costs and a huge statistical effort and that the table is a cumbersome way of presenting information. For this reason, the make matrix of Catalonia is therefore unavailable for 2001.[73]

To build a SAM, however, we need a symmetric table that can be calculated indirectly using both the use and make matrices. To avoid the statistical gap, we estimated the symmetric table in a two-stage process. First, we estimated a make table at basic prices for the Catalan economy for 2001, on the basis of the structure of the make matrix of the Spanish economy and indirect information about few productions provided by IDESCAT. With this information we applied the RAS method to the coefficients of the Spanish make matrix.

[73] See, IDESCAT (2007).

ISBN:978-84-693-0717-5/DL:T-442-2010

The RAS method, originally proposed by Stone (1961) and Stone and Brown (1962), was developed within the Cambridge Computable Model of Economic Growth.[74] Generally speaking, this method consists of modifying the initial matrix of structural coefficients and multiplying it by correction coefficients in rows and columns, so that the totals (horizontally and vertically) of the elements of the estimated table are as close as possible to the real values.[75] With this technique, a new matrix of technical coefficients is calculated on the basis of information about new sectoral production and the matrix stemming from coefficients.[76] The appendix 2.1 at the end of the chapter describes the RAS procedure.

We then used the extended use table provided by IDESCAT and the make table that we had estimated to obtain the symmetric table,[77] sector by sector. Specifically, matrix *A* of direct structural coefficients for the symmetric matrix, or input-output coefficients, was derived from the use matrix in two steps. First, the elements in the use matrix were divided by the domestic output of the absorbing industry. Second, the resulting matrix *H* was pre-multiplied by the transpose of the share matrix *D*: $A=D'H$. Matrix *D* was derived from the make table, and its elements were calculated by dividing each commodity by the total commodity output.[78]

A symmetric input-output table is an industry-by-industry or product-by-product table. To create this table, the data in the make and use tables

[74] See, Bacharach (1970).
[75] This method is a transfer of the theory of matrix adjustments with restrictions to the estimation of input-output matrices. This adaptation was used at first as an updating technique of the intermediate transaction matrix. Subsequently, it was redirected towards spatial projection in order to estimate regional input-output tables based on a specific national table.
[76] The results obtained in several empirical analyses tend to reassert the RAS technique as the one which provides the closest results to direct methods. In order to look into this statement in depth, we refer to Malizia and Bond (1974), Round (1978), Pedreño (1986) and Alvárez (2001), among others.
[77] The symmetric nature of the symmetric table means that we can obtain the matrices of technical coefficients and the Leontief matrices, which are the basis for the economic structural analysis that facilitates the input-output framework.
[78] Miller and Blair (1985) describe these calculations.

ISBN:978-84-693-0717-5/DL:T-442-2010

of the economy are rearranged into a single table.[79] Though similar in structure to the use table, the symmetric table has two basic differences:

a) It has the same number of rows and columns, both for the data in the demand rows (intermediate and final) and the data in the production columns (intermediate consumption, value added and imports).

b) By including imports we can obtain the total resources so that the same table reflects both supply and demand. The symmetric table therefore captures the well known balance between the uses and resources of the input-output framework.

In a symmetric table, the units of functional analysis have to be the homogenous production units. These are aggregated and generate the homogeneous activity sectors, with pure structures of production costs. However, the homogeneous production units and the homogeneous production sectors exist only in theory. To estimate the production coefficients of homogeneous sectors, we can apply two hypotheses:

a) ***Industry Technology Hypothesis*.** This assumes that the technology of the homogeneous activity sectors does not differ from the technology of the main activity sectors.

b) ***Product Technology Hypothesis*.** This assumes that each product has a characteristic technology, regardless of the type of unit it develops.[80]

[79] According to the Spanish statistical institute, the objective of the symmetric table is analytical in nature. This concerns redefining accounting operations in order to obtain equation models that are applicable to the analysis of various aspects of economic reality. As these models are valid only under certain assumptions about the role of production of goods and services, the make and use tables need to be reordered until a structure consistent with these hypotheses is achieved. Specifically, for the input-output framework the table has to respond to a model of "simple production": namely, the columns of matrices of intermediate consumption and primary inputs reflect the functions of "production" of one or more (types of) specific products. To do this, some sectors of activities are "conceptual", in the sense that they are created by national accounting. These are called "homogeneous sectors." Each sector of homogeneous activity represents the production structures (costs) of a unique type of product in the economic system (obviously, in agreement with the level of disaggregation chosen).

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

We selected the Industry Technology Hypothesis because the lack of information prevented us from combining the two hypotheses.[81]

We used the symmetric table and information about the distribution of regional income to construct the SAM for Catalonia for 2001. The complete list of accounts incorporated into the SAM is shown in table 2.3. The structure of our database has important limitations mainly because of lack of regional statistics for such important variables as the division of consumers into socioeconomic groups and the description of the external relationships in the regional economy.[82]

The SAM for Catalonia can be seen in the appendix 2.2. Our database comprises twenty-seven production activities and two factors of production: labour and capital. The rows of the activities show intermediate outputs, private consumption, public consumption, gross capital investment, and exports to external markets. The columns reflect the resources of each sector: intermediate inputs, remuneration of employees, gross operating surplus, taxes on production, and imports from the external sector. Similarly, the labour account receives its income from wages and salaries of the households in the economy. The capital account receives the operating surplus, which in turn constitutes a household income.

The consumer's income is made up of employee remuneration, operating surplus and transfers from the public sector. This agent spends on consumption and pays income taxes to the central government. The residual value constitutes private savings.

---

[80] The basic procedure of the product and the industry technology hypothesis for calculating a symmetric table is described in Miller and Blair (1985).
[81] According to the Spanish statistics institute and from a purely methodological perspective, although it is possible to construct symmetric tables based on just one of these hypotheses, results from a mechanical application may lack economic significance: in the case of "product technology", negative values could be obtained for some inputs and, in the case of "industry technology", approaches may be technically or economically absurd. The best strategy for developing symmetric input-output tables is therefore to combine the two hypotheses.
[82] This is a common problem when constructing a regional SAM (see, for example, Rubio (1995), Cardenete (1998), Llop (2001), and De Miguel (2003)).

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

Table 2.3. List of accounts in the SAM for Catalonia

SECTORS OF PRODUCTION

1. Agriculture
2. Fishing
3. Energy, minerals, coke, petroleum and fuels
4. Electrical energy, gas and water
5. Food
6. Textile
7. Manufacture of wood and cork
8. Paper
9. Chemistry
10. Rubber and plastic products
11. Other non-metallic mineral products
12. Metal
13. Machinery
14. Electrical equipment, electronics and optics
15. Automobiles
16. Other industries
17. Construction
18. Commerce
19. Hotel management
20. Transport and communications
21. Financial intermediation
22. Real estate activities and entrepreneurial services
23. Public services
24. Education
25. Sanitary and veterinary activities, social services
26. Other services, social activities and personal services
27. Homes that employ domestic staff

FACTORS OF PRODUCTION

28. Labour
29. Capital

PRIVATE AND PUBLIC AGENTS

30. Households
31. Net production taxes
32. Net product taxes
33. Direct taxes
34. Social Security contributions
35. Government

SAVING AND INVESTMENT

36. Saving-investment

EXTERNAL RELATIONS

37. Foreign sector

ISBN:978-84-693-0717-5/DL:T-442-2010

Public sector earnings come from net production taxes,[83] net product taxes,[84] direct taxes,[85] and social security contributions. The corresponding column reflects government consumption and public transfers to consumers and businesses.[86] Since public revenues are not sufficient to cover public costs, the government records a surplus, which provides a value of public deficit in the capital account.

The saving-investment account column shows gross fixed capital formation.[87] The row, on the other hand, reflects private savings intended to finance investment. The foreign agent row reflects sectorial imports of goods and services and the column reflects sectorial exports. The difference between these two values is the trade balance, which translates into a deficit with foreign countries and a surplus with the rest of Spain in the saving-investment account.

2.4.1. Obtaining the Regional GDP

Once the regional SAM01 has been obtained, the main macro-dimensions of the Catalan economy for 2001 can be calculated. The regional GDP can be obtained using the definitions shown in expressions (2.1) and (2.2), in the two ways shown below:

[83] Net production taxes are the difference between the so-called other production taxes and other production subsidies, by which productive activity is taxed.
[84] Net product taxes are the difference between taxes on products and subsidies on products. These taxes include VAT and taxes and duties on imports.
[85] Direct taxes are the sum of personal income tax (central administration), other direct taxes (central administration) and other taxes ceded to the autonomous region (IDESCAT, 2004).
[86] These public transfers are the sum of total pensions in 2001 (Social Security pensions, non-contributory Social Security pensions and community care pensions), total contributory unemployment benefits, contributory benefits for partial unemployment, welfare benefits (subsidy), seasonal welfare payments for farm workers, active employability assistance, unemployment benefits, and coverage rates (IDESCAT, 2004).
[87] The saving-investment account reflects the different sources of savings and investment in the Catalan economy.

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

Table 2.4. GDP-expenditure. Thousands of euros, 2001

+Private consumption	73,612,148
+Public consumption	16,663,135
+Gross capital formation	29,732,483
+Total Exports	92,350,782
- Total imports	86,967,277
TOTAL GDP	125,391,271

Table 2.5. GDP-income. Thousands of euros, 2001

+Wages and salaries	52,713,137
+Gross operating surplus	56,933,465
+Social Security contributions	13,337,872
+Indirect taxes on production	2,406,797
TOTAL GDP	125,391,271

2.5. The NAMEA for Catalonia

To build the NAMEA for Catalonia we need some environmental information that is essential for empirical modelling and is often difficult to obtain at the regional level. The NAMEA for Catalonia integrates the SAM database described in the section above with the Satellite Account on Atmospheric Emissions.[88] Our database is therefore applied to atmospheric emissions and it is constructed by adding columns related to the greenhouse gas emitted by production activities and consumption.

The information in the account on atmospheric emissions includes the discharges of pollutants generated by sectors and consumption. The database originally included the emissions of ten pollutants. As our aim was

[88] The sectorial direct emissions has obtained in the development of the agreement 9703/ project 180570: "Elaboració de la Comptabilitat Satèl.lit del Medi Ambient a Catalunya, la corresponent a l'aire", supervised by Vicent Alcántara. Financed for Generalitat de Catalunya (Departament de Medi Ambient i Habitatge).

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

to model greenhouse effects, we used only the six emissions that show greenhouse pollution in the regional economy. The six gases we analysed are those that must follow the guidelines of the Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), nitrogen monoxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6). The appendix 2.3 contains the complete NAMEA used in our empirical analysis.

2.6. Conclusions

The starting point of this chapter was the construction of a social accounting matrix for Catalonia (2001). This matrix enables the interdependence between agents and sectors to be understood by providing a complete representation of the circular flow of income. However, we must bear in mind that SAMs include neither environmental variables (such as emissions of air, water or soil pollutants, toxic waste etc.) nor natural resources or environmental quality.

For this reason, in order to have a more detailed database of the interconnections between branches of activity and institutional sectors and, in turn, between these and the environment, we have added environmental information to a SAM (which contains economic information) in order to obtain a social accounting matrix with environmental accounts for Catalonia for 2001. A NAMEA is simply a double entrance table in which the origin of the resources in the Catalan economy can be observed in the rows and the uses of these resources made by economic agents can be seen in the columns.

A NAMEA has been used because it allows information about monetary flows stemming from the Regional Accounts of Catalonia to be integrated with the physical measuring of various polluting gases emitted into the atmosphere. The inter-connections between economic accounts and environmental accounts are thus revealed, and clear insight is provided as to whether or not there is a causal relation between activities of greater

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economic influence and those which cause greater harm to the environment.

We are aware that our matrices have some informative limitations because of problems of obtaining some variables at a regional level. In any case, the SAM01 and the NAMEA01 are useful databases which will be used to carry out different analyses that will be presented in subsequent chapters.

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UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
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ISBN:978-84-693-0717-5/DL:T-442-2010

Appendix 2.1

The RAS technique is based on an inter-industrial transaction matrix *Z*(0) and on a vector of effective production w(0), which together enable the initial matrix of technical coefficients *A*(0) to be defined. On the basis of this matrix, a new matrix of technical coefficients *A**(1) is calculated. It should be as similar as possible to *A*(0), and comply with the most recent statistical information, which normally comprises a new vector of production *w*(1), and new margins of the unknown new matrix of intermediate consumption *Z*(1), traditionally shown as row vector *v*(1) and column vector *u*(1). That is:

$$u = \begin{bmatrix} u_1 \\ \dots \\ u_n \end{bmatrix} \; with \;\; u_i = \sum_{j=1}^{n} z_{ij};$$

$$v = [v_1 \dots v_n] \; with \;\; v_i = \sum_{i=1}^{n} z_{ij} \; ; and \;\; w = [w_1 \dots w_n].$$

In other words, *u* is the total of the rows of intermediate consumption, *v* is the columns sum of intermediate consumption, and *w* represents effective production. The RAS method is carried out in the following stages:

1. The intermediate consumption is initially calculated by rows (u^1) using the initial technical coefficient matrix [*A*(0)] and the new final production [*w*(1)]:

$$u^1 = A(0)\, w(1).$$

2. The diagonal matrix r^1, which shows the first correction coefficients by rows, is obtained by means of the quotient between the known intermediate consumption [*u*(1)] and the intermediate consumptions estimated in the previous stage u^1:

$$r^1 = [u(1)]\left[u^1 \right]^{1},$$

ISBN:978-84-693-0717-5/DL:T-442-2010

where $u(1)$ is the diagonalizable matrix which records the real totals of coefficients by rows. The corrected matrix of coefficients $A^1 = r^1 A(0)$ will satisfy the restriction imposed by rows:

$$\left[A^1\ w(1)\right] i\ \left[r^1\ A(0)\ w(1)\right] i = Z^1\ i = u(1).$$

3. The intermediate consumption by columns (v^1) is calculated using the corrected matrix of technical coefficients (A^1) and final production $w(1)$:

$$v^1 = i'\left[A^1 w(1)\right].$$

4. The first diagonal matrix of correction of coefficients by columns *(s)* is calculated by dividing the known intermediate consumption of the columns $v(1)$ by the estimated values v:

$$s^1 = [v(1)]\left[v^1\right]^{1},$$

where $v(1)$ represents the diagonalised matrix of new totals by columns. Using the previous matrix, we obtain the matrix of corrected coefficients, $A^2 = A^1\ s^1 = r^1 A(0) s^1$, which will now comply with the restriction by columns:

$$i'\left[A^2 w^1\right] = i'\ z^2 = v^1.$$

5. The new corrected matrices are calculated in the same way by carrying out the following interactions by rows :

$$u^2 = \left[A^2 w(1)\right] i, \ldots, u^h = [u(1)]\left[u^h\right]^{1}.$$

6. The following vectors of coefficients are established:

$$r^2 = [u(1)]\left[u^2\right]^{1} \ldots, r^h = [u(1)]\left[u^h\right]^{1}.$$

ISBN:978-84-693-0717-5/DL:T-442-2010

and used to obtain the new corrected matrices:

$$A^{3} = A^{2}s^{2} = r^{2}r^{1}A(0)s^{1}.$$
$$A^{2h\,1} = r^{h}s^{2h} = r^{h}r^{h\ \ 1} \ \ldots\ r^{1}A(0)s^{1}\ \ldots\ s^{h\ \ 1}.$$

7. The columns are corrected in the same way, and new total inputs are estimated as:

$$v^{2} = i'\left[A^{3}w(1)\right] \ \ldots, v^{h} = i'\left[A^{2h1}\ v\ (1)\right]\left[v^{h}\right]^{\ 1}.$$

Subsequently, correction coefficients by columns are equal to:

$$s^{2} = [v(1)]\left[v^{2}\right]^{\ 1}, \ldots, s^{h} = [v\ (1)]\left[v^{h}\right]^{\ 1}.$$

They are used to obtain new corrected matrices:

$$A^{4} = A^{3}s^{3} = r^{2}r^{1}A(0)s^{1}s^{2}.$$
$$A^{2h} = A^{2h\ \ 1}s^{h} = r^{h}r^{h\ \ 1}\ \ldots\ r^{1}A(0)s^{1}\ \ldots\ s^{h\ \ 1}s^{h}.$$

8. The calculation will be complete when the adjusted matrix of technical coefficients:

$$A^{*}(1) = \prod r^{i} A(0) \prod s^{i} = RAS\,,$$

complies accurately enough to the restrictions imposed by rows and columns:

$$u(1) = \left[\ A^{*}(1)w(1)\right] i\,,$$
$$v(1) = i'\left[\ A^{*}(1)w(1)\right].$$

ISBN:978-84-693-0717-5/DL:T-442-2010

Appendix 2.2

Table 2.6. Social Accounting Matrix for Catalonia (2001). Thousands of euros.

SAM			Firms 1	Firms 2	Firms 3	Firms 4	Firms 5	Firms 6	Firms 7	Firms 8	Firms 9	Firms 10	Firms 11
DOMESTIC ECONOMY – PRODUCTION INSTITUTIONS	Firms	1	279,040	6	0	0	4,789,689	231,869	170,130	47,959	12,349	17,429	294
		2	0	10,526	0	0	89,107	0	0	0	0	0	0
		3	43,588	29,232	1,911,665	1,445,409	54,253	20,143	14,844	31,684	818,782	6,707	494,825
		4	51,841	343	13,181	426,676	111,186	120,333	7,964	113,372	192,008	70,764	104,675
		5	679,972	5,538	1,299	2,756	2,818,614	249,197	1,486	39,861	469,704	74,231	8,830
		6	4,456	5,594	380	3,964	16,087	3,196,465	3,388	43,399	34,185	77,470	11,884
		7	2,325	3,648	1,458	3,529	74,597	2,199	538,830	24,687	14,608	9,672	31,421
		8	7,517	314	1,458	5,124	284,826	77,319	10,787	2,735,945	368,655	143,717	37,418
		9	224,062	2,813	18,125	39,400	225,212	842,592	18,484	513,398	5,177,434	1,179,987	132,932
		10	2,790	1,470	5,101	2,030	330,878	58,759	2,065	127,681	414,586	532,073	30,428
		11	1,589	34	4,499	6,381	198,716	5,542	3,596	3,223	71,683	20,029	441,954
		12	3,177	6,518	16,033	18,515	136,262	24,717	21,144	10,142	123,337	124,053	75,462
		13	37,118	1,827	30,926	26,347	110,398	74,240	12,199	103,308	179,508	87,371	75,388
		14	8,408	2,872	1,046	171,038	17,033	12,843	936	19,026	49,395	25,823	9,566
		15	814	30,758	887	1,982	4,100	2,903	193	1,101	1,355	1,141	920
		16	3,255	249	412	11,022	10,251	18,120	8,544	34,043	14,457	5,384	9,787
		17	49,167	7,353	462,746	358,125	166,858	34,745	9,747	20,127	221,073	18,113	154,051
		18	162,728	8,039	22,085	47,231	830,980	497,867	89,805	213,378	584,908	190,756	99,340
		19	3,603	442	3,897	13,101	24,761	12,403	1,352	14,466	36,745	9,672	6,807
		20	31,771	18,372	34,316	138,745	368,886	117,958	22,882	221,005	404,496	100,921	204,714
		21	25,610	3,628	21,737	35,484	129,165	72,833	8,648	110,149	138,697	38,461	32,010
		22	127,238	9,166	48,670	176,887	1,391,644	214,980	42,079	380,527	864,110	139,885	90,510
		23	0	0	0	0	0	0	0	0	0	0	0
		24	969	91	1,267	7,010	17,821	5,542	758	118,089	29,968	7,574	3,311
		25	9,183	394	3,359	8,025	25,234	16,625	1,768	14,230	27,860	6,114	6,439
		26	20,612	595	17,776	22,141	49,048	37,472	5,587	56,843	88,399	32,713	28,404
		27	0	0	0	0	0	0	0	0	0	0	0
	Labour		314,136	68,146	121,250	374,845	1,668,258	1,556,589	257,893	1,418,378	1,986,598	787,620	622,732
	Capital		1,969,524	56,608	307,468	1,189,201	1,730,576	991,339	162,784	1,046,972	2,092,418	631,507	769,894
	Consumption		0	0	0	0	0	0	0	0	0	0	0
	Public Sector	Net production	-182,826	-2,034	1,713	54,645	-12,575	-2,590	-4,027	7,195	11,784	2,783	-837
		Net products	-55,988	129	71,281	97,958	-335,090	-111,057	3,320	14,340	101,722	10,837	30,326
		Direct taxes	0	0	0	0	0	0	0	0	0	0	0
		Social Security taxes	48,766	10,579	44,496	146,841	444,095	414,369	68,652	377,577	528,839	209,667	165,773
		Government	0	0	0	0	0	0	0	0	0	0	0
	Saving-Investment		0	0	0	0	0	0	0	0	0	0	0
REST OF THE WORLD	Foreign Sector	Total imports	4,145,174	574,763	6,216,615	1,570,112	7,670,871	3,937,362	845,096	3,515,520	10,263,686	2,218,553	1,664,587
TOTAL			**8,019,617**	**858,011**	**9,385,148**	**6,404,524**	**23,441,744**	**12,733,676**	**2,330,935**	**11,377,628**	**25,323,351**	**6,781,029**	**5,343,844**

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Table 2.6 (continued). Social Accounting Matrix for Catalonia (2001). Thousands of euros.

SAM			Firms										
			12	13	14	15	16	17	18	19	20	21	22
DOMESTIC ECONOMY	PRODUCTION INSTITUTIONS	Firms 1	1,556	1,056	2,120	140	1,277	31,534	31,604	289,062	1,743	0	1,716
		2	0	0	0	0	0	0	0	206,993	0	0	343
		3	49,202	11,156	26,725	13,328	17,571	254,505	224,480	12,184	1,037,132	23,008	236,771
		4	87,027	33,601	33,821	49,243	32,476	120,767	563,268	311,610	310,462	63,652	288,929
		5	20,711	7,262	18,062	23,148	12,202	22,812	49,622	2,387,006	9,684	358	22,304
		6	11,863	8,978	22,946	49,944	267,879	45,847	64,390	53,639	30,407	90	59,364
		7	31,894	16,239	22,301	26,656	269,305	248,691	157,136	1,681	10,265	90	44,266
		8	79,442	35,120	108,835	37,458	79,707	46,518	623,819	102,656	161,525	85,854	743,597
		9	311,741	81,924	272,778	344,418	178,035	315,783	179,880	56,720	58,490	0	242,261
		10	104,627	137,970	512,472	857,328	121,644	257,860	307,184	47,617	87,929	1,164	87,502
		11	66,315	20,794	91,049	60,186	49,221	2,121,921	49,917	47,477	5,423	0	35,687
		12	3,059,945	967,371	1,409,136	2,253,941	569,247	2,297,033	81,226	10,784	49,387	8,415	31,569
		13	504,562	862,805	260,521	592,035	120,517	575,209	180,766	86,411	65,656	1,343	187,014
		14	116,490	488,571	2,259,170	451,882	82,522	250,480	686,142	54,199	262,237	12,265	1,034,927
		15	16,822	34,063	12,902	3,875,162	5,181	45,847	1,283,082	4,622	312,399	90	189,760
		16	542,970	11,090	18,247	169,473	207,808	81,630	68,526	18,206	26,727	8,594	74,463
		17	123,588	56,574	81,004	97,924	31,199	3,645,375	381,321	57,000	329,636	77,708	1,020,515
		18	398,185	284,785	351,293	465,070	234,126	690,161	984,169	880,772	368,952	18,442	542,513
		19	12,641	16,041	14,653	14,170	19,711	99,968	190,217	46,496	270,371	50,761	183,926
		20	144,397	140,412	154,267	537,601	94,048	426,039	2,626,419	94,533	5,579,984	255,594	1,263,119
		21	79,054	52,415	82,939	76,740	40,398	212,237	686,437	109,659	222,339	1,413,957	1,521,508
		22	184,847	291,254	661,578	435,188	138,313	675,401	3,907,433	717,894	1,185,100	530,256	5,849,947
		23	0	0	0	0	0	0	0	0	0	0	0
		24	5,640	5,545	8,570	17,677	4,655	18,562	60,255	11,064	40,284	5,192	87,502
		25	14,294	15,051	13,731	17,817	9,686	36,230	79,750	39,074	31,182	8,684	62,796
		26	73,705	367,501	32,070	109,569	47,268	155,432	179,880	66,944	52,873	15,488	232,996
		27	0	0	0	0	0	0	0	0	0	0	0
		Labour	1,797,751	1,305,324	1,306,768	1,640,539	646,517	4,435,432	6,318,334	3,354,756	2,783,485	2,516,330	5,352,679
		Capital	1,448,833	992,051	1,057,297	1,349,838	277,352	3,991,980	7,929,001	4,095,448	5,079,222	2,738,336	12,615,685
		Consumption	0	0	0	0	0	0	0	0	0	0	0
		Public Sector: Net production	-58,221	-1,797	-12,500	3,997	20,195	115,364	88,993	16,444	-8,080	58,856	715,902
		Public Sector: Net products	15,195	10,814	44,591	21,953	4,277	49,993	68,017	111,070	141,679	361,814	140,712
		Public Sector: Direct taxes	0	0	0	0	0	0	0	0	0	0	0
		Public Sector: Social Security taxes	478,567	347,481	347,866	436,717	172,105	1,095,192	1,486,052	712,875	861,115	696,192	1,444,790
		Public Sector: Government	0	0	0	0	0	0	0	0	0	0	0
		Saving-Investment	0	0	0	0	0	0	0	0	0	0	0
REST OF THE WORLD	**Foreign Sector**	**Total imports**	7,486,150	6,254,833	8,390,750	7,997,691	1,551,525	463	627,667	679,564	3,802,323	1,213,338	5,362,879
TOTAL			**17,209,791**	**12,856,285**	**17,605,960**	**22,026,833**	**5,305,966**	**22,364,263**	**30,164,986**	**14,684,461**	**23,169,929**	**10,165,871**	**39,677,943**

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
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Table 2.6 (continued). Social Accounting Matrix for Catalonia (2001). Thousands of euros.

SAM				Firms					Labour	Capital	Consumption
				23	24	25	26	27			
DOMESTIC ECONOMY	PRODUCTION INSTITUTIONS	Firms	1	18,029	2,467	20,682	12,995	0	0	0	1,225,870
			2	1,634	2,107	15,195	7,593	0	0	0	386,035
			3	28,939	5,550	6,416	36,009	0	0	0	1,145,137
			4	146,797	43,271	101,636	190,379	0	0	0	1,585,605
			5	8,227	6,013	77,240	176,915	0	0	0	6,762,420
			6	24,739	822	53,773	59,572	0	0	0	2,408,777
			7	2,626	103	760	15,108	0	0	0	31,946
			8	156,308	59,459	46,766	192,806	0	0	0	651,626
			9	29,289	15,058	511,726	290,735	0	0	0	793,149
			10	4,668	1,850	3,883	14,482	0	0	0	56,185
			11	700	2,775	20,429	2,348	0	0	0	52,592
			12	9,627	1,490	2,026	43,994	0	0	0	38,741
			13	47,843	3,186	28,364	50,021	0	0	0	448,449
			14	29,114	8,223	362,733	150,377	0	0	0	698,062
			15	16,745	1,542	2,448	11,429	0	0	0	2,643,560
			16	15,637	12,694	11,143	93,780	0	0	0	1,326,424
			17	72,115	26,980	36,805	92,841	0	0	0	616,389
			18	79,058	25,079	226,318	238,756	0	0	0	12,409,740
			19	33,432	34,843	44,403	181,220	0	0	0	13,330,558
			20	215,412	46,971	69,221	212,611	0	0	0	4,548,237
			21	45,626	22,766	61,876	100,904	0	0	0	3,315,788
			22	537,363	191,534	423,259	1,002,698	0	0	0	9,341,509
			23	0	0	0	0	0	0	0	0
			24	13,886	77,549	8,695	15,500	0	0	0	1,632,516
			25	16,453	2,467	435,837	26,381	0	0	0	2,772,509
			26	29,231	6,167	18,656	289,091	0	0	0	4,265,271
			27	0	0	0	0	0	0	0	1,125,054
		Labour		2,601,271	3,235,381	3,430,056	1,886,168	925,899	0	0	0
		Capital		524,738	569,510	1,415,289	1,900,593	0	0	0	0
		Consumption		0	0	0	0	0	52,713,137	56,933,465	0
		Public Sector	Net production	12,126	-8,892	8,115	32,502	0	0	0	0
			Net products	299,185	130,784	228,167	94,533	0	0	0	0
			Direct taxes	0	0	0	0	0	0	0	13,846,370
			Social Security taxes	813,590	611,318	769,499	405,704	199,156	0	0	0
			Government	0	0	0	0	0	0	0	0
		Saving-Investment		0	0	0	0	0	0	0	23,758,230
REST OF THE WORLD	Foreign Sector	Total imports		146	17	128	977,463	0	0	0	0
TOTAL				**5,834,556**	**5,139,082**	**8,441,540**	**8,805,506**	**1,125,054**	**52,713,137**	**56,933,465**	**111,216,748**

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Table 2.6 (continued). Social Accounting Matrix for Catalonia (2001). Thousands of euros.

SAM				Public Sector					Saving-Investment	Foreign Sector	TOTAL
				Net production taxes	Net products taxes	Direct taxes	Social Security taxes	Government	TOTAL GROSS CAPITAL FORMATION	TOTAL EXPORT	
DOMESTIC ECONOMY	PRODUCTION INSTITUTIONS	Firms	1	0	0	0	0	0	89,865	739,139	8,019,617
			2	0	0	0	0	0	0	138,478	858,011
			3	0	0	0	0	0	-29,194	1,415,098	9,385,147
			4	0	0	0	0	0	846	1,228,792	6,404,524
			5	0	0	0	0	0	199,539	9,286,731	23,441,744
			6	0	0	0	0	0	159,953	6,013,422	12,733,676
			7	0	0	0	0	0	18,394	726,502	2,330,935
			8	0	0	0	0	0	50,276	4,442,776	11,377,628
			9	0	0	0	0	876,451	114,816	12,275,661	25,323,351
			10	0	0	0	0	0	23,661	2,645,143	6,781,029
			11	0	0	0	0	0	39,868	1,919,895	5,343,844
			12	0	0	0	0	0	624,041	5,192,456	17,209,791
			13	0	0	0	0	0	3,257,273	4,845,681	12,856,285
			14	0	0	0	0	6,301	3,157,386	7,176,894	17,605,960
			15	0	0	0	0	3,015	2,176,164	11,345,848	22,026,833
			16	0	0	0	0	0	666,524	1,836,508	5,305,966
			17	0	0	0	0	0	14,115,183	0	22,364,263
			18	0	0	0	0	531,977	896,265	7,792,206	30,164,986
			19	0	0	0	0	13,802	0	0	14,684,461
			20	0	0	0	0	63,356	22,960	5,010,682	23,169,929
			21	0	0	0	0	0	0	1,504,805	10,165,871
			22	0	0	0	0	264,082	3,965,705	5,888,884	39,677,943
			23	0	0	0	0	5,834,556	0	0	5,834,556
			24	0	0	0	0	2,933,589	0	0	5,139,082
			25	0	0	0	0	4,740,369	0	0	8,441,540
			26	0	0	0	0	1,395,637	182,960	925,180	8,805,506
			27	0	0	0	0	0	0	0	1,125,054
		Labour		0	0	0	0	0	0	0	52,713,137
		Capital		0	0	0	0	0	0	0	56,933,465
		Consumption		0	0	0	0	1,570,146	0	0	111,216,748
		Public Sector	Net production	0	0	0	0	0	0	0	856,235
			Net products	0	0	0	0	0	0	0	1,550,562
			Direct taxes	0	0	0	0	0	0	0	13,846,370
			Social Security taxes	0	0	0	0	0	0	0	13,337,872
			Government	856,235	1,550,562	13,846,370	13,337,872	0	0	0	29,591,039
		Saving-Investment		0	0	0	0	11,357,758	0	0	35,115,988
REST OF THE WORLD	Foreign Sector	Total imports		0	0	0	0	0	5,383,505	0	92,350,782
TOTAL				**856,235**	**1,550,562**	**13,846,370**	**13,337,872**	**29,591,039**	**35,115,988**	**92,350,782**	**764,089,734**

ISBN:978-84-693-0717-5/DL:T-442-2010

Appendix 2.3

Table 2.7. National Accounting with Environmental Accounts for Catalonia (2001). Thousands of euros.

NAMEA				Firms										
				1	2	3	4	5	6	7	8	9	10	11
DOMESTIC ECONOMY	PRODUCTION INSTITUTIONS	Firms	1	279,040	6	0	0	4,789,689	231,869	170,130	47,959	12,349	17,429	294
			2	0	10,526	0	0	89,107	0	0	0	0	0	0
			3	43,588	29,232	1,911,665	1,445,409	54,253	20,143	14,844	31,684	818,782	6,707	494,825
			4	51,841	343	13,181	426,676	111,186	120,333	7,964	113,372	192,008	70,764	104,675
			5	679,972	5,538	1,299	2,756	2,818,614	249,197	1,486	39,861	469,704	74,231	8,830
			6	4,456	5,594	380	3,964	16,087	3,196,465	3,388	43,399	34,185	77,470	11,884
			7	2,325	3,648	1,458	3,529	74,597	2,199	538,830	24,687	14,608	9,672	31,421
			8	7,517	314	1,458	5,124	284,826	77,319	10,787	2,735,945	368,655	143,717	37,418
			9	224,062	2,813	18,125	39,400	225,212	842,592	18,484	513,398	5,177,434	1,179,987	132,932
			10	2,790	1,470	5,101	2,030	330,878	58,759	2,065	127,681	414,586	532,073	30,428
			11	1,589	34	4,499	6,381	198,716	5,542	3,596	3,223	71,683	20,029	441,954
			12	3,177	6,518	16,033	18,515	136,262	24,717	21,144	10,142	123,337	124,053	75,462
			13	37,118	1,827	30,926	26,347	110,398	74,240	12,199	103,308	179,508	87,371	75,388
			14	8,408	2,872	1,046	171,038	17,033	12,843	936	19,026	49,395	25,823	9,566
			15	814	30,758	887	1,982	4,100	2,903	193	1,101	1,355	1,141	920
			16	3,255	249	412	11,022	10,251	18,120	8,544	34,043	14,457	5,384	9,787
			17	49,167	7,353	462,746	358,125	166,858	34,745	9,747	20,127	221,073	18,113	154,051
			18	162,728	8,039	22,085	47,231	830,980	497,867	89,805	213,378	584,908	190,756	99,340
			19	3,603	442	3,897	13,101	24,761	12,403	1,352	14,466	36,745	9,672	6,807
			20	31,771	18,372	34,316	138,745	368,886	117,958	22,882	221,005	404,496	100,921	204,714
			21	25,610	3,628	21,737	35,484	129,165	72,833	8,648	110,149	138,697	38,461	32,010
			22	127,238	9,166	48,670	176,887	1,391,644	214,980	42,079	380,527	864,110	139,885	90,510
			23	0	0	0	0	0	0	0	0	0	0	0
			24	969	91	1,267	7,010	17,821	5,542	758	118,089	29,968	7,574	3,311
			25	9,183	394	3,359	8,025	25,234	16,625	1,768	14,230	27,860	6,114	6,439
			26	20,612	595	17,776	22,141	49,048	37,472	5,587	56,843	88,399	32,713	28,404
			27	0	0	0	0	0	0	0	0	0	0	0
		Labour		314,136	68,146	121,250	374,845	1,668,258	1,556,589	257,893	1,418,378	1,986,598	787,620	622,732
		Capital		1,969,524	56,608	307,468	1,189,201	1,730,576	991,339	162,784	1,046,972	2,092,418	631,507	769,894
		Consumption		0	0	0	0	0	0	0	0	0	0	0
		Public Sector	Net production	-182,826	-2,034	1,713	54,645	-12,575	-2,590	-4,027	7,195	11,784	2,783	-837
			Net products	-55,988	129	71,281	97,958	-335,090	-111,057	3,320	14,340	101,722	10,837	30,326
			Direct taxes	0	0	0	0	0	0	0	0	0	0	0
			Social Security taxes	48,766	10,579	44,496	146,841	444,095	414,369	68,652	377,577	528,839	209,667	165,773
			Government	0	0	0	0	0	0	0	0	0	0	0
		Saving-Investment		0	0	0	0	0	0	0	0	0	0	0
REST OF THE WORLD	Foreign Sector	Total imports		4,145,174	574,763	6,216,615	1,570,112	7,670,871	3,937,362	845,096	3,515,520	10,263,686	2,218,553	1,664,587
TOTAL				**8,019,617**	**858,011**	**9,385,148**	**6,404,524**	**23,441,744**	**12,733,676**	**2,330,935**	**11,377,628**	**25,323,351**	**6,781,029**	**5,343,844**

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Table 2.7 (continued). National Accounting with Environmental Accounts for Catalonia (2001). Thousands of euros.

NAMEA				Firms										
				12	13	14	15	16	17	18	19	20	21	22
DOMESTIC ECONOMY	PRODUCTION INSTITUTIONS	Firms	1	1,556	1,056	2,120	140	1,277	31,534	31,604	289,062	1,743	0	1,716
			2	0	0	0	0	0	0	0	206,993	0	0	343
			3	49,202	11,156	26,725	13,328	17,571	254,505	224,480	12,184	1,037,132	23,008	236,771
			4	87,027	33,601	33,821	49,243	32,476	120,767	563,268	311,610	310,462	63,652	288,929
			5	20,711	7,262	18,062	23,148	12,202	22,812	49,622	2,387,006	9,684	358	22,304
			6	11,863	8,978	22,946	49,944	267,879	45,847	64,390	53,639	30,407	90	59,364
			7	31,894	16,239	22,301	26,656	269,305	248,691	157,136	1,681	10,265	90	44,266
			8	79,442	35,120	108,835	37,458	79,707	46,518	623,819	102,656	161,525	85,854	743,597
			9	311,741	81,924	272,778	344,418	178,035	315,783	179,880	56,720	58,490	0	242,261
			10	104,627	137,970	512,472	857,328	121,644	257,860	307,184	47,617	87,929	1,164	87,502
			11	66,315	20,794	91,049	60,186	49,221	2,121,921	49,917	47,477	5,423	0	35,687
			12	3,059,945	967,371	1,409,136	2,253,941	569,247	2,297,033	81,226	10,784	49,387	8,415	31,569
			13	504,562	862,805	260,521	592,035	120,517	575,209	180,766	86,411	65,656	1,343	187,014
			14	116,490	488,571	2,259,170	451,882	82,522	250,480	686,142	54,199	262,237	12,265	1,034,927
			15	16,822	34,063	12,902	3,875,162	5,181	45,847	1,283,082	4,622	312,399	90	189,760
			16	542,970	11,090	18,247	169,473	207,808	81,630	68,526	18,206	26,727	8,594	74,463
			17	123,588	56,574	81,004	97,924	31,199	3,645,375	381,321	57,000	329,636	77,708	1,020,515
			18	398,185	284,785	351,293	465,070	234,126	690,161	984,169	880,772	368,952	18,442	542,513
			19	12,641	16,041	14,653	14,170	19,711	99,968	190,217	46,496	270,371	50,761	183,926
			20	144,397	140,412	154,267	537,601	94,048	426,039	2,626,419	94,533	5,579,984	255,594	1,263,119
			21	79,054	52,415	82,939	76,740	40,398	212,237	686,437	109,659	222,339	1,413,957	1,521,508
			22	184,847	291,254	661,578	435,188	138,313	675,401	3,907,433	717,894	1,185,100	530,256	5,849,947
			23	0	0	0	0	0	0	0	0	0	0	0
			24	5,640	5,545	8,570	17,677	4,655	18,562	60,255	11,064	40,284	5,192	87,502
			25	14,294	15,051	13,731	17,817	9,686	36,230	79,750	39,074	31,182	8,684	62,796
			26	73,705	367,501	32,070	109,569	47,268	155,432	179,880	66,944	52,873	15,488	232,996
			27	0	0	0	0	0	0	0	0	0	0	0
		Labour		1,797,751	1,305,324	1,306,768	1,640,539	646,517	4,435,432	6,318,334	3,354,756	2,783,485	2,516,330	5,352,679
		Capital		1,448,833	992,051	1,057,297	1,349,838	277,352	3,991,980	7,929,001	4,095,448	5,079,222	2,738,336	12,615,685
		Consumption		0	0	0	0	0	0	0	0	0	0	0
		Public Sector	Net production	-58,221	-1,797	-12,500	3,997	20,195	115,364	88,993	16,444	-8,080	58,856	715,902
			Net products	15,195	10,814	44,591	21,953	4,277	49,993	68,017	111,070	141,679	361,814	140,712
			Direct taxes	0	0	0	0	0	0	0	0	0	0	0
			Social Security taxes	478,567	347,481	347,866	436,717	172,105	1,095,192	1,486,052	712,875	861,115	696,192	1,444,790
			Government	0	0	0	0	0	0	0	0	0	0	0
		Saving-Investment		0	0	0	0	0	0	0	0	0	0	0
REST OF THE WORLD	Foreign Sector	Total imports		7,486,150	6,254,833	8,390,750	7,997,691	1,551,525	463	627,667	679,564	3,802,323	1,213,338	5,362,879
TOTAL				**17,209,791**	**12,856,285**	**17,605,960**	**22,026,833**	**5,305,966**	**22,364,263**	**30,164,986**	**14,684,461**	**23,169,929**	**10,165,871**	**39,677,943**

ISBN:978-84-693-0717-5/DL:T-442-2010

Table 2.7 (continued). National Accounting with Environmental Accounts for Catalonia (2001). Thousands of euros.

NAMEA			Firms					Labour	Capital	Consumption
			23	24	25	26	27			
DOMESTIC ECONOMY – PRODUCTION INSTITUTIONS	Firms	1	18,029	2,467	20,682	12,995	0	0	0	1,225,870
		2	1,634	2,107	15,195	7,593	0	0	0	386,035
		3	28,939	5,550	6,416	36,009	0	0	0	1,145,137
		4	146,797	43,271	101,636	190,379	0	0	0	1,585,605
		5	8,227	6,013	77,240	176,915	0	0	0	6,762,420
		6	24,739	822	53,773	59,572	0	0	0	2,408,777
		7	2,626	103	760	15,108	0	0	0	31,946
		8	156,308	59,459	46,766	192,806	0	0	0	651,626
		9	29,289	15,058	511,726	290,735	0	0	0	793,149
		10	4,668	1,850	3,883	14,482	0	0	0	56,185
		11	700	2,775	20,429	2,348	0	0	0	52,592
		12	9,627	1,490	2,026	43,994	0	0	0	38,741
		13	47,843	3,186	28,364	50,021	0	0	0	448,449
		14	29,114	8,223	362,733	150,377	0	0	0	698,062
		15	16,745	1,542	2,448	11,429	0	0	0	2,643,560
		16	15,637	12,694	11,143	93,780	0	0	0	1,326,424
		17	72,115	26,980	36,805	92,841	0	0	0	616,389
		18	79,058	25,079	226,318	238,756	0	0	0	12,409,740
		19	33,432	34,843	44,403	181,220	0	0	0	13,330,558
		20	215,412	46,971	69,221	212,611	0	0	0	4,548,237
		21	45,626	22,766	61,876	100,904	0	0	0	3,315,788
		22	537,363	191,534	423,259	1,002,698	0	0	0	9,341,509
		23	0	0	0	0	0	0	0	0
		24	13,886	77,549	8,695	15,500	0	0	0	1,632,516
		25	16,453	2,467	435,837	26,381	0	0	0	2,772,509
		26	29,231	6,167	18,656	289,091	0	0	0	4,265,271
		27	0	0	0	0	0	0	0	1,125,054
	Labour		2,601,271	3,235,381	3,430,056	1,886,168	925,899	0	0	0
	Capital		524,738	569,510	1,415,289	1,900,593	0	0	0	0
	Consumption		0	0	0	0	0	52,713,137	56,933,465	0
	Public Sector	Net production	12,126	-8,892	8,115	32,502	0	0	0	0
		Net products	299,185	130,784	228,167	94,533	0	0	0	0
		Direct taxes	0	0	0	0	0	0	0	13,846,370
		Social Security taxes	813,590	611,318	769,499	405,704	199,156	0	0	0
		Government	0	0	0	0	0	0	0	0
	Saving-Investment		0	0	0	0	0	0	0	23,758,230
REST OF THE WORLD	Foreign Sector	Total imports	146	17	128	977,463	0	0	0	0
TOTAL			**5,834,556**	**5,139,082**	**8,441,540**	**8,805,506**	**1,125,054**	**52,713,137**	**56,933,465**	**111,216,748**

ISBN:978-84-693-0717-5/DL:T-442-2010

Table 2.7 (continued). National Accounting with Environmental Accounts for Catalonia (2001). Thousands of euros.

NAMEA				Public Sector					Saving-Investment	Foreign Sector	TOTAL
				Net production taxes	Net products taxes	Direct taxes	Social Security taxes	Government	TOTAL GROSS CAPITAL FORMATION	TOTAL EXPORT	
DOMESTIC ECONOMY	PRODUCTION INSTITUTIONS	Firms	1	0	0	0	0	0	89,865	739,139	8,019,617
			2	0	0	0	0	0	0	138,478	858,011
			3	0	0	0	0	0	-29,194	1,415,098	9,385,147
			4	0	0	0	0	0	846	1,228,792	6,404,524
			5	0	0	0	0	0	199,539	9,286,731	23,441,744
			6	0	0	0	0	0	159,953	6,013,422	12,733,676
			7	0	0	0	0	0	18,394	726,502	2,330,935
			8	0	0	0	0	0	50,276	4,442,776	11,377,628
			9	0	0	0	0	876,451	114,816	12,275,661	25,323,351
			10	0	0	0	0	0	23,661	2,645,143	6,781,029
			11	0	0	0	0	0	39,868	1,919,895	5,343,844
			12	0	0	0	0	0	624,041	5,192,456	17,209,791
			13	0	0	0	0	0	3,257,273	4,845,681	12,856,285
			14	0	0	0	0	6,301	3,157,386	7,176,894	17,605,960
			15	0	0	0	0	3,015	2,176,164	11,345,848	22,026,833
			16	0	0	0	0	0	666,524	1,836,508	5,305,966
			17	0	0	0	0	0	14,115,183	0	22,364,263
			18	0	0	0	0	531,977	896,265	7,792,206	30,164,986
			19	0	0	0	0	13,802	0	0	14,684,461
			20	0	0	0	0	63,356	22,960	5,010,682	23,169,929
			21	0	0	0	0	0	0	1,504,805	10,165,871
			22	0	0	0	0	264,082	3,965,705	5,888,884	39,677,943
			23	0	0	0	0	5,834,556	0	0	5,834,556
			24	0	0	0	0	2,933,589	0	0	5,139,082
			25	0	0	0	0	4,740,369	0	0	8,441,540
			26	0	0	0	0	1,395,637	182,960	925,180	8,805,506
			27	0	0	0	0	0	0	0	1,125,054
		Labour		0	0	0	0	0	0	0	52,713,137
		Capital		0	0	0	0	0	0	0	56,933,465
		Consumption		0	0	0	0	1,570,146	0	0	111,216,748
		Public Sector	Net production	0	0	0	0	0	0	0	856,235
			Net products	0	0	0	0	0	0	0	1,550,562
			Direct taxes	0	0	0	0	0	0	0	13,846,370
			Social Security taxes	0	0	0	0	0	0	0	13,337,872
			Government	856,235	1,550,562	13,846,370	13,337,872	0	0	0	29,591,039
		Saving-Investment		0	0	0	0	11,357,758	0	0	35,115,988
REST OF THE WORLD	Foreign Sector	Total imports		0	0	0	0	0	5,383,505	0	92,350,782
TOTAL				**856,235**	**1,550,562**	**13,846,370**	**13,337,872**	**29,591,039**	**35,115,988**	**92,350,782**	**764,089,734**

ISBN:978-84-693-0717-5/DL:T-442-2010

Table 2.7 (continued). National Accounting with Environmental Accounts for Catalonia (2001).

NAMEA				Emissions									
				SO_x (t)	NO_x (t)	COVNM (t)	CH_4 (t)	CO (t)	CO_2 (kt)	N_2O (t)	SF_6 (kg)	HFC (kg)	PFC (kg)
DOMESTIC ECONOMY	PRODUCTION INSTITUTIONS	Firms	1	388.2	12,478.70	114,711.80	158,784.40	9,571.20	662.1	6,356.60	0	0	0
			2	74.7	1,424.20	36.6	3.5	83.4	88.5	2.3	0	0	0
			3	25,686.2	14,900.2	2,122.0	3,182.7	3,346.9	5,008.1	118.1	0	0	0
			4	4,996.9	3,694.4	6,031.8	24,967.4	532.4	2,093.8	32.4	0	0	0
			5	1,509.70	2,313.80	3,214.50	60.4	708.2	491.7	11.4	0	0	0
			6	825.7	1,363.1	7,574.1	33.3	419.0	274.8	6.4	0	0	0
			7	216.5	247.3	268.1	8.4	74.2	66.1	1.5	0	0	0
			8	1,049.1	1,557.9	8,787.9	40.6	470.0	355.6	7.8	0	0	0
			9	9,220.10	10,817.20	26,990.60	1,429.70	3,158.90	2,869.30	229.3	0	198,750.00	0
			10	419.8	479.6	1,189.80	16.3	143.8	126.7	2.9	0	0	0
			11	15,968.50	21,416.70	1,769.70	211.2	14,482.30	8,983.30	129	0	0	0
			12	988.1	1,270.8	11,649.7	38.4	8,551.2	481.5	11.1	0	0	0
			13	242.4	276.9	1,516.40	9.4	83.1	77.8	1.7	0	0	0
			14	274.3	313.3	1,096.4	10.7	94.0	86.2	1.8	1,457.4	0	0
			15	453.0	517.5	9,486.6	17.6	155.2	166.2	3.1	0	0	0
			16	262.8	505.1	4,035.6	10.8	156.5	104.2	2.1	0	0	0
			17	18.9	1,314.30	23,773.50	4.6	425.9	128.4	2.3	0	0	0
			18	1,038.40	712.9	6,169.60	30.5	426.9	253.1	4.5	0	0	0
			19	443.4	72.9	9.3	12.3	108	91.3	1.5	0	0	0
			20	10,131.7	45,531.7	23,307.8	1,033.9	100,523.7	6,973.5	1,050.0	0	0	0b
			21	127.7	21	2.7	3.5	31.1	26.3	0.4	0	0	0
			22	905.4	148.8	19	25.1	220.5	186.5	3.1	0	0	0
			23	256.5	42.1	5.4	7.1	62.5	52.8	0.9	0	0	0
			24	153.2	25.2	3.2	4.2	37.3	31.6	0.5	0	0	0
			25	242.6	39.9	5.1	6.7	59.1	50	200.8	0	0	0
			26	446.4	1,248.50	7,189.70	99,954.10	207	308.5	633.5	0	0	0
			27	0	0	0	0	0	0	0	0	0	0
		Labour		0	0	0	0	0	0	0	0	0	0
		Capital		0	0	0	0	0	0	0	0	0	0
		Consumption		4,142.30	52,645.40	47,312.90	4,193.80	193,458.70	9,952.80	81.5	0	44,913.90	58
		Public Sector	Net production	0	0	0	0	0	0	0	0	0	0
			Net products	0	0	0	0	0	0	0	0	0	0
			Direct taxes	0	0	0	0	0	0	0	0	0	0
			Social Security taxes	0	0	0	0	0	0	0	0	0	0
			Government	0	0	0	0	0	0	0	0	0	0
		Saving-Investment		0	0	0	0	0	0	0	0	0	0
REST OF THE WORLD	Foreign Sector	Total imports		0	0	0	0	0	0	0	0	0	0
TOTAL				80,483	175,379	308,280	294,101	337,591	39,991	8,897	1,457	243,664	58

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Chapter 3

Analysis of Linear Multipliers in a NAMEA: An Application to the Case of Catalonia

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3.1. Introduction

In recent years, societies have been consuming their natural resources inappropiately. This has caused serious environmental problems, one of which is the climate change process. Climate change is one of the greatest threats to sustainable development. It is also one of the greatest environmental challenges facing the global economy, human health and social welfare. Certain human activities, such as the burning of fossil fuels, produce emissions that add carbon dioxide to the atmosphere. This, in turn, causes climate change due to the escalation of the greenhouse effect, a natural phenomenon caused by gases in the atmosphere. This effect may increase temperatures to such an extent that the earth would be unhabitable.[89]

The escalation of the greenhouse effect and consequent warming of the planet have generated great concern. This is reflected in the number and scale of scientific projects and international conferences that have been carried out since the 1980s to analyse the problem and propose solutions.[90] At the Rio Summit in 1992, the United Nations Framework Convention on Climate Change was drawn up. By signing this treaty, the developed countries (which are responsible for approximately 60% of the world's annual carbon dioxide emissions) promised to reduce their greenhouse gas

[89] According to the Intergovernmental Panel on Climate Change, in the contribution made by Working Group I to the Fourth Assessment Report (Paris, 2007) global warming is unequivocal and can be attributed with over 90% certainty to the action of humans. The average global temperature on the earth's surface has increased by 0.74ºC in the last hundred years. The surface temperature over the last ten years of the twenty-first century is predicted to increase between 1.8 and 4.0ºC with respect to the last twenty years of the twentieth century. Atmospheric CO_2 concentrations have increased by 35.36% since the preindustrial era. All of this has had a significant negative impact on ecosystems and socioeconomic systems throughout the planet, including a considerable impact in the south of Europe.

[90] For example, the Toronto Conference on the Changing Atmosphere was held in 1988. This was the first high-level meeting where scientists and politicians debated measures to be taken to fight climate change. In 1990, the Second World Climate Conference was held in Geneva (Switzerland). At the 1992 Rio Summit, the United Nations Framework Convention on Climate Change was drawn up and signed. In 1995, the Berlin Climate Summit took place. The Johannesburg Summit, organised by the United Nations, was held in 2002. Its main theme was how to transform the world in order to ensure the long-term preservation of life. The participants reviewed the essential issues for guaranteeing the sustainable development of the earth. In 2007, the 13th United Nations Climate Change Conference was held in Bali. After long negotiations, all of the countries signed an agreement that enabled a new protocol to be negotiated from 2008 onwards, replacing the Kyoto Protocol.

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emissions to their pre-1990 levels by 2010. Despite this breakthrough, it became evident that a stricter agreement was needed. In 1997, a legally binding protocol was reached in Kyoto in which the developed countries promised to reduce by 5.2% their collective emissions of six greenhouse gases, three of which were of human origin (carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)), and three of industrial origin (hydrofluorocarbons (HFC), perfluorocarbons (PFC_S) and sulphur hexafluoride (SF_6)). They were to do this between 2008 and 2012, taking the 1990 levels as a reference.[91] This document, known as the Kyoto Protocol, came into effect on 16th February 2005, after it had been ratified by Russia.[92]

The European Union has had to reduce the aforementioned emissions by 8%. It was agreed that Spain would not increase greenhouse gas emissions beyond 15% in the 2008-2012 period. 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 (Departament de Medi Ambient i Habitatge, 2008).

In this context the interdependencies between economic agents and atmospheric emissions need to be quantified and hierarchized. The Social and Environmental Accounting Matrix of Catalonia for 2001 can be used to analyse the relations between the economy and the environment. That is, we use a NAMEA (*National Accounting* Matrix with *Environmental* Accounts) because it makes it possible to visualize the existing network of direct

[91] The United States signed the agreement but did not ratify it under the Bill Clinton or George W. Bush administrations, so its signature was symbolic until 2001, when the country withdrew from the Protocol. The Bush administration explained the decision by saying that while they shared the idea of reducing emissions, they considered the Protocol's application inefficient and unfair because it involved only industrialized countries and excluded some of the greatest gas emitters of the developing world (China and India, in particular), which would seriously harm the American economy. In contrast, the European Union, an especially active agent in specifying the Protocol, promised to reduce its average total emissions between 2008 and 2012 by 8% with respect to 1990. However, a different margin based on various economic and environmental variables was granted to each country according to the "load distribution principle". This distribution in the European Union is as follows: Germany (-21%), Austria (-13%), Belgium (-7.5%), Denmark (-21%), Italy (-6.5%), Luxembourg (-28%), the Netherlands (-6%), United Kingdom (-12.5%), Finland (0%), France (0%), Spain (+15%), Greece (+25%), Ireland (+13%), Portugal (+27%), and Sweden (+4%).
[92] Russia ratified the Kyoto Protocol in November 2004 after getting the European Union to pay for restructuring its industry and modernising its facilities, especially those related to fuel.

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interconnections in the economy and society, that is, between branches of activity and institutional sectors and, in turn, between these sectors and the environment. With this matrix we have obtained the linear multiplier matrix that will enable us to better observe the effects between the production and the pollution of the different sectors.[93]

Manresa and Sancho (2004) conducted the first example of integrated economic and environmental analysis for Catalonia, taking 1987 as the base year. The paper analysed the sectorial power intensity of the Catalan economy using a regional SAM that differentiated the polluting emissions originating from production and those originating from final consumption. The authors observed that the energy sectors themselves use the energy sources with the greatest intensity.

Rodríguez, Llanes and Cardenete (2007) showed that a SAM with environmental accounts can be used for economic and environmental efficiency analysis. They used a database with Spanish data for the year 2000, and applied it to water resources and greenhouse gas emissions. The matrix was used as a database for a multisectoral model of economic and environmental performance, which made it possible to calculate the domestic multipliers and their decomposition into direct, indirect and induced effects. The study demonstrated that there is no causal interrelation between those sectors with greater backward economic linkages and those with greater environmental deterioration.

Flores and Sánchez (2007) analysed and assessed the most important environmental impacts on the economy of Aragon, relating the main economic dimensions to the uses of resources and levels of pollution. To carry out this analysis, they first constructed a social accounting matrix including environmental accounts (SAMEA) for Aragon for 1999. In particular, water resources and several types of aquatic and atmospheric pollution were incorporated into this SAMEA. An open Leontief model was

[93] According to Llop (2001): "The SAM model, although similar to the input-output model, has a clear difference: the extended multipliers do not only incorporate production relations in the income generating process but also include income distribution relations as well as final demand relations".

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constructed on the basis of these matrices. This model enabled water and pollution to be associated to final demands, and revealed the role these demands play in the use of water resources and the generation of pollution.

Finally, Cardenete, Fuentes and Polo (2008) presented estimates of energy intensities and CO_2 emissions for Andalusia's economy in 2000. Energy intensities of productive sectors are calculated in several scenarios using a SAM model. The results indicate there are important variations in energy intensities across sectors as well as substantial changes when consumption and investment are endogenous.

The methods that integrate economic information and environmental effects are very useful for determining the environmental consequences of economic activity. The improvement of databases and linear models will allow the effects of the circular flow of income and the associated environmental loads to be analysed jointly. This area of research captures both environmental and economic aspects of the environmental problems that affect the global economy.

The aim of this chapter is to analyse the Catalan economy (2001) with a linear model of multipliers. We will focus on the analysis of the emission multipliers. To complete the analysis, we also analyse the impact of a 10% reduction in greenhouse emissions on emission multipliers.[94] This emission-reduction percentage would bring the Catalan economy into compliance with the maximum emissions level allowed by the Kyoto Protocol. We consider three possible scenarios that would allow this goal to be met. First, we simulate a 10% reduction in regional emissions and a 5% drop in the endogenous income of the multipliers' model (production, factorial and private income). Second, we simulate a 10% reduction in

[94] On 23 January 2008, the European Commission met to endorse an action plan to fight climate change known as "20 20 by 2020". This has become the mantra used by the Commission to present itself to the rest of the world as a champion in the fight against climate change. The plan calls for a 20% reduction in CO_2 emissions and the use of 20% of renewable energy sources (with 10% of fuel from biofuel) by 2020. In order to reach these percentages, each country must contribute in proportion to its per capita GDP. Spain will have to obtain 20% of its energy from renewable energy sources by 2020, which is more than twice the current level (8.7% in 2005), and reduce its greenhouse gas emissions by 10%.

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emissions and a 10% increase in endogenous income. Finally, we simulate a 10% reduction in emissions and a 5% increase in endogenous income. We also analyse the decomposition of the emission multipliers into own effects, open effects and circular effects to capture the different channels of emission generation.

The rest of the chapter is organised as follows. The next section describes the linear SAM model. Section 3.3 presents the decomposition of the multipliers. Section 3.4 describes the extension of the SAM model with greenhouse emissions and section 3.5 analyses the results. The chapter ends with a conclusion section.

3.2. The Linear SAM Model

The linear SAM model shows the released effects generated in the economic activity of the various agents with a perspective of the circular flow of income. The relations captured by this model incorporate the interdependences within the productive sphere, final demand decisions, and income distribution operations.

SAM models calculate countable or extended multipliers that quantify the global effects in terms of increase in income, produced by exogenous income instruments. By analysing the extended multipliers, it is possible to determine which agents have the greatest effects on economic activity and which ones have the smallest effects.

The origins of this method are found in the pioneering works of Stone (1978), and Pyatt and Round (1979), which used a SAM of the Sri Lankan economy to show the relationships between production, income, and demand. Defourny and Thorbecke (1984) proposed a complementary analysis of traditional multipliers: the structural-path analysis. This contribution captured not only the influence but also the transmission channels of the multiplier effects between the various agents in the economy.

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The starting point in the SAM model is to divide the accounts into two types: endogenous and exogenous. Table 3.1 contains the accounting identities inherent to a SAM in which the accounts have been divided into these two types.

Table 3.1. Endogenous and exogenous accounts in a SAM

		EXPENDITURE				
		Endogenous	**Sum**	**Exogenous**	**Sum**	**Total**
INCOME	**Endogenous**	T_{nn}	n	Injections T_{nx}	x	$\mathbf{y_n}$
	Exogenous	Outlays T_{xn}	l	Residual Balance T_{xx}	t	$\mathbf{y_x}$
TOTAL		$\mathbf{y'_n}$		$\mathbf{y'_z}$		

Source: Defourny and Thorbecke (1984).

According to table 3.1, the sum of the row of endogenous accounts is column vector y_n with two different parts: the endogenous accounts (T_{nn}, whose sum is represented by vector n) and the exogenous accounts (T_{nx}, whose sum is represented by vector x). In other words:

$$y_n = n + x. \tag{3.1}$$

The components of the matrix of transactions between endogenous accounts, T_{nn}, can be obtained from the ratios of the corresponding totals in columns:

$$T_{nn} = A\hat{y}_n , \tag{3.2}$$

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where $\hat{y}_n$ is the diagonal matrix of the elements of vector y_n. Similarly, matrix A contains the transactions of each endogenous account in relation to the column total in the SAM $\left(a_{ij} = \frac{T_{ij}}{y'_j} \right)$.

Vector n can be obtained by using matrix A in the following way:

$$n = A\,y_n. \tag{3.3}$$

By combining expressions (3.1) and (3.3), we obtain:

$$y_n = n + x = Ay_n + x = (I - A)^{-1} x = Mx, \tag{3.4}$$

where y_n is the vector of endogenous income in every account, I is the identity matrix, A is a matrix of structural coefficients (calculated by dividing the transactions in the SAM by total endogenous income of each account) and x is the vector of exogenous income. In expression (3.4), $M = (I - A)^{-1}$ is the matrix of SAM multipliers. This matrix shows the overall effects (direct and indirect) on the endogenous accounts caused by unitary and exogenous changes in the exogenous income.

Within the structure of a SAM, the accounts that represent potential tools of economic policy or variables determined outside the economic system are traditionally considered exogenous. The usual assumption of endogeneity made in SAM models follows the Pyatt and Round (1985) criteria, which consider sectors of production, factors (labour and capital), and private consumers as endogenous components. On the other hand, the government, the saving-investment account and the foreign sector are considered exogenous components. This assumption, therefore, captures the complete relationships of the circular flow of income and shows the connections between productive income, factorial and personal distribution of income, and consumption patterns. The SAM model is similar to the input-output model but with one clear difference: in the process of income creation, the extended multipliers incorporate not only production relations but also relations of income distribution and final demand.

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3.3. Decomposition of Multipliers

The traditional endogeneity assumption of Stone (1978) and Pyatt and Round (1979) considers activities, factors of production and households to be endogenous components. So, matrix A of structural coefficients has the following structure:

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

where A_{11} contains the input-output coefficients, A_{13} contains the coefficients of the household sectorial consumption, A_{21} contains the factors of production coefficients, and A_{32} contains the coefficients of factor income of consumers.

To provide a deeper insight into the analysis of SAM multipliers, Pyatt and Round (1979) divided matrix M into different circuits of interdependence. Specifically, it can be seen that:

$$\begin{aligned} y &= Ay + x \\ &= \left(A - \bar{A}\right)y + \bar{A}y + x \\ &= \left(I - \bar{A}\right)^{-1}\left[\left(A - \bar{A}\right)y + x\right] \\ &= \dot{A}y + \left(I - \bar{A}\right)^{-1}x \\ &= \dot{A}^2 y + \left(I + \dot{A}\right)\left(I - \bar{A}\right)^{-1}x \\ &= \dot{A}^3 y + \left(I + \dot{A} + \dot{A}^2\right)\left(I + \bar{A}\right)^{-1}x \\ &= M_3 M_2 M_1 x, \end{aligned} \tag{3.5}$$

Where $\dot{A} = \left(I - \bar{A}\right)\left(A - \bar{A}\right)$, $M_1 = \left(I - \bar{A}\right)^{-1}$, $M_2 = \left(I + \dot{A} + \dot{A}^2\right)^{-1}$, and $M_3 = \left(I - \dot{A}^3\right)^{-1}$.

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Finally, matrix $\bar{A}$ has the following structure:

$$\bar{A} = \begin{bmatrix} A_{11} & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & A_{33} \end{bmatrix}.$$

In the expression above, matrix *M* of total SAM multipliers has been defined by three multiplicative components that convey different economic meanings.[95] After the corresponding matrix algebra has been applied, it can be seen that the first block M_1 has the following elements:

$$M_1 = \begin{bmatrix} (I - A_{11}) & 0 & 0 \\ 0 & I & 0 \\ 0 & 0 & (I - A_{33})^{-1} \end{bmatrix}.$$

Matrix M_1 contains the own effects explained by the connections between the accounts belonging to the same income relationships. Specifically, the perspective of income transmission reflected in M_1 responds to the effects of intersectorial linkages and the effects of transactions between consumers.

Additionally, matrix M_2 is a follows:

$$M_2 = \begin{bmatrix} I & (I - A_{11})^{-1} A_{13}\, I\, A_{32} & (I - A_{11})^{-1} A_{13} \\ A_{21} & I & A_{21}(I - A_{11})^{-1} A_{13} \\ (I - A_{33}) A_{32}\, A_{21} & (I - A_{33})^{-1} A_{32} & I \end{bmatrix}.$$

This block contains the open effects caused by the accounts on the other parts of the circular flow of income. As it shows the effects of the accounts on the other income circuits of the system, the main diagonal in M_2 is unitary and the other elements are positive.

Finally, matrix M_3 has the following structure:

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[95] Note that the decomposition in equation (3.5) is not unique. In consequence, the interpretation of the decomposed multipliers depends basically on the division of the matrix of expenditure share coefficients, that is, the structure of matrix $\bar{A}$.

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$$M_3 = \begin{bmatrix} \left[I-(I-A_{11})^{-1}A_{13}(I-A_{33})^{-1}A_{32}A_{21}\right]^{-1} & 0 & 0 \\ 0 & \left[I-A_{21}(I-A_{11})^{-1}A_{13}(I-A_{33})^{-1}A_{32}\right]^{-1} & 0 \\ 0 & 0 & \left[I-(I-A_{33})^{-1}A_{32}A_{21}(I-A_{11})^{-1}A_{13}\right]^{-1} \end{bmatrix}.$$

Block M_3 contains the circular effects on the accounts that are activated because of exogenous inflows. Component M_3 is a block diagonal matrix, showing the closed-loop effects of circular flow caused by the own exogenous shocks on the accounts.

The decomposition of SAM multipliers identifies the channels through which income effects can be produced and transmitted throughout the economy. Logically, this kind of information is very useful for establishing the origin of income shocks on economic agents and institutions, and it provides deeper insights into the circular flow of income.

In order to better interpret the results, we perform an additive decomposition of the multiplier matrix. This decomposition, proposed by Stone (1978), uses an additive formula calculated by a simple transformation of the previous multiplicative division:

$$M = M_3 M_2 M_1 = I + (M_1 - I) + (M_2 - I)\, M_1 + (M_3 - I)\, M_2\, M_1. \tag{3.6}$$

where I includes the initial injection of income that begins the entire multiplier process, $(M_1 - I)$ shows the net contribution of own effects in net terms, $(M_2 - I)M_1$ quantifies the open net effects and, finally, $(M_3 - I)M_2 M_1$ represents the net contribution of the circular effects.[96]

It should be pointed out that, in addition to this multiplier decomposition process, some authors have proposed alternative analyses. For example, Defourny and Thorbecke (1984) proposed the so-called

[96] There are many examples of this method in the literature. We can cite Bottiroli and Targetti (1988) in the area of income distribution, Khan (1999) in the analysis of poverty, Xie (2000) for topics related to the environment, and de Miguel et al. (1998) and Llop and Manresa (1999) in regional studies.

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structural or trajectory analysis.[97] This method observes the paths along which the multipliers travel and has the advantage of obtaining the entire network through which the influence is transmitted, from a source account to a destination account.

We can also use the following transformation of the above expression (3.6):

$$M - I = (M_1 - I) + (M_2 - I)M_1 + (M_3 - I)M_2M_1. \tag{3.7}$$

This new expression (3.7) leads to the total net multiplier effect, that is $(M - I)$, which is the result of the aggregation of the own net effects $(M_1 - I)$, the open net effects $(M_2 - I)M_1$ and, lastly, the circular net effects $(M_3 - I)M_2 M_1$.

3.4. Extension of the SAM Model with Greenhouse Emissions: The NAMEA Model

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 emissions per unit of endogenous income. In this matrix each element is the amount of gas type i (in physical units) per monetary unit of endogenous income in account j. That is:

$$B = E(\hat{Y})^{-1}, \tag{3.8}$$

where E is a matrix of total greenhouse emissions made from the endogenous accounts of the model (i.e. activities of production, factors and

[97] For an extended view of this method and possible empirical applications, see Crama, Defourny and Gazón (1984); Polo, Roland-Host and Sancho (1991); Sonis, Hewings and Sulistyowati (1997); Thorbecke (1998); Azis (1999); Ferri and Uriel (2000); Roberts (2005).

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consumers), and $\hat{Y}$ is the diagonal matrix of the elements in vector y_n of endogenous income.

The amount of emissions associated with a given level of exogenous income (X) can then be calculated as follows:

$$f = B(I - A)^{-1} X, \qquad (3.9)$$

where f is the vector of i greenhouse emissions. The elements in matrix $B(I - A)^{-1}$ are the *emission multipliers*, which measure the amount of type i emissions caused by exogenous and unitary inflows to account j. With this approach we can therefore analyse how unitary changes in the exogenous demand (an increase or decrease in investment and exports, for example) affect the amount of greenhouse emissions. This information is valuable for environmental protection since it shows the environmental impacts associated with production activities, factors of production and private consumption.

Taking into account expressions (3.4), (3.5), (3.6) and (3.9), the NAMEA emission multiplier matrix can be decomposed into:

$$BM = B(I - A)^{-1} = BM_3M_2M_1. \qquad (3.10)$$

According to the additive decomposition of the income multipliers (expressions (3.6) and (3.7)), the NAMEA multiplier matrix of polluting emissions can be divided into:

$$B(M - I) = B(M_1 - I) + B(M_2 - I)M_1 + B(M_3 - I)M_2M_1. \qquad (3.11)$$

This expression allows the total net emission multipliers, $B(M\text{-}I)$, to be obtained as a result of aggregating the net own effects $B(M_1\text{-}I)$, the net open effects, $B(M_2\text{-}I)M_1$, and finally, the net circular effects, $B(M_3\text{-}I)M_2 M_1$.

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3.5. Empirical Application to Catalan Greenhouse Emissions

Our analysis is based on SAM methodology, which reflects the relationships between demand and production, production and income, and income and demand.[98] We also extend these relations to the effects on greenhouse pollution in the regional economy. The analytical framework developed in section 3.4 shows how the exogenous and unitary inflows to production activities, factors, and consumers affect greenhouse gas emissions. Therefore, it quantifies how much increase there is in greenhouse emissions when there is a unit of increase in exogenous demand.

The NAMEA for Catalonia integrates the SAM database described in the preceding chapter with the Satellite Account on Atmospheric Emissions.[99] Our database is therefore applied to atmospheric emissions and it is constructed by adding columns of the greenhouse gases emitted by production activities and consumption. The information in the account on atmospheric emissions includes the discharge of pollutants generated by sectors and consumption. This database originally included the emissions of ten pollutants. As our aim was to model greenhouse effects, we used only the three emissions that show greenhouse pollution in the regional economy.[100] The three gases we analysed are those that must follow the guidelines of the Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), and nitrogen monoxide (N_2O). The appendix 2.3 of the chapter 2, contains the complete NAMEA used in our empirical analysis.

[98] In contrast, the calculation of multipliers in the traditional input-output model omits the relationships in the circular flow of income from the productive sector towards the primary factors revenue and public or private expenditure. It also omits the feedback effects from these to the productive sectors. Although the input-output model captures the impact of changes in final demand on productive sectors, the chain of events is interrupted at this point since it does not take into account the impact of production on income, consumption and savings.

[99] The sectorial direct emissions has obtained in the development of the agreement 9703/ project 180570: "Elaboració de la Comptabilitat Satèl.lit del Medi Ambient a Catalunya, la corresponent a l'aire", supervised by Vicent Alcántara. Financed for Generalitat de Catalunya (Departament de Medi Ambient i Habitatge).

[100] Only we centre on these three gases because they are those who have a more significant weight in Catalonia.

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3.5.1. Emission Multipliers

In the emission multipliers, sectors, labour (gross wages and salaries plus social contributions) capital (the gross operating surplus) and consumption were considered as endogenous items. The productive branches are disaggregated into the 27 sectors that appear in our social and environmental accounting matrix. The other accounts were considered as exogenous items.

The emission multipliers show how the production sectors and consumers are linked to the pollution they generate. In the SAM model, an increase in exogenous demand leads to an increase in endogenous income. At the same time, the direct relationship between pollution levels and endogenous income means that an increase in the latter increases the former.

Table 3.2 contains the emission multipliers. They show the changes in Catalan emissions when there is an exogenous and unitary inflow to the endogenous accounts (production, factors and consumers). Table 3.2 should be read as follows: the first row and the first column indicate that when agriculture is subject to an exogenous and unitary increase in its exogenous demand, CH_4 emissions increase by 0.021919 tonnes.

The sum of the columns in table 3.2 shows the increase in emissions for each greenhouse gas when there is a unitary injection in the exogenous demand for all accounts simultaneously. These total values, then, reflect the effects on each type of emission caused by the joint inflows to all sectors of production, factors and consumers. The pollutant most affected is CH_4, which increases by 0.088895 tons per unitary increase in all the endogenous components of the model. CO_2 emissions increase by 0.010082 kilotons and N_2O emissions increase by 0.002603 tons.

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Table 3.2. Emission Multipliers *($B(I - A)^{-1}$)*

	CH_4 (t)	CO_2 (kt)	N_2O (t)
1. Agriculture	0.021919	0.000222	0.000865
2. Fishing	0.000590	0.000207	0.000021
3. Energy, Minerals, Coke, petroleum and fuels	0.000757	0.000726	0.000025
4. Electrical energy, gas and water	0.005290	0.000663	0.000038
5. Food	0.005878	0.000205	0.000224
6. Textile	0.001742	0.000190	0.000056
7. Manufacture of wood and cork	0.002932	0.000178	0.000106
8. Paper	0.001314	0.000203	0.000038
9. Chemistry	0.001107	0.000298	0.000041
10. Rubber and plastic products	0.001240	0.000200	0.000037
11. Other non-metallic mineral products	0.001293	0.002071	0.000061
12. Metal	0.000921	0.000162	0.000025
13. Machinery	0.001146	0.000122	0.000025
14. Electrical equipment, electronics and optics	0.000753	0.000123	0.000021
15. Automobiles	0.000921	0.000147	0.000026
16. Other industries	0.001295	0.000199	0.000037
17. Construction	0.001835	0.000459	0.000054
18. Commerce	0.001945	0.000291	0.000057
19. Hotel management	0.003016	0.000254	0.000096
20. Transport and communications	0.001593	0.000625	0.000100
21. Financial intermediation	0.001644	0.000219	0.000046
22. Real estate activities, entrepreneurial services	0.001695	0.000236	0.000047
23. Public services	0.001882	0.000250	0.000052
24. Education	0.001953	0.000249	0.000054
25. Sanitary, veterinary activities, social services	0.001931	0.000252	0.000080
26. Other services, social and personal services	0.013565	0.000272	0.000127
27. Homes that employ domestic staff	0.001881	0.000229	0.000052
Labour	0.002286	0.000278	0.000064
Capital	0.002286	0.000278	0.000064
Households	0.002286	0.000278	0.000064
Total	**0.088895**	**0.010082**	**0.002603**

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Table 3.2 shows which accounts have the greatest influence on greenhouse gas emissions when they receive exogenous inflows. For example, the first column shows that one unit of new exogenous demand to sector 1 (agriculture) generates 0.021919 tons of CH_4. One unit of new exogenous demand to sector 26 (other services, social activities, and personal services), on the other hand, generates 0.013565 tons of CH_4. In the second column, the energy sectors (sectors 3 and 4) and sector 11 (other non-metallic mineral products) generate 0.000726 kilotons of CO_2, 0.000663 kilotons of CO_2, and 0.002071 kilotons of CO_2, respectively. In the third column, sector 1 (agriculture) generates 0.000865 tons of N_2O to meet a new unit of exogenous demand, while sector 5 (food) generates 0.000224 tons of N_2O.

The conclusions we can draw from table 3.2 are that greenhouse gas emissions in Catalonia are affected very differently at the sectorial level and that the effects of production activities, factors and consumption on air pollution are very heterogeneous. Our results also show that the quantitative increases in greenhouse gas emissions will essentially depend on the account that receives the exogenous inflow in demand.

3.5.2. Changes in the Greenhouse Emission Multipliers

In this section we analyse the impact on emission multipliers of a 10% reduction in total greenhouse gas emissions. This percentage of reduction in emissions would bring the Catalan economy in line with the total amount of emissions allowed by the Kyoto Protocol. The analysis involved three different scenarios of emission reduction. First we simulated a 10% reduction in greenhouse gas emissions together with a 5% decrease in endogenous income. Then, we simulated a 10% reduction in emissions with a 10% increase in endogenous income. Finally, we simulated a 10% reduction in emissions with a 5% increase in endogenous income. The reason of introducing these alternative situations is based on the possible impacts on production and consumption of any control policy of emissions.

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The simulation analysis involved modifying the emissions per unit of endogenous income in matrix *B*. According to expression (3.8), of the emissions model, in the simulations we reduced the total emissions used to calculate matrix *B* (i.e. the *E* values) by 10%. Additionally, we varied the endogenous income in the diagonal matrix $\hat{Y}$ by different amounts. In the first simulation, we decreased the values of $\hat{Y}$ by 5%, and in the second and third situations we increased the values of $\hat{Y}$ by 10% and 5%, respectively.

Table 3.3 shows the impact on emission multipliers of a 10% reduction in greenhouse gas emissions and a 5% decrease in endogenous income. The last row shows the changes in the emissions of the corresponding gas when there is an exogenous inflow to all the endogenous accounts of the model. In this situation, there is a general increase in the emissions of all greenhouse gases: CH_4 emissions increase by 12.18%, CO_2 emissions by 11.75% and N_2O emissions by 12.43%.

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Table 3.3. Changes (%) in emission multipliers:
10% reduction in emissions and 5% reduction in endogenous income

	CH_4 (t)	CO_2 (kt)	N_2O (t)
1. Agriculture	-3.23%	13.25%	-3.65%
2. Fishing	30.29%	6.90%	24.74%
3. Energy, minerals, coke, petroleum and fuels	12.15%	-1.86%	10.35%
4. Electrical energy, gas and water	2.46%	3.45%	25.17%
5. Food	6.62%	18.53%	5.29%
6. Textile	21.93%	20.85%	20.21%
7. Manufacture of wood and cork	12.00%	19.02%	10.00%
8. Paper	28.47%	19.48%	28.69%
9. Chemistry	26.60%	9.16%	20.24%
10. Rubber and plastic products	27.94%	18.71%	27.67%
11. Other non-metallic mineral products	27.25%	-2.30%	15.07%
12. Metal	30.80%	18.37%	32.52%
13. Machinery	23.27%	23.67%	31.09%
14. Electrical equipment, electronics and optics	33.09%	22.40%	34.06%
15. Automobiles	32.29%	22.49%	33.41%
16. Other industries	28.01%	19.33%	28.91%
17. Construction	31.11%	14.19%	31.25%
18. Commerce	30.62%	22.32%	30.96%
19. Hotel management	20.30%	24.08%	19.21%
20. Transport and communications	30.86%	6.44%	12.18%
21. Financial intermediation	32.47%	26.11%	33.79%
22. Real estate activities and entrepreneurial services	31.63%	24.69%	33.34%
23. Public services	28.82%	23.23%	30.77%
24. Education	31.07%	25.61%	32.92%
25. Sanitary, veterinary activities, social services	30.07%	24.56%	19.90%
26. Other services, social and personal services	-0.41%	20.83%	9.63%
27. Homes that employ domestic staff	31.64%	27.22%	33.37%
Labour	25.06%	20.86%	26.70%
Capital	25.06%	20.86%	26.70%
Households	18.80%	14.81%	20.36%
Total	**12.18%**	**11.75%**	**12.43%**

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Table 3.3 also shows which accounts generate the greatest increases in gas emissions when they receive an exogenous and unitary inflow. The first column shows that the highest increases in CH_4 are caused by sector 14 (electrical equipment, electronics and optics) with an increase of 33.09%, and by sector 21 (financial intermediation), with an increase of 32.47%. The highest increases in CO_2 emissions are caused by sector 27 (homes that employ domestic staff) with an increase of 27.22%, and sector 21 (financial intermediation) with an increase of 26.11%. The highest increases in N_2O emissions are caused by sector 14 (electrical equipment, electronics and optics) and sector 21 (financial intermediation), with values of 34.06% and 33.79%, respectively.

Another important aspect of table 3.3 is that very few sectors reduce their emission multipliers. Specifically, sector 1 (agriculture) shows a reduction in CH_4 emissions of -3.26% and sector 26 (other services, social activities, personal services) shows a reduction of -0.41%. For CO_2 emissions, sector 11 (other non-metallic mineral products) shows a reduction of -2.30% and sector 3 (energy products, minerals, coke, petroleum and fuels) shows a reduction of -1.86%. Finally, N_2O emissions, sector 1 (agriculture) shows a value of -3.65%.

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Table 3.4. Changes (%) in emission multipliers: 10% reduction in emissions and 10% increase in endogenous income

	CH_4 (t)	CO_2 (kt)	N_2O (t)
1. Agriculture	-20.18%	-35.20%	-19.79%
2. Fishing	-49.72%	-29.74%	-44.85%
3. Energy, minerals, coke, petroleum and fuels	-33.63%	-21.97%	-31.94%
4. Electrical energy, gas and water	-25.16%	-27.14%	-44.89%
5. Food	-31.38%	-40.35%	-30.34%
6. Textile	-43.33%	-42.15%	-41.97%
7. Manufacture of wood and cork	-35.72%	-40.49%	-34.17%
8. Paper	-48.07%	-40.90%	-48.04%
9. Chemistry	-46.63%	-32.02%	-41.00%
10. Rubber and plastic products	-47.81%	-40.64%	-47.48%
11. Other non-metallic mineral products	-47.11%	-21.26%	-36.17%
12. Metal	-49.90%	-39.99%	-50.91%
13. Machinery	-44.05%	-44.59%	-49.87%
14. Electrical equipment, electronics and optics	-51.51%	-43.65%	-52.02%
15. Automobiles	-50.79%	-43.68%	-51.42%
16. Other industries	-47.91%	-41.02%	-48.53%
17. Construction	-50.14%	-37.48%	-50.06%
18. Commerce	-49.82%	-43.67%	-49.92%
19. Hotel management	-42.56%	-45.06%	-41.79%
20. Transport and communications	-49.79%	-29.47%	-33.71%
21. Financial intermediation	-51.39%	-46.64%	-52.21%
22. Real estate and entrepreneurial services	-50.64%	-45.55%	-51.76%
23. Public services	-48.58%	-44.36%	-49.91%
24. Education	-50.53%	-46.23%	-51.77%
25. Sanitary, veterinary and social services	-49.63%	-45.42%	-40.42%
26. Other services, social and personal services	-22.59%	-42.09%	-31.43%
27. Homes that employ domestic staff	-51.08%	-47.58%	-52.22%
Labour	-46.19%	-42.34%	-47.45%
Capital	-46.19%	-42.34%	-47.45%
Households	-40.81%	-36.57%	-42.19%
Total	**-34.13%**	**-34.12%**	**-34.36%**

The second scenario analysed was a 10% reduction in total greenhouse gas emissions combined with a 10% increase in production and factorial and personal income. Table 3.4 shows that the total changes in emission multipliers are negative for all three greenhouse gases. This means that a reduction in total emissions accompanied by an increase in production and consumer income would reduce emissions per unit of income in the regional economy. The last row in table 3.4 shows that there are similar reductions in the three greenhouse gases. Specifically, the reduction in CH_4 emission is -34.13%, the reduction in CO_2 emission is -34.12% and the reduction in N_2O emission is -34.36%.

Another aspect of table 3.4 that should be mentioned is that all the values in this table are negative. However, the quantitative impact depends on the account and the type of gas analysed. The largest reductions in greenhouse gas emission multipliers are as follows: for CH_4, sector 14 (electrical equipment, electronics and optics) with -51.51%; for CO_2, sector 27 (homes that employ domestic staff) with -47.58%; and finally, for N_2O, sector 27 (homes that employ domestic staff) with -52.22%.

The third scenario analysed was a 10% reduction in greenhouse gas emissions together with a 5% increase in endogenous income. Table 3.5 shows a general reduction in multipliers, though this was not as large as in the previous scenario. Again, all values in table 3.5 are negative but the individual changes are different in quantitative terms. The highest value is for the effects caused by sector 21 (financial intermediation) on N_2O emissions (-35.76%). The smallest value is for the effects caused by sector 1 (agriculture) on N_2O emissions (-15.26%).

ISBN:978-84-693-0717-5/DL:T-442-2010

Table 3.5. Changes (%) in emission multipliers: 10% reduction in emissions and 5% increase in endogenous income

	CH_4 (t)	CO_2 (kt)	N_2O (t)
1. Agriculture	-15.51%	-24.85%	-15.26%
2. Fishing	-34.08%	-21.40%	-31.01%
3. Energy, minerals, coke, petroleum and fuels	-23.97%	-16.52%	-22.93%
4. Electrical energy, gas and water	-18.64%	-19.68%	-31.09%
5. Food	-22.06%	-28.00%	-21.38%
6. Textile	-29.87%	-29.18%	-28.99%
7. Manufacture of wood and cork	-24.87%	-28.14%	-23.86%
8. Paper	-33.05%	-28.40%	-33.06%
9. Chemistry	-32.10%	-22.78%	-28.57%
10. Rubber and plastic products	-32.84%	-28.16%	-32.65%
11. Other non-metallic mineral products	-32.42%	-16.13%	-25.58%
12. Metal	-34.24%	-27.81%	-34.96%
13. Machinery	-30.41%	-30.72%	-34.27%
14. Electrical equipment, electronics and optics	-35.33%	-30.10%	-35.70%
15. Manufacture of transport material	-34.87%	-30.12%	-35.33%
16. Other industries	-32.90%	-28.43%	-33.32%
17. Construction	-34.40%	-26.01%	-34.38%
18. Commerce	-34.18%	-30.09%	-34.27%
19. Hotel management	-29.27%	-30.99%	-28.75%
20. Transport and communications	-34.20%	-21.20%	-24.02%
21. Financial intermediation	-35.18%	-32.03%	-35.76%
22. Real estate and entrepreneurial services	-34.71%	-31.31%	-35.48%
23. Public services	-33.33%	-30.55%	-34.24%
24. Education	-34.57%	-31.76%	-35.43%
25. Sanitary, veterinary and social services	-34.01%	-31.23%	-28.26%
26. Other services, social and personal services	-17.04%	-29.15%	-22.59%
27. Homes that employ domestic staff	-34.91%	-32.62%	-35.70%
Labour	-31.66%	-29.26%	-32.49%
Capital	-31.66%	-29.26%	-32.49%
Households	-28.24%	-25.72%	-29.11%
Total	**-24.20%**	**-24.13%**	**-24.35%**

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In summary, a reduction in greenhouse gas emissions together with a reduction in production and factorial and personal income increases emissions per unit of new income to sectors, factors and households. On the other hand, a reduction in greenhouse gas emissions together with an increase in production and personal and factorial income considerably reduces the unitary emissions of all three greenhouse gases in the regional economy.

3.5.3. Descomposition of the Emission Multipliers Matrix

Decomposing emission multipliers serves as an interesting exercise, which shows the relevance of the various interdependent channels of income in the Catalan economy and their conection with the environment.

Tables 3.6, 3.7 and 3.8 summarize the results of the decomposition analysis, which consists of calculating the matrices of the own net effects $B(M_1 - I)$, the open net effects $B(M_2 - I)M_1$ and, finally, the circular net effects $B(M_3 - I)M_2M_1$. Additionally, the above mentioned tables reflect the percentages that every net effect contributes to the total emission multipliers.[101]

[101] The complete matrices of the additive decomposition of multipliers are gathered at the end of the chapter.

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Table 3.6. Additive decomposition in the emissions of CH_4 (t)

	Own Effects		Open Effects		Circular Effects		Total Effects
	Value	**(%)**	**Value**	**(%)**	**Value**	**(%)**	
1. Agriculture	0.001247	58.84%	0.000014	0.68%	0.000858	40.48%	0.002120
2. Fishing	0.000101	17.31%	0.000008	1.36%	0.000477	81.33%	0.000586
3. Energy, minerals, coke, petroleum and fuels	0.000153	36.67%	0.000004	1.04%	0.000260	62.29%	0.000418
4. Electrical energy, gas and water	0.000494	35.54%	0.000015	1.06%	0.000882	63.39%	0.001391
5. Food	0.005008	85.24%	0.000014	0.24%	0.000853	14.52%	0.005875
6. Textile	0.000819	47.07%	0.000015	0.87%	0.000905	52.06%	0.001739
7. Manufacture of wood and cork	0.002107	71.97%	0.000014	0.46%	0.000807	27.57%	0.002928
8. Paper	0.000354	27.01%	0.000016	1.20%	0.000941	71.78%	0.001310
9. Chemistry	0.000313	29.78%	0.000012	1.16%	0.000725	69.06%	0.001050
10. Rubber and plastic products	0.000357	28.86%	0.000015	1.17%	0.000866	69.97%	0.001238
11. Other non-metallic mineral products	0.000303	24.17%	0.000016	1.25%	0.000935	74.58%	0.001253
12. Metal	0.000173	18.86%	0.000012	1.34%	0.000733	79.80%	0.000918
13. Machinery	0.000439	38.33%	0.000012	1.02%	0.000695	60.65%	0.001146
14. Electrical equipment, electronics and optics	0.000118	15.71%	0.000010	1.39%	0.000624	82.90%	0.000753
15. Manufacture of transport material	0.000190	20.68%	0.000012	1.31%	0.000718	78.01%	0.000920
16. Other industries	0.000409	31.67%	0.000015	1.13%	0.000869	67.21%	0.001293
17. Construction	0.000330	18.01%	0.000025	1.35%	0.001479	80.63%	0.001835
18. Commerce	0.000304	15.65%	0.000027	1.39%	0.001613	82.96%	0.001944
19. Hotel management	0.001429	47.38%	0.000026	0.87%	0.001560	51.75%	0.003015
20. Transport and communications	0.000228	14.74%	0.000022	1.41%	0.001298	83.85%	0.001548
21. Financial intermediation	0.000091	5.54%	0.000026	1.56%	0.001527	92.90%	0.001644
22. Real estate and entrepreneurial services	0.000191	11.25%	0.000025	1.46%	0.001479	87.29%	0.001695
23. Public services	0.000314	16.68%	0.000026	1.37%	0.001542	81.95%	0.001881
24. Education	0.000100	5.12%	0.000031	1.57%	0.001822	93.32%	0.001952
25. Sanitary, veterinary and social services	0.000259	13.40%	0.000028	1.43%	0.001644	85.17%	0.001930
26. Other services, social and personal services	0.000737	33.30%	0.000024	1.10%	0.001452	65.60%	0.002214
27. Homes that employ domestic staff	0.000000	0.00%	0.000031	1.65%	0.001850	98.35%	0.001881
Labour	0.000000	0.00%	0.001387	60.67%	0.000899	39.33%	0.002286
Capital	0.000000	0.00%	0.001387	60.67%	0.000899	39.33%	0.002286
Households	0.000000	0.00%	0.001349	60.01%	0.000899	39.99%	0.002248
Total	**0.016570**	**31.09%**	**0.004616**	**8.66%**	**0.032111**	**60.25%**	**0.053297**

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The analysis of table 3.6 reveals that the circular effects (60.25% of the net total effects) and own effects (31.09% of total effects) have greater weight than the open effects (8.66%). On the other hand, in three accounts (labour, capital and households) the open effects are considerably greater than the circular effects. Nevertheless, in these accounts and account 27 (homes that employ domestic staff) own effects are null. This is consequence of the structure of the NAMEA, since it only presents an account for the consumption sector, and this can be a limitation when showing the interrelationships within the private sector of the economy.

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Table 3.7. Additive decomposition in the emissions of CO_2 (kt)

	Own Effects		Open Effects		Circular Effects		Total Effects
	Value	(%)	Value	(%)	Value	(%)	
1. Agriculture	0.000033	23.81%	0.000034	24.55%	0.000072	51.64%	0.000139
2. Fishing	0.000045	43.30%	0.000019	18.27%	0.000040	38.43%	0.000104
3. Energy, minerals, coke, petroleum and fuels	0.000160	83.25%	0.000010	5.40%	0.000022	11.35%	0.000192
4. Electrical energy, gas and water	0.000227	67.57%	0.000035	10.45%	0.000074	21.98%	0.000336
5. Food	0.000078	42.68%	0.000034	18.47%	0.000071	38.85%	0.000184
6. Textile	0.000056	33.41%	0.000036	21.46%	0.000076	45.13%	0.000168
7. Manufacture of wood and cork	0.000050	33.40%	0.000032	21.46%	0.000068	45.14%	0.000150
8. Paper	0.000055	32.32%	0.000037	21.81%	0.000079	45.87%	0.000172
9. Chemistry	0.000095	51.38%	0.000029	15.67%	0.000061	32.95%	0.000184
10. Rubber and plastic products	0.000074	40.91%	0.000034	19.04%	0.000073	40.05%	0.000181
11. Other non-metallic mineral products	0.000275	70.42%	0.000037	9.53%	0.000078	20.05%	0.000390
12. Metal	0.000044	32.52%	0.000029	21.74%	0.000061	45.74%	0.000134
13. Machinery	0.000030	26.02%	0.000028	23.84%	0.000058	50.14%	0.000116
14. Electrical equipment, electronics and optics	0.000041	34.64%	0.000025	21.06%	0.000052	44.30%	0.000118
15. Manufacture of transport material	0.000051	36.43%	0.000029	20.48%	0.000060	43.09%	0.000139
16. Other industries	0.000072	40.13%	0.000035	19.29%	0.000073	40.58%	0.000179
17. Construction	0.000271	59.71%	0.000059	12.98%	0.000124	27.31%	0.000454
18. Commerce	0.000083	29.48%	0.000064	22.72%	0.000135	47.80%	0.000283
19. Hotel management	0.000055	22.16%	0.000062	25.08%	0.000131	52.76%	0.000248
20. Transport and communications	0.000164	50.49%	0.000052	15.95%	0.000109	33.56%	0.000324
21. Financial intermediation	0.000027	12.67%	0.000061	28.14%	0.000128	59.19%	0.000216
22. Real estate and entrepreneurial services	0.000048	20.88%	0.000059	25.49%	0.000124	53.63%	0.000231
23. Public services	0.000051	21.10%	0.000061	25.42%	0.000129	53.48%	0.000241
24. Education	0.000018	7.36%	0.000073	29.85%	0.000153	62.79%	0.000243
25. Sanitary, veterinary and social services	0.000043	17.36%	0.000065	26.63%	0.000138	56.01%	0.000246
26. Other services, social and personal services	0.000057	24.13%	0.000058	24.45%	0.000122	51.42%	0.000236
27. Homes that employ domestic staff	0.000000	0.00%	0.000074	32.22%	0.000155	67.78%	0.000229
Labour	0.000000	0.00%	0.000168	60.67%	0.000109	39.33%	0.000278
Capital	0.000000	0.00%	0.000168	60.67%	0.000109	39.33%	0.000278
Households	0.000000	0.00%	0.000079	41.97%	0.000109	58.03%	0.000188
Total	**0.002203**	**33.48%**	**0.001587**	**24.12%**	**0.002791**	**42.41%**	**0.006580**

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Table 3.7 shows the importance that every effect of interdependence has on the CO_2 emission multipliers. In this table, the circular effects have the greatest weight (42.41 % of the net total effects). The own effects (33.48 %) are in second place, and the open effects (24.12 %) have least weight. On the other hand, in both the labour and capital accounts the open effects are considerably higher than the circular effects and in the consumption account the circular effects are slightly higher than the open effects.

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Table 3.8. Additive decomposition in the emissions of N_2O (t)

	Own Effects		Open Effects		Circular Effects		Total Effects
	Value	**(%)**	**Value**	**(%)**	**Value**	**(%)**	
1. Agriculture	0.000048	66.38%	0.000000	0.39%	0.000024	33.23%	0.000072
2. Fishing	0.000005	25.57%	0.000000	0.86%	0.000013	73.57%	0.000018
3. Energy, minerals, coke, petroleum and fuels	0.000005	39.20%	0.000000	0.70%	0.000007	60.10%	0.000012
4. Electrical energy, gas and water	0.000008	24.26%	0.000000	0.87%	0.000025	74.87%	0.000033
5. Food	0.000199	89.19%	0.000000	0.12%	0.000024	10.69%	0.000223
6. Textile	0.000030	54.06%	0.000000	0.53%	0.000025	45.41%	0.000056
7. Manufacture of wood and cork	0.000083	78.39%	0.000000	0.25%	0.000023	21.37%	0.000106
8. Paper	0.000011	29.10%	0.000000	0.82%	0.000026	70.09%	0.000038
9. Chemistry	0.000012	36.15%	0.000000	0.74%	0.000020	63.12%	0.000032
10. Rubber and plastic products	0.000012	32.88%	0.000000	0.77%	0.000024	66.35%	0.000037
11. Other non-metallic mineral products	0.000010	27.67%	0.000000	0.83%	0.000026	71.49%	0.000037
12. Metal	0.000004	16.29%	0.000000	0.96%	0.000021	82.75%	0.000025
13. Machinery	0.000005	21.14%	0.000000	0.91%	0.000019	77.95%	0.000025
14. Electrical equipment, electronics and optics	0.000004	17.17%	0.000000	0.95%	0.000017	81.88%	0.000021
15. Manufacture of transport material	0.000006	21.59%	0.000000	0.90%	0.000020	77.51%	0.000026
16. Other industries	0.000012	32.97%	0.000000	0.77%	0.000024	66.26%	0.000037
17. Construction	0.000012	21.71%	0.000000	0.90%	0.000041	77.39%	0.000053
18. Commerce	0.000011	19.10%	0.000001	0.93%	0.000045	79.97%	0.000056
19. Hotel management	0.000052	54.04%	0.000001	0.53%	0.000044	45.43%	0.000096
20. Transport and communications	0.000018	33.31%	0.000000	0.77%	0.000036	65.92%	0.000055
21. Financial intermediation	0.000003	6.68%	0.000000	1.08%	0.000043	92.25%	0.000046
22. Real estate and entrepreneurial services	0.000005	11.15%	0.000000	1.02%	0.000041	87.83%	0.000047
23. Public services	0.000008	15.49%	0.000001	0.97%	0.000043	83.53%	0.000052
24. Education	0.000002	4.55%	0.000001	1.10%	0.000051	94.35%	0.000054
25. Sanitary, veterinary and social services	0.000009	16.51%	0.000001	0.96%	0.000046	82.53%	0.000056
26. Other services, social and personal services	0.000014	25.10%	0.000000	0.86%	0.000041	74.04%	0.000055
27. Homes that employ domestic staff	0.000000	0.00%	0.000001	1.15%	0.000052	98.85%	0.000052
Labour	0.000000	0.00%	0.000039	60.67%	0.000025	39.33%	0.000064
Capital	0.000000	0.00%	0.000039	60.67%	0.000025	39.33%	0.000064
Households	0.000000	0.00%	0.000038	60.21%	0.000025	39.79%	0.000063
Total	**0.000587**	**36.48%**	**0.000125**	**7.74%**	**0.000898**	**55.78%**	**0.001610**

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Table 3.8 shows the importance that every effect of interdependence has on the total emission multipliers of N_20. In this table, the circular effects present the largest values (in twenty-two accounts these effects exceed 60%).

Finally, in the last three accounts (labour, capital and households) the open effects are considerably higher than the circular effects. The explanation is the structure of our social and environmental database, which has a single account for the consumption sector and, therefore, does not capture the interrelationships within the private sector of the economy.

3.6. Conclusions

In recent years, natural levels of greenhouse gases have increased due to emissions of CO_2 from fossil fuels, methane, nitrogen oxide produced by agriculture, changes in soil use, and various inert industrial gases that do not occur naturally. If the concentration of greenhouse gases continues to increase, the greenhouse effect will cause a global increase in air temperature that may lead to serious environmental problems such as climate change, damage to natural ecosystems, and impoverishment of the environment. All of these negative impacts on the environment will also have adverse effects on human health.

In this chapter we have defined a linear model of emission multipliers for the Catalan economy in 2001. This model shows how unitary increases in exogenous demand affect greenhouse gas emissions. The linear SAM model is similar to the input-output model designed by Leontief, but the SAM model incorporates a greater level of endogeneity of the accounts. As a result, it captures the complete circular flow of income as it is not limited to the production sphere but incorporates income distribution and the income generation processes.

With the aim of reducing greenhouse gas emissions in the Catalan economy, we analysed three alternative scenarios. The first scenario was a

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10% reduction in greenhouse gas emissions and a 5% cut in endogenous income (production, and factorial and private income). This led to an overall increase in emission multipliers of all greenhouse gases. The second scenario was a 10% reduction in greenhouse gas emissions and a 10% increase in endogenous income. This led to a considerable reduction in the emission multipliers of all greenhouse gases analysed. The third scenario was a 10% reduction in greenhouse gas emissions and a 5% increase in endogenous income. This scenario also led to a general reduction in greenhouse gas emissions per unit of exogenous demand.

Additionally, we also decomposed the total emission multipliers into own effects, open effects and circular effects. This decomposition shows the different channels of income generation and its effects on greenhouse gas emissions. For all the gases considered, the circular effects are the most important component in total multipliers.

We should bear in mind that policies designed to reduce emissions may conflict with a society's development goals since there is a close relationship between economic growth, the consumption of natural resources, and the generation of pollution and environmental loads. Policymakers must, therefore, harmonise economic and ecological objectives in order to ensure both the development of society and the preservation of the environment.

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ISBN:978-84-693-0717-5/DL:T-442-2010

Appendix 3.1

Table 3.9. Endogenous accounts and greenhouse gases

SECTORS OF PRODUCTION	
1. Agriculture	19. Hotel management
2. Fishing	20. Transport and communications
3. Energy, minerals, coke, petroleum and fuels	21. Financial intermediation
4. Electrical energy, gas and water	22. Real estate activities and entrepreneurial services
5. Food	23. Public services
6. Textile	24. Education
7. Manufacture of wood and cork	25. Sanitary and veterinary activities, social services
8. Paper	26. Other services, social activities and personal services
9. Chemistry	27. Homes that employ domestic staff
10. Rubber and plastic products	**FACTORS OF PRODUCTION**
11. Other non-metallic mineral products	28. Labour
12. Metal	29. Capital
13. Machinery	**PRIVATE AGENTS**
14. Electrical equipment, electronics and optics	30. Households
15. Automobiles	**GASES**
16. Other industries	Methane (CH_4)
17. Construction	Carbon dioxide (CO_2)
18. Commerce	Nitrous oxide (N_2O)

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

Appendix 3.2

Table 3.10. $M=(M_3 M_2 M_1)$

	1	2	3	4	5	6	7	8	9	10	11	12
1	1.081142	0.015327	0.007448	0.024584	0.269751	0.057583	0.122845	0.033620	0.026719	0.031579	0.027126	0.021305
2	0.004061	1.014496	0.001129	0.003811	0.008142	0.004030	0.003504	0.004088	0.003243	0.003811	0.004036	0.003162
3	0.034309	0.058643	1.266145	0.331940	0.035823	0.037829	0.036893	0.039482	0.077142	0.041350	0.164329	0.029444
4	0.027269	0.012031	0.008603	1.092760	0.029160	0.036380	0.024905	0.037045	0.028569	0.035384	0.045766	0.024569
5	0.165918	0.043347	0.019860	0.066483	1.224685	0.102499	0.070827	0.077781	0.081747	0.084277	0.072566	0.057149
6	0.022113	0.020944	0.006842	0.023222	0.023152	1.358243	0.023118	0.030733	0.020999	0.038950	0.026998	0.022336
7	0.003910	0.007672	0.002376	0.005418	0.008639	0.004196	1.304310	0.007494	0.004245	0.005867	0.012648	0.008569
8	0.020854	0.011066	0.006213	0.020185	0.040029	0.033401	0.026337	1.339239	0.041786	0.054470	0.030850	0.024803
9	0.059010	0.018934	0.011661	0.033330	0.049950	0.137490	0.037794	0.102466	1.282953	0.264387	0.061163	0.051083
10	0.009693	0.008501	0.004165	0.010336	0.026713	0.017596	0.009345	0.025838	0.030082	1.098359	0.016569	0.016995
11	0.006315	0.004114	0.009735	0.015183	0.016869	0.006654	0.007372	0.006054	0.009869	0.009792	1.100043	0.010652
12	0.015386	0.024827	0.016797	0.032939	0.025192	0.020117	0.029321	0.018921	0.023116	0.042403	0.041678	1.239264
13	0.015238	0.009988	0.009866	0.018862	0.018332	0.020072	0.017746	0.024281	0.019513	0.028162	0.029754	0.048468
14	0.019146	0.015397	0.007040	0.052703	0.022595	0.022597	0.019200	0.024245	0.020570	0.025662	0.024200	0.027751
15	0.026826	0.059273	0.008485	0.027901	0.029139	0.030520	0.027171	0.030119	0.023976	0.028492	0.030156	0.025202
16	0.010602	0.006910	0.003862	0.013282	0.011420	0.013069	0.015174	0.015515	0.009988	0.012459	0.014289	0.049140
17	0.027442	0.023895	0.080313	0.109069	0.034202	0.027506	0.026460	0.026365	0.034581	0.027633	0.068053	0.027998
18	0.117645	0.063798	0.034040	0.107414	0.142283	0.155929	0.141670	0.129870	0.111711	0.133588	0.125578	0.112099
19	0.080047	0.045086	0.025120	0.084712	0.081273	0.085885	0.076051	0.089617	0.069816	0.082766	0.088952	0.069357
20	0.071671	0.066283	0.027983	0.099458	0.096979	0.091663	0.082313	0.107706	0.086303	0.095663	0.128025	0.072458
21	0.040166	0.025633	0.015313	0.045879	0.048298	0.049140	0.041192	0.056205	0.041308	0.046879	0.048249	0.038333
22	0.137352	0.077992	0.044809	0.154038	0.203566	0.156974	0.140390	0.180130	0.152422	0.155531	0.150071	0.117180
23	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
24	0.010899	0.006145	0.003504	0.012321	0.012045	0.012263	0.010690	0.025812	0.011018	0.012798	0.012608	0.009750
25	0.019397	0.010631	0.006107	0.020231	0.019831	0.021195	0.018270	0.021710	0.016970	0.019734	0.021294	0.016700
26	0.032047	0.017437	0.012063	0.035073	0.033107	0.035721	0.031335	0.039454	0.030160	0.036601	0.038947	0.031951
27	0.006366	0.003536	0.001931	0.006542	0.006326	0.006716	0.005988	0.006976	0.005379	0.006423	0.006933	0.005437
Labour	0.188911	0.171534	0.078299	0.235188	0.262193	0.338038	0.294667	0.346836	0.244334	0.310284	0.306294	0.268385
Capital	0.440367	0.178033	0.112603	0.411517	0.363165	0.325901	0.297239	0.342794	0.287421	0.324641	0.379040	0.269044
Households	0.629277	0.349567	0.190902	0.646705	0.625357	0.663938	0.591906	0.689631	0.531755	0.634924	0.685333	0.537429

ISBN:978-84-693-0717-5/DL:T-442-2010

Table 3.10. (continued) $M=(M_3M_2M_1)$

	13	14	15	16	17	18	19	20	21	22	23	24
1	0.019898	0.018247	0.020998	0.032637	0.044487	0.046643	0.103535	0.036532	0.041436	0.040962	0.046031	0.050137
2	0.003034	0.002699	0.003110	0.003822	0.006416	0.007014	0.021713	0.005768	0.006581	0.006406	0.006958	0.008263
3	0.023926	0.024337	0.027698	0.038625	0.077836	0.067054	0.052618	0.114510	0.045967	0.053500	0.057658	0.049623
4	0.020902	0.018870	0.022496	0.031292	0.044814	0.059477	0.059887	0.048562	0.040873	0.042717	0.062197	0.047690
5	0.053819	0.049217	0.056941	0.072430	0.113272	0.123068	0.306528	0.099276	0.112869	0.110966	0.116793	0.135831
6	0.019278	0.018728	0.023798	0.093316	0.041398	0.043838	0.043979	0.034734	0.037415	0.039128	0.044087	0.044708
7	0.005120	0.005140	0.006369	0.073258	0.024572	0.013241	0.006780	0.005762	0.004965	0.007294	0.006235	0.005796
8	0.021424	0.026123	0.022758	0.044807	0.037377	0.064668	0.045259	0.039320	0.042089	0.058248	0.067376	0.048908
9	0.033882	0.050209	0.059793	0.085028	0.069283	0.053942	0.048637	0.038280	0.034484	0.046793	0.045611	0.044013
10	0.021381	0.043833	0.061487	0.038001	0.030935	0.028994	0.020028	0.017939	0.011800	0.016712	0.014369	0.013928
11	0.006993	0.011381	0.009638	0.017528	0.132640	0.012478	0.013764	0.009762	0.008016	0.012039	0.009444	0.009222
12	0.116070	0.126484	0.173664	0.158779	0.181400	0.040820	0.027441	0.030605	0.022989	0.031372	0.028251	0.025063
13	1.084452	0.030177	0.050331	0.042605	0.056745	0.027817	0.024754	0.020009	0.015650	0.023191	0.026159	0.018475
14	0.063729	1.163948	0.048596	0.041942	0.049632	0.065830	0.038337	0.045425	0.031370	0.064357	0.039471	0.035424
15	0.026071	0.021674	1.237711	0.031052	0.049858	0.103741	0.050887	0.061198	0.045334	0.051722	0.050679	0.053641
16	0.013085	0.012666	0.023846	1.056602	0.027529	0.022715	0.019888	0.017408	0.018624	0.020016	0.021174	0.023346
17	0.023140	0.023248	0.026136	0.031935	1.234711	0.056767	0.041923	0.055741	0.041538	0.066876	0.050647	0.040982
18	0.104487	0.096813	0.113112	0.154961	0.205338	1.212367	0.236607	0.162490	0.163109	0.175724	0.180179	0.195534
19	0.066788	0.059458	0.068443	0.085714	0.143184	0.157652	1.148122	0.135685	0.146845	0.142754	0.148983	0.174460
20	0.072363	0.066450	0.100427	0.101889	0.150042	0.242162	0.132676	1.415379	0.144684	0.156552	0.162691	0.137000
21	0.036461	0.035691	0.038448	0.050488	0.077259	0.100008	0.076421	0.070193	1.223614	0.111658	0.075307	0.076813
22	0.128564	0.138707	0.134077	0.163700	0.242409	0.369790	0.275178	0.245600	0.256681	1.365407	0.304266	0.263358
23	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	1.000000	0.000000
24	0.009382	0.008712	0.010331	0.012423	0.019677	0.022859	0.020489	0.018627	0.019509	0.021190	0.022015	1.037696
25	0.016235	0.014383	0.016593	0.020943	0.033532	0.037084	0.035907	0.029207	0.032849	0.032976	0.035395	0.038310
26	0.056070	0.025094	0.033270	0.041882	0.061155	0.062122	0.058130	0.047419	0.052519	0.056946	0.057567	0.061304
27	0.005154	0.004628	0.005324	0.006444	0.010974	0.011963	0.011574	0.009628	0.011328	0.010972	0.011435	0.013512
Labour	0.253982	0.222662	0.257085	0.338174	0.524919	0.519458	0.507346	0.382870	0.517548	0.411062	0.707644	0.901085
Capital	0.255563	0.234808	0.269210	0.298841	0.559881	0.663104	0.636827	0.568893	0.602230	0.673582	0.422718	0.434664
Households	0.509545	0.457470	0.526295	0.637015	1.084801	1.182562	1.144173	0.951763	1.119777	1.084644	1.130362	1.335749

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Table 3.10. (continued) $M=(M_3M_2M_1)$

	25	26	27	**Labour**	**Capital**	**Households**
1	0.050442	0.048271	0.049348	0.059963	0.059963	0.059963
2	0.009052	0.007525	0.007836	0.009522	0.009522	0.009522
3	0.051872	0.056148	0.043619	0.053001	0.053001	0.053001
4	0.050676	0.058949	0.037542	0.045617	0.045617	0.045617
5	0.135077	0.136679	0.134579	0.163527	0.163527	0.163527
6	0.049671	0.046570	0.044556	0.054140	0.054140	0.054140
7	0.005917	0.008680	0.005240	0.006367	0.006367	0.006367
8	0.042346	0.063551	0.031635	0.038440	0.038440	0.038440
9	0.120814	0.083063	0.037971	0.046138	0.046138	0.046138
10	0.016821	0.016924	0.012543	0.015241	0.015241	0.015241
11	0.011821	0.010028	0.007458	0.009062	0.009062	0.009062
12	0.030036	0.034749	0.022222	0.027002	0.027002	0.027002
13	0.022448	0.024469	0.016688	0.020277	0.020277	0.020277
14	0.085175	0.054300	0.031235	0.037954	0.037954	0.037954
15	0.050534	0.047423	0.052996	0.064395	0.064395	0.064395
16	0.020783	0.029249	0.020620	0.025055	0.025055	0.025055
17	0.041043	0.049660	0.031548	0.038334	0.038334	0.038334
18	0.206552	0.190526	0.190151	0.231052	0.231052	0.231052
19	0.157598	0.156695	0.169437	0.205882	0.205882	0.205882
20	0.132873	0.147151	0.121488	0.147619	0.147619	0.147619
21	0.077309	0.079511	0.069302	0.084209	0.084209	0.084209
22	0.273252	0.331789	0.216181	0.262680	0.262680	0.262680
23	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
24	0.021608	0.020555	0.022311	0.027110	0.027110	0.027110
25	1.088938	0.034117	0.038120	0.046320	0.046320	0.046320
26	0.057818	1.084208	0.060125	0.073058	0.073058	0.073058
27	0.012195	0.010773	1.013723	0.016674	0.016674	0.016674
Labour	0.696657	0.493441	1.065359	1.294512	0.294512	0.294512
Capital	0.508903	0.571530	0.291202	0.353838	1.353838	0.353838
Households	1.205560	1.064971	1.356561	1.648350	1.648350	1.648350

ISBN:978-84-693-0717-5/DL:T-442-2010

Appendix 3.3

Table 3.11. $B(M_1\text{-}I)$

	CH_4 (t)	CO_2 (kt)	N_2O (t)
1. Agriculture	0.0012472	0.0000331	0.0000479
2. Fishing	0.0001014	0.0000450	0.0000046
3. Energy, minerals, coke, petroleum and fuels	0.0001533	0.0001598	0.0000048
4. Electrical energy, gas and water	0.0004945	0.0002270	0.0000080
5. Food	0.0050082	0.0000785	0.0001991
6. Textile	0.0008186	0.0000561	0.0000301
7. Manufacture of wood and cork	0.0021072	0.0000500	0.0000828
8. Paper	0.0003540	0.0000555	0.0000109
9. Chemistry	0.0003128	0.0000947	0.0000116
10. Rubber and plastic products	0.0003571	0.0000741	0.0000120
11. Other non-metallic mineral products	0.0003030	0.0002749	0.0000101
12. Metal	0.0001732	0.0000436	0.0000040
13. Machinery	0.0004391	0.0000302	0.0000053
14. Electrical equipment, electronics and optics	0.0001182	0.0000409	0.0000037
15. Automobiles	0.0001902	0.0000508	0.0000056
16. Other industries	0.0004093	0.0000719	0.0000121
17. Construction	0.0003305	0.0002709	0.0000116
18. Commerce	0.0003042	0.0000833	0.0000108
19. Hotel management	0.0014289	0.0000549	0.0000519
20. Transport and communications	0.0002282	0.0001635	0.0000184
21. Financial intermediation	0.0000910	0.0000274	0.0000031
22. Real estate activities, entrepreneurial services	0.0001906	0.0000482	0.0000053
23. Public services	0.0003138	0.0000509	0.0000080
24. Education	0.0000999	0.0000179	0.0000025
25. Sanitary, veterinary activities, social services	0.0002587	0.0000427	0.0000092
26. Other services, social and personal services	0.0007371	0.0000571	0.0000138
27. Homes that employ domestic staff	0.0000000	0.0000000	0.0000000
Labour	0.0000000	0.0000000	0.0000000
Capital	0.0000000	0.0000000	0.0000000
Households	0.0000000	0.0000000	0.0000000
Total	**0.0165702**	**0.0022028**	**0.0005872**

ISBN:978-84-693-0717-5/DL:T-442-2010

Appendix 3.4

Table 3.12. $B(M_2-I)M_1$

	CH_4 (t)	CO_2 (kt)	N_2O (t)
1. Agriculture	0.0000144	0.0000342	0.0000003
2. Fishing	0.0000080	0.0000190	0.0000002
3. Energy, minerals, coke, petroleum and fuels	0.0000044	0.0000104	0.0000001
4. Electrical energy, gas and water	0.0000148	0.0000351	0.0000003
5. Food	0.0000143	0.0000340	0.0000003
6. Textile	0.0000152	0.0000360	0.0000003
7. Manufacture of wood and cork	0.0000135	0.0000321	0.0000003
8. Paper	0.0000158	0.0000374	0.0000003
9. Chemistry	0.0000122	0.0000289	0.0000002
10. Rubber and plastic products	0.0000145	0.0000345	0.0000003
11. Other non-metallic mineral products	0.0000157	0.0000372	0.0000003
12. Metal	0.0000123	0.0000292	0.0000002
13. Machinery	0.0000117	0.0000277	0.0000002
14. Electrical equipment, electronics and optics	0.0000105	0.0000248	0.0000002
15. Automobiles	0.0000120	0.0000286	0.0000002
16. Other industries	0.0000146	0.0000346	0.0000003
17. Construction	0.0000248	0.0000589	0.0000005
18. Commerce	0.0000271	0.0000642	0.0000005
19. Hotel management	0.0000262	0.0000621	0.0000005
20. Transport and communications	0.0000218	0.0000517	0.0000004
21. Financial intermediation	0.0000256	0.0000608	0.0000005
22. Real estate activities, entrepreneurial services	0.0000248	0.0000589	0.0000005
23. Public services	0.0000259	0.0000614	0.0000005
24. Education	0.0000306	0.0000725	0.0000006
25. Sanitary, veterinary activities, social services	0.0000276	0.0000655	0.0000005
26. Other services, social and personal services	0.0000244	0.0000578	0.0000005
27. Homes that employ domestic staff	0.0000310	0.0000736	0.0000006
Labour	0.0013867	0.0001685	0.0000386
Capital	0.0013867	0.0001685	0.0000386
Households	0.0013490	0.0000790	0.0000379
Total	**0.0046157**	**0.0015869**	**0.0001246**

ISBN:978-84-693-0717-5/DL:T-442-2010

Appendix 3.5

Table 3.13. $B(M_3-I)M_2M_1$

	CH_4 (t)	CO_2 (kt)	N_2O (t)
1. Agriculture	0.0008582	0.0000719	0.0000240
2. Fishing	0.0004767	0.0000399	0.0000133
3. Energy, minerals, coke, petroleum and fuels	0.0002604	0.0000218	0.0000073
4. Electrical energy, gas and water	0.0008820	0.0000739	0.0000247
5. Food	0.0008529	0.0000714	0.0000239
6. Textile	0.0009055	0.0000758	0.0000253
7. Manufacture of wood and cork	0.0008072	0.0000676	0.0000226
8. Paper	0.0009405	0.0000788	0.0000263
9. Chemistry	0.0007252	0.0000607	0.0000203
10. Rubber and plastic products	0.0008659	0.0000725	0.0000242
11. Other non-metallic mineral products	0.0009347	0.0000783	0.0000261
12. Metal	0.0007329	0.0000614	0.0000205
13. Machinery	0.0006949	0.0000582	0.0000194
14. Electrical equipment, electronics and optics	0.0006239	0.0000522	0.0000175
15. Automobiles	0.0007178	0.0000601	0.0000201
16. Other industries	0.0008688	0.0000727	0.0000243
17. Construction	0.0014794	0.0001239	0.0000414
18. Commerce	0.0016128	0.0001350	0.0000451
19. Hotel management	0.0015604	0.0001307	0.0000436
20. Transport and communications	0.0012980	0.0001087	0.0000363
21. Financial intermediation	0.0015271	0.0001279	0.0000427
22. Real estate activities, entrepreneurial services	0.0014792	0.0001239	0.0000414
23. Public services	0.0015416	0.0001291	0.0000431
24. Education	0.0018217	0.0001525	0.0000510
25. Sanitary, veterinary activities, social services	0.0016441	0.0001377	0.0000460
26. Other services, social and personal services	0.0014524	0.0001216	0.0000406
27. Homes that employ domestic staff	0.0018501	0.0001549	0.0000518
Labour	0.0008990	0.0001092	0.0000250
Capital	0.0008990	0.0001092	0.0000250
Households	0.0008990	0.0001092	0.0000250
Total	**0.0321115**	**0.0027907**	**0.0008979**

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UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
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Chapter 4

Input-Output Analysis of Alternative Policies Implemented on the Energy Activities: An Application for Catalonia

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4.1. Introduction

In recent years, the increase in the economic activity of modern societies has led to an increase in the standard of living and welfare. This economic development is linked to growing pressure on the environment, mainly as the result of the exploitation and use of energy and natural resources, but also as the result of an increase in population, motor vehicle transportation, and new techniques for making agriculture more productive or industry more efficient. The environment is the source of all the materials that people use to satisfy their needs, and it is also the final destination of the pollutants generated. Consequently, environmental policies must consider not only the negative effects of economic activities, but also the appropriate use and preservation of natural resources.

One of the major problems of resource analysis is the relative lack of energy products and the fact that some of them are not renewable (for example, petroleum, natural gas, and coal). The use of energy in production and consumption activities is growing, and this often leads to an inadequate consumption of these energy products. This, connected with a lack of energy saving and energy efficiency, produces a continuous increase in the demand for energy resources. In this chapter, we analyse the effects of alternative policies which may help to ensure that energy products are better used.

In recent decades, the input-output price model has become a useful instrument for analysing production relations. For example, Manresa et al. (1988) used an input-output price model to evaluate the new indirect taxes established after Spain had joined the EEC. McKean and Taylor (1991) built an input-output price model for the Pakistan economy to measure how alterations in the prices of imports and sectorial inputs affected internal costs of production. Llop (2008), on the other hand, used a price model to analyze the economic impacts of alternative water policies on the Spanish production system. Cardenete and Sancho (2002) analyzed the weights and the elasticities of the indirect taxes in the Andalusian economy, in order to

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establish how they affected the competitiveness of the regional production structure. De Miguel (2003) used the input-output price model to analyze price changes in Extremadura caused by alterations in the structures of sectorial prices and indirect taxation. Additionally, Llop and Manresa (2004) used an input-output price model to evaluate the influence of factor and import prices on regional prices in Catalonia.

In the literature there is not a single study that uses the input-output price model to analyse the impacts of policy measures on energy activities. There are several, however, that use the quantity-oriented input-output methodology. Particularly interesting among these is the study by Hudson and Jorgenson (1974), who proposed a methodology that joined an input-output model with an econometric model to evaluate the impact of policy measures on the supply and demand for energy. Forsund (1985) used an extension of the input-output model to analyze air pollution. Later in the eighties, Proops (1988) used the extended input-output model to devise indicators on direct and indirect consumption of energy. In the nineties, Proops et al. (1993) compared Germany and the United Kingdom, taking the indicators that Proops himself proposed in 1988, and applying them to air pollution. Hawdon and Pearson (1995) applied an input-output model to the United Kingdom to show how the interrelations among energy, environment and economy can be analyzed.

For Spanish applications, Pajuelo (1980) used an extended input-output quantity model to study air pollution. Other important contributions have been made by Alcántara and Roca (1995) and Antón et al. (1996). The former developed an input-output methodology for measuring the demand for energy and carbon dioxide emissions. The latter used the input-output table for the Spanish economy to evaluate the level of CO_2 emissions in several growth scenarios of the domestic economy. Morillas et al. (1996) made a dynamic study of the influence of demand structure on economic growth and air pollution in Andalusia. More recently, Manresa and Sancho (2004) estimated sectorial energy intensities and CO_2 emissions for the

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Catalan economy. In order to evaluate the energy intensities, they used the SAM (social accounting matrix) multiplier analysis.

The purpose of this chapter is to analyze the economic impact of different policies implemented on the energy activities of the Catalan production system through the use of an input-output price model. We focus on energy sectors because the use and the production of energy goods exert a negative pressure on the environment. The emissions caused by energy activities are very important in most economies and this explains why these activities have received the attention of public authorities when they define environmental measures of pollution control.[102]

We use two versions of the input-output model: a competitive price formulation and a mark-up price formulation. These two versions behave unevenly, since they differ in their hypotheses about how production prices are established. The competitive formulation is a setting in which production prices are equal to the average cost of production. The mark-up formulation is a setting in which production prices lead to a fixed capital rent.

This chapter shows the economic impact of a variety of policies implemented on energy activities of the Catalan production system. This information helps us to understand the relation between the economy and the environment, and can be useful for implementing resource policies that guarantee sustainable development and economic efficiency.

The chapter is structured as follows. In the second section we present the two versions of the input-output price model: the competitive formulation and the mark-up formulation. In section 4.3 we describe the results of the simulations for Catalonia. Finally, the chapter ends with some concluding remarks.

[102] In Catalonia, for example, in the year 2000 energy activities were responsible for 36.6% of the sulphur oxide emissions, 10% of the nitrogen oxide emissions, and 34% of the carbon dioxide emissions (MMA, 2005).

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4.2. The Price Model

The analytical framework used to evaluate the economic impact of the policies implemented on energy activities is based on the Leontief price model. This approach assumes that each industry produces a single good by means of the combination of intermediate inputs and primary factors of production (labor and capital) in fixed proportions, under the assumption of constant returns to scale. This technology, in which the outputs produced and the factors are used as inputs, assumes that sectorial benefits are equal to zero. On the other hand, it should be pointed out that the model ignores the consumer's utility function so the final demand does not take part in the price definition.

The study deals with 27 production sectors, which include two energy activities: energy products, minerals, coke, petroleum and fuels (sector 3), and electrical energy, gas and water (sector 4).

We use two versions of the input-output model: a competitive price formulation and a mark-up price formulation. The first version assumes that the sectorial prices are equal to the average cost of production. Therefore, if we bear in mind that j = 1, 2,…., 27, the price structure for the branch of activity j can be expressed as:

$$p_j = (1+\tau_j)\left[\sum_{i=1}^{27} p_i a_{ij} + (1+s_j)wl_j + rk_j + (1+t_j^m)p_j^m m_j\right]. \qquad (4.1)$$

In this equation, p_j represents the price of production in sector j; w, r and p_j^m are, respectively, the price of labour (wage), the price of capital and the price of imports. Additionally, a_{ij} stands for the input-output coefficients; l_j, k_j and m_j are coefficients that represent, respectively, the labour, capital and imported goods per euro of output in j. Finally, s_j is the tax rate of the Social Security paid by sector j, t_j^m represents the ad-valorem rate of the imports in j, and τ_j is the ad-valorem tax on the production in net terms.

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The simulations include a tax on the energy used by the sectors. Once we have added this tax, we can use the following expression to evaluate the effects on prices:

$$p_j = (1+\tau_j)\left[\sum_{i \neq E}^{27} p_i a_{ij} + (1+t_E)\, p_E\, a_{Ej} + (1+s_j)\, wl_j + rk_j + (1+t_j^m)\, p_j^m m_j\right], \quad (4.2)$$

where E = 3, 4 represent the energy sectors, and t_E is a tax on intermediate energy uses.

The second version of the input-output model is a mark-up price formulation, which defines the prices of production as:

$$p_j = (1+T_j)(1+\tau_j)\left[\sum_{i=1}^{27} p_i a_{ij} + (1+s_j)\, wl_j + (1+t_j^m)\, p_j^m m_j\right], \quad (4.3)$$

where T_j is the benefit tax or mark-up in sector j. When we add a tax on the energy sectors, expression (4.3) is modified as follows:

$$p_j = (1+T_j)(1+\tau_j)\left[\sum_{i \neq E}^{27} p_i a_{ij} + (1+t_E)\, p_E\, a_{Ej} + (1+s_j)\, wl_j + (1+t_j^m)\, p_j^m m_j\right]. \quad (4.4)$$

The two versions of the input-output model differ in the way they treat the sectorial benefits. For the competitive price approach, we assume that r is constant and this involves a fixed benefit in all the productive activities (rk_j). This approach is a scenario in which the capital price and benefits are constant. The second version of the model assumes that the production sectors have a constant rate of profit (T_j), which in turn means that there must be a fixed rate of capital returns in all branches of production. This situation is a scenario in which production prices maintain a fixed percentage of sectorial benefits.

The results of the empirical analysis will reflect the variations of prices in levels and percentages, since the calibration procedure assumes that all the reference prices are equal to unity. Thus, the results will be a measure of the price indices (p_1, p_2, ..., p_{27}), which have been considered endogenous in the model definition.

Apart from analyzing the effects on production prices, we can also evaluate how the different policies implemented on the energy activities affect the consumption prices. Namely, the consumption prices (p_c) are defined endogenously using a normalized basket of goods, which define the weights of the final prices:

$$p_c = \sum_{j=1}^{27} p_j \alpha_j \ , \qquad (4.5)$$

where p_j are the prices of production, and α_j represents the share of final consumption for each good j with respect to all the goods consumed $\left(C = \sum_{j=1}^{27} C_j \right)$: $\alpha_j = \frac{C_j}{C}$.

We can also evaluate the effects on intermediate energy uses. If we assume that in each j = 1, 2, ..., 27, the intermediate costs of energy are kept constant, it follows that:

$$p_E x_{Ej} = p_E^S \, x_{Ej}^S \ ,$$

where p_E (E = 3, 4) are the prices of the energy in the benchmark equilibrium and p_E^S are the prices in the simulations. Similarly, x_{Ej} is the intermediate demand for energy in the benchmark equilibrium, and x_{Ej}^S is the demand in the simulations. Since in the value-based Leontief price model all the benchmark prices are equal to one (that is to say, p_E = 1), the new uses of energy in sector j are calculated as:

$$X_{Ej}^S = \frac{x_{Ej}}{p_E^S} .$$

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Finally, the amount of energy used in the production system (X_{Ej}^{S}) in the new settings is equal to:

$$X_{Ej}^{S} = \sum_{j=1}^{27} x_{Ej}^{S} = \sum_{j=1}^{27} \frac{x_{Ej}}{p_E^S}. \tag{4.6}$$

In expression (4.6), x_{Ej} are the intermediate energy uses available from the input-output table.

We can also obtain an approximation of the influence that each setting exerts on the consumers' real income. In particular, the changes in private real income (ΔI) are calculated using the following expression:

$$\Delta I = I - I^S = \sum_{j=1}^{27} p_j C_j - \sum_{j=1}^{27} p_j^s C_j = \sum_{j=1}^{27} \left(p_j - p_j^s\right) C_j, \tag{4.7}$$

where p_j^S is the consumption price of good *j* after the simulations, p_j is the consumption price of *j* in the benchmark, and C_j is the consumption of *j*. 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.[103]

When a tax on intermediate energy uses is introduced, the public revenues (*R*) are calculated as:

$$R = \sum_{j=1}^{27} t_E \, p_E^S \, x_{Ej}^S. \tag{4.8}$$

The method of analysis described above allows us to evaluate the effects on production prices, consumption prices, intermediate energy uses, and private real income under the different policies that affect the energy sectors. All this information is a considerable help in defining and

[103] 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.

implementing measures for improving the industrial efficiency of energy consumption.

4.3. Empirical Results

In the empirical application, we used data extracted from the latest input-output table available for Catalonia, for the year 2001 (IDESCAT, 2007). The input-output table makes it possible to construct a matrix representation for the uses and resources of the productive sectors of the Catalan production system.

The input-output table used shows a sectorial disaggregation of 27 production sectors: two agricultural sectors, two energy sectors (the first one includes the energy products, minerals, coke, petroleum and fuels, and the second one includes electrical energy, gas and water), 12 industrial sectors, a branch of the building industry and, finally, 10 branches of the service sectors.

The results provided by the Leontief model are the final effects of an exogenous modification in the cost items, once all the reactions and interactions in the production process have been completed. In particular, an increase in the expenditures of the production sectors are associated to an increase in production prices, which makes it possible to retrieve these additional expenditures, and to keep a sectorial benefit equal to zero in the modified setting.

The simulations carried out not only introduce a 10% tax on intermediate energy uses but also greater efficiency of energy uses, consisting of a reduction in intermediate energy uses by 10%.[104] We have

[104] According to Manresa and Sancho (2004), we should consider which mechanisms, or public policies, would induce economic agents to introduce new technologies entailing huge energy savings and the subsequent reduction in the emissions of pollutants. The result of such consideration by economists (see Bovenberg & Cnossen (1995)), the public authorities of many countries, and environmental conferences such as the ones held in Toronto (1988) Cairo (1990), Rio (1992), and Berlin (1995), has been the introduction of environmental taxes as an instrument of control and a fundamental source of funds to regulate the various sources of energy sources and their emissions.

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Laia Pié dols
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also calculated joint effects: that is to say, a 10% tax on energy uses together with a 10% decrease in energy uses.

Table 4.1 shows the changes in production prices after the various simulations. The first two columns show how production prices adapt when we introduce a 10% tax on intermediate energy uses. This tax causes a general increase in production prices. In particular, the price of sector 3 (energy products, minerals, coke, petroleum and fuels) rises by 3.834% in the competitive formulation and by 3.859% in the mark-up formulation. If we look at sector 4 (electrical energy, gas and water), we observe higher price effects (4.726% in the competitive formulation and 5.727% in the mark-up formulation). On the other hand, a closer look at the first two columns reveals that production prices rise in all other sectors, but the chemical industry (sector 9), other non-metallic mineral products (sector 11) and transport and network communications (sector 20) are particularly sensitive to taxation on energy uses. It is remarkable that the two versions of the model differ in the impacts on production prices, and that mark-up prices are higher than competitive ones.

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Table 4.1. Changes in production prices (%)

Sectors	Situation 1		Situation 2		Situation 3	
	Competitive	Mark-up	Competitive	Mark-up	Competitive	Mark-up
1. Agriculture	0.257%	0.393%	-0.237%	-0.360%	-0.025%	-0.038%
2. Fishing	0.329%	0.375%	-0.305%	-0.347%	-0.032%	-0.036%
3. Energy, minerals, coke, petroleum and fuels	3.834%	3.859%	-3.560%	-3.581%	-0.368%	-0.370%
4. Electrical energy, gas and water	4.726%	5.727%	-4.372%	-5.280%	-0.452%	-0.548%
5. Food	0.301%	0.426%	-0.277%	-0.390%	-0.029%	-0.041%
6. Textile	0.390%	0.517%	-0.359%	-0.471%	-0.037%	-0.050%
7. Manufacture of wood and cork	0.275%	0.358%	-0.254%	-0.328%	-0.026%	-0.034%
8. Paper	0.368%	0.500%	-0.339%	-0.456%	-0.035%	-0.048%
9. Chemistry	0.831%	1.000%	-0.769%	-0.921%	-0.080%	-0.096%
10. Rubber and plastic products	0.451%	0.599%	-0.416%	-0.547%	-0.043%	-0.058%
11. Other non-metallic mineral products	1.770%	2.207%	-1.638%	-2.035%	-0.170%	-0.212%
12. Metal	0.254%	0.336%	-0.234%	-0.307%	-0.024%	-0.032%
13. Machinery	0.138%	0.197%	-0.127%	-0.180%	-0.013%	-0.019%
14. Electrical equipment, electronics and optics	0.174%	0.238%	-0.160%	-0.218%	-0.017%	-0.023%
15. Manufacture of transport material	0.193%	0.271%	-0.177%	-0.247%	-0.018%	-0.026%
16. Other industries	0.329%	0.440%	-0.304%	-0.402%	-0.031%	-0.042%
17. Construction	0.537%	0.847%	-0.496%	-0.778%	-0.051%	-0.143%
18. Commerce	0.437%	0.776%	-0.402%	-0.708%	-0.042%	-0.076%
19. Hotel management	0.468%	0.781%	-0.430%	-0.710%	-0.045%	-0.075%
20. Transport and communications	0.923%	1.399%	-0.853%	-1.287%	-0.088%	-0.135%
21. Financial intermediation	0.172%	0.324%	-0.159%	-0.295%	-0.016%	-0.032%
22. Real estate activities and entrepreneurial services	0.206%	0.434%	-0.190%	-0.397%	-0.020%	-0.045%
23. Public services	0.513%	0.669%	-0.471%	-0.609%	-0.049%	-0.065%
24. Education	0.238%	0.323%	-0.219%	-0.294%	-0.023%	-0.032%
25. Sanitary and veterinary activities; social services	0.282%	0.423%	-0.260%	-0.385%	-0.027%	-0.041%
26. Other services and social activities; personal	0.463%	0.733%	-0.426%	-0.667%	-0.044%	-0.072%
27. Homes that employ domestic staff	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%

Situation 1: 10% tax on energy uses.
Situation 2: 10% reduction in energy uses.
Situation 3: 10% tax on energy uses and 10% reduction in energy use.

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In situation 2 we reduce the sectorial uses of energy by 10%, and this can be interpreted as an improvement in the energy efficiency of the production sphere. In this simulation, there is a general decrease in production prices. Specifically, in sector 3 there is a price decrease of 3.560% and 3.581% in the competitive and the mark-up formulation, respectively. In sector 4, prices drop by 4.372% in the competitive formulation and by 5.280% in the mark-up formulation. Again, the results show a wide range of sectorial variation, and prices in the chemical industry (sector 9), other non-metallic mineral products (sector 11), and transport and network communications (sector 20) are most affected by the reduction in the uses of energy. Finally, as in the previous situations, mark-up prices react with more intensity than competitive prices.

Situation 3 shows the effects of a 10% reduction in energy uses combined with a 10% tax on energy uses. One interesting result is that, with the exception of energy production (sector 3 and sector 4), changes in production prices are very close to zero.[105] This suggests that it may be possible to put into practice an energy policy that intervenes in energy prices and quantities simultaneously, and barely modifies production prices.

The conclusion of table 4.1 is that the energy policies analyzed have very different consequences on production prices. Taxation measures tend to increase prices, and efficiency measures tend to decrease them. The combination of a tax on energy uses and a reduction in intermediate demand (situation 3) suggests that it is possible to generate practically no effects on production prices.

We can complete the analysis by calculating some additional aggregated indicators, which will give us a better understanding of the economic impact of the various scenarios. Table 4.2 shows the changes in the consumer price index, the intermediate demand for energy, the public

[105] The price in sector 3 decreases by 0.368% in the competitive formulation and by 0.370% in the mark-up formulation, while the price in sector 4 decreases by 0.452% in the competitive formulation and by 0.548% in the mark-up formulation.

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revenues of the taxation on intermediate energy uses and, finally, private real income.

Table 4.2. Changes in aggregated variables

Sectors	Situation 1		Situation 2		Situation 3	
	Competitive	Mark-up	Competitive	Mark-up	Competitive	Mark-up
Consumption prices: p_c **(%)**	0.510%	0.746%	-0.470%	-0.683%	-0.049%	-0.071%
Energy uses: X^S_E **(%)**	-12.820%	-13.242%	-6.281%	-5.820%	-17.845%	-17.805%
Public revenue: ***R*** **(thousands of euro)**	1,068,355	1,072,083	-----	-----	1,041,972	1,041,619
Changes in real income: ΔI **(thousands of euro)**	-460,479	-673,536	424,721	616,470	44,014	64,105

Situation 1: 10% tax on energy uses.
Situation 2: 10% reduction in energy uses.
Situation 3: 10% tax on energy uses and 10% reduction in energy uses.

The taxation on intermediate energy uses increases the consumer price index, which is higher in the mark-up formulation than in the competitive formulation (0.746% and 0.510%, respectively). In contrast, the demand-side policy of reducing energy uses by 10% decreases the consumer price index by 0.470% in the competitive model, and by 0.683% in the mark-up model. On the other hand, if we combine the demand-side policy with the tax on the energy uses, the effects on consumption prices are practically insignificant (-0.049% in the competitive formulation and -0.071% in the mark-up formulation). This suggests that it is possible to implement energy policies that have barely any effect on the final prices of the economy.

Table 4.2 also shows the changes in the amount of energy used within the production sphere. If we apply a 10% tax on the energy, there is a 12.820% reduction in the sectorial demand for energy in the competitive version of the model, and a 13.242% reduction in the mark-up version. In situation 2, we again observe a reduction in energy uses (-6.281% for the competitive definition and -5.820% for the mark-up definition). If we

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combine the demand-side policy with the tax on energy uses, there is a greater decrease in energy uses and, in addition, the effect is almost equal in the two versions (-17.845% in the competitive and -17.805% in the mark-up).

The public revenues raised by the tax implemented on energy uses appear also in table 4.2. In the first situation, when a 10% tax on intermediate energy uses is introduced, the revenues total 1,068,355 thousand euros in the competitive version and 1,072,083 thousand euros in the mark-up version. When a demand-side policy is combined with a tax (situation 3) the revenues raised by the two versions of the model are very similar (1,041,972 thousand euros in the competitive model and 1,041,619 thousand euros in the mark-up model). Note that, public revenues are independent of the simulation and the version of the model analysed, since the values in table 4.2 are very similar.

The effects on private real income are measured in thousands of euros. Depending on the version of the model and the political setting, the results are very different. If we apply a tax on intermediate energy uses, private real income suffers a negative effect of 460,479 thousand euros in the competitive model, and 673,536 thousand euros in the mark-up model. Note that the effect on consumers is especially significant in the mark-up formulation, as it reduces private real income by 46% more than in the competitive model. On the other hand, a reduction in energy uses has a positive effect on private real income of 424,721 and 616,470 thousand euros depending on the version of the model. The combination of a reduction in energy uses with a tax (situation 3) improves private real income (44,014 thousand in the competitive definition and 64,105 thousand in the mark-up definition). Therefore, the impacts on consumer real income are very sensitive to the way in which the production system defines production prices.

Taxation on intermediate energy uses (situation 1) increases production prices and the consumer price index. These effects lead to a decrease in the intermediate demand for energy and, as energy

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consumption is one of the main sources of atmospheric pollution, this measure would ensure the environmental objectives. However, from the consumer's point of view, the consumer price index rises and this has a negative effect on real income.

When energy uses are reduced, both production prices and the consumer price index fall. There is a reduction in intermediate energy uses, and a positive effect on private real income. Therefore, this is a good policy for consumers, since prices go down, but not so good for the environment, as the reduction in the intermediate demand for energy is quite small.

When a tax on intermediate energy uses is combined with a reduction in the intermediate demand for energy (situation 3), both production prices and the consumer price index are very close to zero. There is a sharp decrease in the intermediate demand for energy, and there is a positive effect on consumers' real income. That is, this is a good policy for the environment, since it considerably reduces energy consumption, and is positive for private agents. In conclusion, the combination of a tax on energy uses and an improvement in the energy efficiency of the production system seems to be a measure that accomplishes both economic and environmental goals. Specifically, this situation suggests that it is possible to avoid inflation, collect public funds, preserve private real income, and reduce energy consumption within the production sphere.

4.4. Conclusions

In this chapter we have defined a price model, based on the traditional input-output model, and applied it to the Catalan production system for the year 2001. Our purpose was to analyze the economic impact of various policies implemented on the energetic activities. Energy is a basic resource for social and economic welfare, since it gives people mobility and comfort and it is essential for the production of most industrial activities. Moreover, the use and production of energy exerts considerable pressure on the environment, by influencing climate change, damaging natural ecosystems, impoverishing the environmental profile and harming human health.

We have used two versions of the input-output model: a competitive version and a mark-up version. The two formulations of the input-output model have been used to simulate three energy policy scenarios. The first one involves a 10% tax on intermediate energy uses. The second one reduces intermediate energy uses by 10%. Later, we analyze the effect of applying situation one and three together: that is, a reduction in energy uses by 10% and a 10% tax on intermediate energy uses.

The results show that a tax on intermediate energy uses increases the consumer price index, and this decreases the intermediate demand for energy and has a negative effect on private real income. On the other hand, when energy uses are reduced, both the consumer price index and intermediate energy uses decrease, and there is a positive effect on real income. When a tax is combined with a reduction in the intermediate demand for energy, production prices and the consumer price index are very close to zero. There is a sharp decrease in the intermediate demand for energy and a positive effect on consumers real income.

The comparison of the two versions of the model shows that prices and private real income are very sensitive to the price definition in the production sphere, whereas the demand for energy is quite similar in the two versions of the model. This could mean that the impacts on the uses of energy resources do not depend on how the production system sets production prices.

Policy makers have a set of measures that can help to reduce energy consumption. In order to understand the effects involved, we need to capture the complex relationships that exist within the economy, and we also need to take into account the different channels through which the impacts are transmitted. Our results suggest that the policies analysed have different effects on production prices, consumer price indices, tax collection, intermediate demand for energy, and private real income.

The analytical approach used in this chapter gives interesting results that can help to design and implement policies that help to reduce the intermediate consumption of energy, and so decrease the amount of atmospheric pollution that may be caused by an inappropriate use of energy. In this sense, the input-output price model is a useful method that shows the effects that new political actions have on production activities because it captures the complex relations within the production system.

We would like to stress that the conclusions we draw from the model should be interpreted cautiously, because of the restrictions of the Leontief analysis. These limitations come from the lack of substitution between factors and the null role of final demand in the economy price setting. Despite these deficiencies, the model also has unquestionable advantages. The faithful link with economic activity shows the effects of interdependence between production sectors. The Leontief model also makes it possible to perform a disaggregated analysis of production activities, and this leads to greater knowledge of the reality of the production sphere.

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UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

Chapter 5

Multisectorial Effects of Environmental Policies: Price and Quantity Approaches for Catalonia

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5.1. Introduction

One of the main social and scientific concerns in the last few years has been climate change. It is a problem that affects the whole world and, in fact, the solution requires an international response. We have to remember that not only it is an environmental phenomenon; it can also have important economic and social consequences.[106]

In 2007 this issue became one of the main social and scientific priorities, especially when governments began to intervene more directly. At the end of 2008, the European Union (EU) signed a climate change agreement and pledged to reduce the Union's greenhouse gas emissions by 20% before 2020.[107] There are several sources of greenhouse gas emissions: burning fossil fuels to generate electricity, transport, industrial processes, agriculture, tourism, housing, etc. These gases are, therefore, closely linked to our model of society and our energy consumption.[108] 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%.[109]

The measures established to reduce emissions were that sectors causing the most pollution, covered by the European Union Emission Trading Scheme (ETS), will have to reduce their emissions by 21% in relation to 2005; the remaining sectors, such as transport and housing, by 10%. In order to prevent the sectors that pollute to an extreme, and

[106] As the Stern Review (2006) concluded, "a shared vision of the objectives must exist, and consensus must be reached on action frameworks". It must be based on a shared vision of long-term goals and agreement on frameworks that will accelerate action.
[107] 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%.
[108] Taking into account greenhouse gas emissions in the whole world in 2000, two thirds are generated by energy use—24% in the generation of electricity, 14% in industry, 14% in transport, 8% in buildings, and 5% in other energy-related activities—while a third corresponds to other emission sources—18% to land use, 14% to agriculture, and 3% to waste products (Stern's calculation, 2006, based on data from the World Resources Institute).
[109] 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.

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

therefore worst hit by the emissions trading rights auction, from taking their factories out of the EU and causing massive job losses, provisions have been made to grant 100% of emission rights free to those exceeding a specific threshold.

For countries outside the ETS system, a reduction objective has been assigned on the basis of GDP.[110] In addition, from 2013 onwards, industries will begin to pay to acquire most of their emission trading rights, instead of receiving them free from the State, as has occurred up to now.[111] Thus, many trading permits will be auctioned, but 88% of the revenue from auctioning trading permits will end up in national treasuries to finance the development of renewable energies and 10% will be used to create a solidarity mechanism: part of this money will be set aside for countries lacking development in renewable energies. And the remaining 2% will be assigned to nine East European countries as a supplementary financial aid to back energy enterprises.

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—such as transport, housing, agriculture and livestock farming, or waste treatments—in relation 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.[112]

In this context, it is true that many enterprises will have to cover the costs, but they will also obtain benefits and will be more competitive if they

[110] In this way, the richest countries will have to reduce their greenhouse gas emissions by up to 20%. And the poorest will be able to increase them by up to 20%.
[111] The EU Emission Trading Scheme is a system that enables enterprises to exchange CO_2 emission allowances (also known as "polluting permits"), which will be payments to encourage enterprises to adapt to EU environmental regulations as of 2013. The first sector to pay these allowances in full will be the electricity sector, followed progressively by the aviation, the aluminium and ammonia manufacturing and the petrochemical sectors, among others.
[112] According to the Kyoto Protocol, before 2012 the EU must reduce its greenhouse gas emissions by 8% in relation to 1990. By ratifying the Kyoto Protocol, Spain pledged not to increase greenhouse gas emissions in the period 2008–2012 by more than 15% in relation to the 1990 levels, but it is one of the countries that has increased carbon production most—as much as 45%.

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

can save energy or develop low carbon production. Therefore, climate change also represents an opportunity to improve, not so much standards of living, but quality of life.[113] Nevertheless, the introduction of measures by EU member states, such as ecological taxes on the use of polluting products, has not been ruled out.

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, promoting technology policies, support for innovation and the deployment of low carbon technologies have been considered. And finally, 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.[114]

Thus, a good way to control emissions would be to impose taxes, as the Stern Review has suggested. This leads us to think a priori that, thanks to the imposition of an environmental tax, both economic and environmental benefits could be obtained. However, an economy has different taxes, and this must be taken into account, for example, if taxes on work are reduced in return for the imposition of an environmental tax. By increasing indirect taxation, production costs and, by extension, prices

[113] According to José Manuel Barroso (2008): "If we just continue as before, by 2030 world energy demand will be 50 per cent higher than today and global carbon dioxide emissions will have risen by nearly 60 per cent. Our citizens are already witnessing dramatic price increases of energy today. If we have the courage to change, we can slash our oil and gas import bill by 50 billion euros by 2020. We can cut our external dependency on oil and gas and increase our energy security. A Europe that depends less on carbon, with a stronger renewable energy component, is of course also more secure from any possible problem of energy supply. [...] The new climate-friendly economy is a major economic opportunity for Europe. Globally, the overall value of the low carbon energy sector could be as high as 3 trillion dollars per year worldwide by 2050, and it could employ more than 25 million people. Alone the global carbon market, which our EU Emissions Trading Scheme has pioneered, is already worth 20 billion euros a year today and it could be worth twenty times that by 2030. So building a low carbon economy offers the chance to create thousands of new businesses, hundreds of thousands of new jobs and a vast new export market on which Europe can be a world leader".

[114] As the Stern Review (2006) has stated: "… if we wish to reduce the seriousness of the negative effects, adaptation measures are especially urgent in poor countries, the most vulnerable to climate change. If the measures to be taken are regarded as a reasonable cost to "insure ourselves" against the worst effects of climate change, we may possibly still be in time to prevent the worst risks".

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

increase. However, when social security contributions drop, labour production costs are reduced, which may stimulate the creation of jobs and reduce prices (Manresa and Sancho, 2007). We have to be careful, therefore, when this tax substitution is put into practice, and the challenge lies in finding the best way of doing so. It is important to implement environmental or green taxation policies that allow us to reduce polluting emissions, improve private welfare and create employment at the same time.[115]

If we analyse 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".[116] The double dividend hypothesis consists, therefore, of exploring under which conditions this trade-off might not exist, in which case 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. This is because they lead, in many cases, to quantitative analytical frameworks that estimate the effects of a certain tax policy on variations in CO_2 emissions, as well as other pollution factors, the economic cost associated with this policy, and the economic and social benefits stemming from such

[115] This is what many authors call double dividend: a reduction of polluting emissions (first dividend), private welfare improvement (second dividend) and/or creation of jobs (second dividend on employment), through neutral environmental tax policies (Manresa and Sancho, 2007).
[116] See, for example, Manresa and Sancho (2007) or Rodríguez (2002).

ISBN:978-84-693-0717-5/DL:T-442-2010

public interventions. One of the first studies by Bovenberg and De Mooij (1994) 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, we can mention the papers by Labandeira and Rodríguez (2004), who studied the impact of an environmental tax on carbon dioxide emissions, or Faehn et al. (2009) who analyzed aspects of fiscality and environment using a general equilibrium model with imperfect competition. On the other hand, Manresa and Sancho (2007) analysed the impact of recycling ecotaxes towards lower labor taxes in Spain. At the regional level, André, Cardenete and Velázquez (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 chapter, we use two linear multisectorial models based on a social accounting matrix (SAM) to analyse the economic impact on Catalonia of the implementation of policies that would reduce CO_2 emissions. The first model used is a price version of the SAM modelisation that shows the cost impacts and the price mechanisms of the different simulations analysed. The second model used is a quantity version of the SAM modelisation that allows to quantify how much reduction in regional income it is needed to get a significant reduction in pollutant emissions.

In recent years, SAMs have become extremely useful tools for the economic analysis. They first appeared in the ground-breaking studies by Stone (1978) and Pyatt and Round (1979), and since then, other studies have shown the usefulness of these databases.[117] A SAM provides a great deal of empirical information, making it useful to define different economic models. It shows all the transactions occurring among the stakeholders of a specific economic system and, in addition, it shows the existing relationship between income distribution, consumer patterns and the production structure.

[117] Chapter 2 reviews the literature that uses SAM models.

ISBN:978-84-693-0717-5/DL:T-442-2010

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.[118] 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 (2007), where it was 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. On the other hand, she also presented an additive decomposition of the global price multipliers in order to isolate the effects of the capital account on the overall price multipliers.

If we focus on the literature of atmospheric pollution and environmental regulations, we notice that none of them uses the SAM price framework to analyse possible implications of policy measures of pollution control. Morever, there are few papers that the use input-output price model applied to environmental issues. The first paper is realized by Llop (2008) in which it was used a price model to analyze the economic impacts of alternative water policies on the Spanish production system. On the other hand, Llop and Pié (2008) proposed an input-output price model to analyse the economic effects on the Catalan economy caused by alternative policies implemented on the energy activities of the regional production system.

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

ISBN:978-84-693-0717-5/DL:T-442-2010

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.

In this chapter, we use the model proposed by Roland-Holst and Sancho (1995) to assess the economic impact of the implementation of different policies to reduce CO_2 emissions in Catalonia. The information obtained from this analysis will allow to see the existing relationship between the economy and the generation of emissions. This study, therefore, can help to define and put into practice an environmental policy to guarantee a reduction in the Catalan CO_2 emissions.

The second model used is an extension of the exogenous determination of production in the input-output quantity model (Miller and Blair, 1985) to a SAM database. This approach allows to complete the results because it shows the reduction in the level of total endogenous income of the SAM model needed to reduce emissions in an exogenously determined quantity. With this analysis we can quantify the degree of adjustments in the economic agents if the emissions levels are reduced to the level established by the UE policy. This information complements the one of the price adaptations provided by previous model, as captures the quantities responses needed to an exogenously determined level of emissions.

The two models used illustrate different economic impacts on regional variables of alternative 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 recently by the European Union. In general terms, this plan aims to reduce emissions of greenhouse-effect gases in the EU by 20% between 2009 and 2020, and stipulates that, by this date, 20% of energy should be derived from renewable resources, and energy efficiency should have improved by 20%. Taking into account this interesting direction of the

European environmental policy, the present chapter is an intend of simulate some aspects that can be in line with the European directives.

The rest of the chapter is organised as follows. The next section describes the SAM price model. Section 5.3 presents the SAM quantity model in which some variables are exogenously fixed. Section 5.4 describes the empirical results of the diferents simulations for Catalonia. The chapter ends with a conclusion section.

5.2. The SAM Price Model

5.2.1. 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.[119] 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.

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

ISBN:978-84-693-0717-5/DL:T-442-2010

Table 5.1. Simple structure of a SAM

	I. Production	II. Factors	III. Households	IV. Rest	Total
I. Production	T_{11}	0	T_{13}	T_{14}	Y_1
II. Factors	T_{21}	0	0	T_{24}	Y_2
III. Households	0	T_{32}	T_{33}	T_{34}	Y_3
IV. 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 5.1 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 this table, 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 5.1 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

ISBN:978-84-693-0717-5/DL:T-442-2010

(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:

$$\begin{aligned} p_1 &= p_1 A_{11} + p_2 A_{21} + \overline{p}_4 A_{41}; \\ p_2 &= p_3 A_{32} + \overline{p}_4 A_{42}; \\ p_3 &= p_1 A_{13} + p_3 A_{33} + \overline{p}_4 A_{43}. \end{aligned} \tag{5.1}$$

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

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

And 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 formula:

$$v = \overline{p}_{(4)} A_{(4)}, \tag{5.2}$$

where $A_{(4)}$ is the submatrix of the SAM composed by A_{41}, A_{42}, and A_{43}, with the formula:

$$A_{(4)} = \begin{bmatrix} A_{41} & A_{42} & A_{43} \end{bmatrix}.$$

If we transform expression (5.1) to matrix notation:

$$p = pA + v = v(I - A)^{-1} = v\,M. \tag{5.3}$$

where v is a row vector of exogenous costs and $M = (I - A)^{-1}$ is the matrix of SAM 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 models:[120]

[120] This type of model is developed in chapter 3.

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

$$Y = AY + x = (I - A)^{-1} x = Mx. \qquad (5.4)$$

However, according to the model we chose, matrix *M* can be interpreted in one or another way. In the SAM price model it can be interpreted through the columns; in the quantity model it can be interpreted through the rows. In this chapter, we will only focus on the SAM price model, since we carry out a detailed study using the quantity model in chapter 2.

5.2.2. Emissions and Environmental Policies

The pollutant emissions are calculated in the same way than in chapter 3, that is, assuming that there is an invariable relationship between the emissions to the atmosphere and the value of endogenous income.

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 endogenous account *j*. That is:

$$B = E(\hat{Y})^{-1}, \qquad (5.5)$$

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),[121] and $\hat{Y}$ is the diagonal matrix of the elements of vector *Y* of endogenous income. Following equation (5.5), we can obtain the pollutant emissions as:

$$E = B\hat{Y}, \qquad (5.6)$$

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

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

ISBN:978-84-693-0717-5/DL:T-442-2010

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:

$$p\hat{Y} = p^S \hat{Y}^S, \tag{5.7}$$

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:

$$Y^S = (p^S)^{-1}\hat{Y}. \tag{5.8}$$

The new emissions associated to the simulations (E^s) are calculated trough the combination of expressions (5.6) and (5.8):

$$E^S = B\hat{Y}^S. \tag{5.9}$$

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 (1xj) that shows the relative index of emissions in each endogenous account as follows:

$$g = \frac{e'E}{e'E\bar{e}}, \tag{5.10}$$

ISBN:978-84-693-0717-5/DL:T-442-2010

where e' is a unitary row vector with dimension ($1 \times k$), E is the matrix of sectorial emissions of pollutants and $\overline{e}$ is a unitary column vector of dimension ($j \times 1$).[122]

The simulations are applied individually according to the sectorial relative contribution to emissions by sectors and consum.[123] That is, the level of taxation is defined in a row vector t ($1 \times j$), calculated as follows:

$$t = \tau g, \tag{5.11}$$

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.

5.2.3. Private Real Income and Public Revenues

We can also obtain an approximation of the influence that each setting exerts on the consumers' real income. In particular, the changes in private real income (ΔI) are calculated using the following expression:

$$\begin{aligned} \Delta I &= \sum_{j=1}^{27} p_j C_j - \sum_{j=1}^{27} p^S{}_j C_j = \\ &= \sum_{j=1}^{27} \left(p_j - p^S{}_j\right) C_j, \end{aligned} \tag{5.12}$$

[122] 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.
[123] The SAMEA for the Catalan economy shows emissions for both sectors of production and private agents.

ISBN:978-84-693-0717-5/DL:T-442-2010

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.[124]

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

$$R = \sum_{j=1}^{27} \tau\, g\, P_j Y_j = \\ = \sum_{j=1}^{27} t\, P_j Y_j. \qquad (5.13)$$

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

$$R = \sum_{j=1}^{27} \tau\, g\, P_j C_j = \\ = \sum_{j=1}^{27} t\, P_j C_j. \qquad (5.14)$$

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

$$R = \sum_{i=1}^{27} \tau\, g\, P_i T_{ij} = \\ = \sum_{i=1}^{27} t\, P_i T_{ij}. \qquad (5.15)$$

[124] 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.

ISBN:978-84-693-0717-5/DL:T-442-2010

5.3. The SAM Quantity Model: Exogenous Determination of Total Income

This section applies the exogenous determination of variables typically focused on the input-output model (Miller and Blair (1985)) to the SAM framework. The basic interpretation of the elements of the multipliers matrix, α_{ij}, is that they translate a change in exogenous demand for a particular account *j, (X_j)*, into a change in endogenous income of sector *(Y_i)*:[125]

$$\alpha_{ij} = \frac{\Delta Y_i}{\Delta X_j} \quad or \quad \Delta Y_i = \alpha_{ij} \Delta X_j.$$

It would be slightly cumbersome but completely accurate to call α_{ij} an exogenous demand to endogenous income multiplier. We consider α_{jj} the on-diagonal element in the *jth* column of the multipliers matrix. If we use the same interpretation, we can define:

$$\alpha_{jj} = \frac{\Delta Y_j}{\Delta X_j} \quad or \quad \Delta Y_j = \alpha_{jj} \Delta X_j.$$

Suppose that we define α_{ij}^* as the ratio of α_{ij} to α_{jj}, that is:

$$\alpha_{ij}^* = \frac{\alpha_{ij}}{\alpha_{jj}} = \frac{\left[\frac{\Delta Y_i}{\Delta X_j}\right]}{\left[\frac{\Delta Y_j}{\Delta X_j}\right]} = \frac{\Delta Y_i}{\Delta Y_j} \quad or \quad \Delta Y_i = \alpha_{ij}^* \Delta Y_j.$$

Thus, α_{ij}^* could be termed an income-to-income multiplier. We consider the matrix of these mulipliers, $\left(I - A^*\right)^{-1} = \left[\alpha_{ij}^*\right]$ found by dividing each element

[125] This approach is apparently first discussed in Evans and Hoffenberg (1952) and again in Ritz and Spaulding (1975).

ISBN:978-84-693-0717-5/DL:T-442-2010

in a column of $(I - A)^{-1}$ by the on-diagonal element of that column. Then each of the elements in column *j* of $(I - A^*)^{-1}$ indicates by how much the income of that sector (the row label) would change if the income of sector *j* changed by one euro. Suppose that sector *j* increase its output to some amunt, $\overline{Y_j}$. Then, postmultiplication of $(I - A^*)^{-1}$ by a vector $\overline{Y}$, with $\overline{Y_j}$ as its *jth* element and zeros elsewhere, will generate a vector of total income necessary from each sector in the economy because of the exogenously determined income of sector *j*. That is:

$$Y = (I - A^*)^{-1}\overline{Y}. \tag{5.16}$$

This expression allows to calculate how much income is needed to satisfy some level of fixed income that can be established a priori. In our case, we determine a level of income $\overline{Y}$ that satisfies a 20% reduction in the level of emissions of the sectors which produce most CO_2 equivalent emissions, according to expression (5.9).

5.4. Empirical Results

In the empirical application, we used a national accounting matrix with environmental accounts (NAMEA) for the Catalan economy with 2001 data. As it is described in Chapter 2, 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

ISBN:978-84-693-0717-5/DL:T-442-2010

discharges of pollutants generated by sectors and consumption. This database originally included the emissions of ten pollutants. In this chapter, we used only the four emissions that show greenhouse pollution in the regional economy. The four gases we analysed 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.).

5.4.1. Relative Emissions

Table 5.2 shows the relative index of emissions for each endogenous account, following expression (5.10) 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 network (sector 20), with 14.953%. We can also highlight, however, 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 and social activities; 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.

The results of table 5.2 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

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

applied to generate a minimum distortion on the economic activity and on the productive system.

Table 5.2. 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%
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%
Labour	0.000%
Capital	0.000%
Households	20.560%

5.4.2. 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 labour) 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 analysed the introduction of a 20% tax on final consumption. Finally, we calculated the impact of a 20% tax on total production.

The values in matrix *M* reflect both the absolute variation and the percentatge variation in prices, because the calibration produce takes all benchmark prices equal to unity.

Table 5.3 shows the changes in production prices after the various simulations. The first column in table 5.3 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 also increase, and 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 the most sensitive to the introduction of the new taxation.[126]

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%.[127]

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 labour) 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.

[126] Other sectors which also undergo a significant increase in prices are food (sector 5) with 1.328%, hotel management (sector 19) with 1.154%, other services, social and personal services (sector 26) with 1.095%, sanitary, veterinary activities and social services (sector 25) with 1.060% and public services (sector 23) with 1.058%. Factors of production (capital and labour) and households increase their prices by 1.045%, real estate activities and entrepreneurial services (sector 22) by 1.011% and chemistry (sector 9) by 1.003%.

[127] 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%.

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

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 comunications (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 5.3 is that different policies have very 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 companies.

ISBN:978-84-693-0717-5/DL:T-442-2010

Table 5.3. 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. Manufacture of transport material	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 and entrepreneurial services	1.011%	0.886%	0.384%	1.352%
23. Public services	1.058%	0.928%	0.400%	1.340%
24. Education	0.958%	0.729%	0.472%	1.206%
25. Sanitary, veterinary and 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%
Labour	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%

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.

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

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 5.4.

If we apply a 20% tax on intermediate and final consumption, the CO_2 equivalent emissions would diminish by 8.71 %. This is the situation in which the emissions reduce to a greater extend. On the other hand, when we introduce a 20% tax on intermediate consumption, the CO_2 equivalent emissions are reduced by 1.82 %. In contrast, if we apply a tax on final consumption the CO_2 equivalent emissions reduce by 7.22 %. And finally, when we introduced a tax on total production the CO_2 equivalent emissions diminished by 5.81 %.

Additionally, 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 5.4 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.

Table 5.4. Changes in aggregated variables

	Situation 1	Situation 2	Situation 3	Situation 4
Emissions (%)	-8.71%	-1.82%	-7.22%	-5,81%
Elasticity emissions (%)	-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

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.

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

ISBN:978-84-693-0717-5/DL:T-442-2010

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 analysed 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. If, on the other hand, 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. 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 analysed.

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 situation one (a 20% tax on both intermediate consumption and final consumption). This situation reduces more the emissions of CO_2, but it is not a good situation for the consumers. 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.

ISBN:978-84-693-0717-5/DL:T-442-2010

5.4.3. Quantity Effects of a 20% Reduction in Sectorial Greenhouse Emissions

As we saw in table 5.2, the agents which produce most CO_2 equivalent emissions are agriculture (sector 1), energy, minerals, coke, petroleum and fuels (sector 3), other non-metallic mineral products (sector 11), transport and communications (sector 20), and households. This observation led us to the question of what amount it would be necessary to reduce the final production of the different production activities and the income of the factors of production and consumers so as to give rise to a 20% reduction in the CO_2 equivalent emissions of sector 1, sector 3, sector 11, sector 20 and households. In order to undertake this analysis we extended the input-output model proposed by Miller and Blair (1985) to a SAM framework following expression (5.16).

In the simulations, there is analysed a level of fixed endogenous income that satisfies the desired reduction in the level of emissions according to expression (5.9). The analysis involves five different scenarios. In the first one, we analysed by what amount the endogenous accounts would need to reduce their level of income to give rise to a 20% reduction in the CO_2 equivalent emissions of agriculture (sector 1). In subsequent scenarios, we applied exactly the same changes so as to reduce the emissions in energy, minerals, coke, petroleum and fuels (sector 3), other non-metallic mineral products (sector 11), transport and communications (sector 20) and households.

Table 5.5 shows the changes in total income and in CO_2 equivalent emissions in each simulation. The first column shows by what amount it would be necessary to reduce the final production of the various production activities, the factorial income and the private income to enable agriculture (sector 1) to reduce its CO_2 equivalent emissions by 20%; as we can see, in order to achieve this objective, sectorial production would have to be reduced by between 15% and 26% approximatelly. The most noteworthy case is that of households, in which a reduction in final production of

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25.95% would be required. Apart from this, transport and communications (sector 20) would need to reduce its final production by 25.72%, textile (sector 6) by 25.58%, real estate and entrepreneurial services (sector 22) by 24.92%, and agriculture (sector 1) by 24.35%. The CO_2 equivalent emissions would reduce by 23.36%, which would enable us to comply with the agreement on climate change signed by the European Union in late 2008, in which an undertaking was given to reduce emissions of greenhouse effect gases by 20% by the year 2020.

In the following column, energy, minerals, coke, petroleum and fuels (sector 3) would reduce its CO_2 equivalent emissions by 20%. The application of this simulation gives results that are fairly similar to those of the previous one: energy, minerals, coke, petroleum and fuels (sector 3) would need to reduce its final production by 26.75%, households by 25.66%, textile (sector 6) by 22.52%, and real estate and entrepreneurial services (sector 22) by 24.84%. Total CO_2 equivalent emissions would be reduced by 23.22%, and we would thus also comply with the EU agreement.

In the following scenario, the emissions are reduced in other non-metallic mineral products (sector 11), and it is observed that all production activities, factors of production and households are affected between 15% and 25% in order to obtain the reduction in emissions of sector 11. Sectors more affected would be households, with 25.85%, transport and communications (sector 20) with 25.74%, textile (sector 6) with 25.56% and real estate and entrepreneurial services (sector 22) with 24.88%. Additonally, total emissions would be reduced by 23.66%.

In the fourth scenario, emisions of transport and communications (sector 20) are reduced by 20%. Once again the results show a wide range of percentage variation, machinery (sector 13) is the sector which would need to least reduce (by 15.47%) its final production in order to meet the proposed objective, while transport and communications (sector 20) would need the largest reduction (by 30%). In addition to this, households would

ISBN:978-84-693-0717-5/DL:T-442-2010

reduce their income by 26.28%, textile (sector 6) would reduce its income by 25.78%, and real estate and entrepreneurial services (sector 22) by 25.25%. In this situation, total emissions would reduce by 23.76%.

The last scenario reduces private emisions by 20%. In this simulation, households and transport and communications (sector 20), are the most affected with reductions of 29.20% and 27.50% respectively, in its income. With regard to other sectors, textile (sector 6) would need to have a reduction of 27.30%, real estate and entrepreneurial services (sector 22) a reduction of 26.80%, and hotel management (sector 19) of 26.54%. In this scenario the reduction in total CO_2 equivalent emissions (24.88%) is greater than in the preceding scenarios.

The conclusions that we can draw from table 5.5 are that by applying the reductions in the emissions of the sectors that pollute most we would succeed in reducing total CO_2 equivalent emissions between 23% and 26% approximatelly, which would enable us to comply with the agreement signed by the European Union. Despite this positive effect to the atmosphere, the economic impacts would be very distorsioning and very assymmetric individually on the different agents involved.

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

Table 5.5. Changes in endogenous income (%)

	Situation A	Situation B	Situation C	Situation D	Situation E
1. Agriculture	-24.35%	-20.44%	-20.48%	-20.71%	-22.40%
2. Fishing	-20.84%	-20.76%	-20.80%	-21.10%	-23.26%
3. Energy, minerals, coke, petroleum and fuels	-22.64%	-26.75%	-22.88%	-23.37%	-24.13%
4. Electrical energy, gas and water	-20.64%	-20.55%	-20.65%	-21.03%	-22.53%
5. Food	-23.27%	-23.05%	-23.10%	-23.35%	-25.26%
6. Textile	-25.58%	-25.52%	-25.56%	-25.78%	-27.30%
7. Manufacture of wood and cork	-22.21%	-22.18%	-22.30%	-22.38%	-23.26%
8. Paper	-24.22%	-24.16%	-24.21%	-24.48%	-25.51%
9. Chemistry	-22.24%	-22.13%	-22.20%	-22.30%	-23.09%
10. Rubber and plastic products	-17.16%	-17.11%	-17.17%	-17.38%	-18.14%
11. Other non-metallic mineral products	-16.59%	-16.62%	-23.94%	-16.74%	-17.37%
12. Metal	-19.95%	-19.95%	-19.99%	-20.11%	-20.67%
13. Machinery	-15.32%	-15.29%	-15.34%	-15.47%	-16.22%
14. Electrical equipment, electronics and optics	-18.98%	-18.94%	-18.97%	-19.26%	-20.10%
15. Manufacture of transport material	-22.30%	-22.25%	-22.28%	-22.59%	-23.78%
16. Other industries	-18.54%	-18.49%	-18.53%	-18.78%	-20.35%
17. Construction	-21.15%	-21.30%	-21.20%	-21.43%	-22.09%
18. Commerce	-23.30%	-23.21%	-23.26%	-23.57%	-25.47%
19. Hotel management	-23.85%	-23.77%	-23.82%	-24.18%	-26.54%
20. Transport and communications	-25.72%	-25.66%	-25.74%	-30.00%	-27.50%
21. Financial intermediation	-23.43%	-23.36%	-23.40%	-23.75%	-25.46%
22. Real estate and entrepreneurial services	-24.92%	-24.84%	-24.88%	-25.25%	-26.80%
23. Public services	0.00%	0.00%	0.00%	0.00%	0.00%
24. Education	-18.76%	-18.69%	-18.74%	-19.02%	-20.83%
25. Sanitary, veterinary and social services	-20.11%	-20.04%	-20.08%	-20.34%	-22.22%
26. Other services, social and personal services	-21.31%	-21.24%	-21.29%	-21.58%	-23.60%
27. Homes that employ domestic staff	-22.38%	-22.30%	-22.35%	-22.66%	-25.16%
Labour	-22.41%	-22.35%	-22.42%	-22.80%	-23.88%
Capital	-23.90%	-23.73%	-23.80%	-24.31%	-25.31%
Households	-25.95%	-25.85%	-25.91%	-26.28%	-29.20%
Average income	**-23.63%**	**-23.56%**	**-23.58%**	**-24.05%**	**-25.64%**
Total emissions	**-23.36%**	**-23.22%**	**-23.66%**	**-23.76%**	**-24.88%**

Situation A: 20% reduction in the CO_2 emissions of Agriculture (sector 1).
Situation B: 20% reduction in the CO_2 emissions of Energy, minerals, coke, petroleum and fuels (sector 3).
Situation C: 20% reduction in the CO_2 emissions of Other non-metallic mineral products (sector 11).
Situation D: 20% reduction in the CO_2 emissions of Transport and communications (sector 20).
Situation E: 20% reduction in the CO_2 emissions of Households.

5.5. Conclusions

In this chapter we have used two models: a price model, to evaluate the economic impact of implementing different policies that would make it possible to reduce CO_2 equivalent emissions; and a quantity-based model, through which we analyse different measures that would help us to reduce CO_2 equivalent emissions in those sectors that produce most of this emissions.

The first model is the price model proposed by Roland-Holst and Sancho (1995), in which a constant price structure is assumed. The SAM price model is therefore 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 on the basis of the SAM price model proposed. 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 overall 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,

ISBN:978-84-693-0717-5/DL:T-442-2010

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 analysed, 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 analysed.

Having observed the relative index of emissions for each endogenous account and identified that the sectors producing most CO_2 equivalent emissions are agriculture (sector 1), energy, minerals, coke, petroleum and fuels (sector 3), other non-metallic mineral products (sector 11), transport and communications (sector 20) and households, we subsequently applyed a second model, based on a quantity approach. This method analyses the amount by which it would be necessary to reduce the final production of the various different production activities, factors of production and consumers in order to ensure that agriculture (sector 1), energy, minerals, coke, petroleum and fuels (sector 3), other non-metallic mineral products (sector 11), transport and communications (sector 20) and households reduce individually their CO_2 equivalent emissions by 20%.

The results show that CO_2 equivalent emissions would reduce between 23% and 26%, and would therefore comply with the agreement on climate change signed by the European Union in late 2008, by which it undertook to reduce emissions of greenhouse-effect gases in the member

ISBN:978-84-693-0717-5/DL:T-442-2010

states by 20% by the year 2020. However, the economic effects of such accomplishment would force to reduce endogenous income in a greater extend. This would make these measures impracticable in practise. These results can, however, be used to find solutions for fighting against climate change, since policy makers can use the results 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, which would be obliged to reduce significantly their production levels, in the long term they would in fact be extremely beneficial for the Catalan economy and society at large.

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UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

Chapter 6

Conclusions

ISBN:978-84-693-0717-5/DL:T-442-2010

ISBN:978-84-693-0717-5/DL:T-442-2010

6.1. - Summary of Results and Conclusions

I shall conclude this doctoral research project by synthesizing the principal results and conclusions that can be arrived at on the basis of the analysis that was conducted. Although individual chapters conclude with their own specific conclusions, they have each been written with a common purpose in mind: to analyse the different economic policies that could enable us to reduce both emissions of greenhouse effect and levels of energy consumption.

As I already indicated above, the analysis involved different economic policies through the application of multisectorial models which show the effects which would be brought about on the economy by different regulations aimed at reducing the emission of greenhouse effect gases in Catalonia, in terms of the data available for the year 2001.

After a review of the linear models and non-linear models applied to the environment, my starting point took the form of the construction of a social accounting matrix (SAM) for Catalonia for the year 2001 which would bring out the interdependence of the various agents and sectors of the economy through a full representation of the circular flow of income. For the purposes of my analyses, I therefore adapted this SAM database (containing all the relevant economic information) by adding environmental information to it. I thus effectively constructed a NAMEA (National Accounting Matrix using Environmental Accounts), which enabled us to combine information concerning monetary incomes in the regional accounts of Catalonia with physical measurements of the emission into the atmosphere of different pollution-causing gases.

I am aware that muy matrices are subject to limitations, due to the difficulty of obtaining certain variables on a regional scale. This problem had already been referred to by Leontief in 1971: "Without invoking a misplaced methodological analogy, the task of securing a massive flow of primary economic data can be compared to that of providing the high-energy physicists with a gigantic accelerator. The scientists have their machines,

ISBN:978-84-693-0717-5/DL:T-442-2010

while the economists are still waiting for their data. In my case not only must society be willing to provide year after year the millions of dollars required for maintenance of a vast statistical machine, but a large number of citizens must be prepared to play at least a passive, and occasionally even an active, part in actual fact-finding operations. It is as if the electrons and protons had to be persuaded to cooperate with the physicist".

For the same reason, I believe that it is necessary to improve the availability of regional statistics. In order to achieve such an improvement, institutions should make a greater effort to publish certain sources of information more regularly so that an accurate analysis of the current situation can be made, in the form of, for example, supply tables, folding contingency tables, or even the original input-output tables themselves. They should also provide more complete information about wages and salaries, V.A.T. and Social Security contributions. Be that as it may, the SAM01 and NAMEA01 constitute fully complete databases that I have used to undertake the analyses discussed in the successive chapters of my study.

In chapter three, I used these databases to define a linear model of emissions multipliers for the Catalan economy for the year 2001. With this model I can observe the effects caused by an increase in a unit of exogenous demand on emissions of greenhouse effect. I proposed different scenarios to meet the objective of reducing emissions of greenhouse effect gases in order to comply with the Kyoto Protocol. A decrease in total emissions combined with an increase in the income of the endogenous accounts would have positive effects on the environment that would enable the Catalan economy to satisfy the objectives of the Kyoto Protocol. Additionally, I broke down the total emission multipliers into own effects, open effects and circular effects, so as the better to observe the different channels of generation of income and their effects on emissions of greenhouse effect gases.

One of the principal conclusions of this chapter was that greenhouse gas emissions in Catalonia are affected very differently at the sectorial level and that the effects of production activities, factors and consumption on air

ISBN:978-84-693-0717-5/DL:T-442-2010

pollution are very heterogeneous. My results also showed that increases in greenhouse gas emissions will essentially depend on the account that receives the exogenous inflow in demand.

In the following chapter, I used an input-output price model to analyse the economic effects that different policies have on the energy-related activities of the Catalan production system. This analysis concentrated on the energy-related sectors because the use and production of energy is linked to negative environmental effects. I used two versions of the input-output model: a competitive definition and a mark-up definition. The competitive definition assumes that sectorial prices are equal to average production costs. In the case of the mark-up definition, on the other hand, production prices represent a fixed return on capital. The two formulations of the input-output price model were used to simulate different policy scenarios. A reduction in intermediate energy use and a tax on intermediate energy consumption led to production prices and the consumer price index very close to zero, a significant reduction in energy consumption and a positive level of private real income.

In the last chapter, I used two linear multisectorial models based on a social accounting matrix to analyse the economic impact on Catalonia of the implementation of policies that would reduce CO_2 emissions. The first model used is a price version of the SAM modelisation that shows the cost impacts and the price mechanisms of the different simulations analysed. The second model used is a quantity version of the SAM modelisation that allows to quantify how much reduction in production it is needed to get a significant reduction in pollutant emissions.

First I calculated the relative index of emissions for each endogenous account. Various simulations were carried out on the basis of the SAM price model. The first took the form of the introduction of a 20% tax on intermediate consumption and final consumption. I subsequently applied a 20% tax on intermediate consumption. The following simulation consisted of introducing a 20% tax on final consumption. Finally, I calculated the impact of a 20% tax on total production.

ISBN:978-84-693-0717-5/DL:T-442-2010

The results suggest that different measures cause different effects on emissions, public revenues and private real income. The best situation for the environment is the introduction of a 20% tax on intermediate consumption and final consumption, but it is not a good situation for the consumers because there exists an overall increase in prices and a negative effect on private welfare. On the other hand, the introduction of a 20% tax on final consumption is good situation for the environment, for the consumer and, in addition, it does not generate inflation.

The second model is used to analyse the amount by which it would be necessary to reduce the final production of the various different production activities, factors of production and consumers in order to ensure that agriculture (sector 1), energy, minerals, coke, petroleum and fuels (sector 3), other non-metallic mineral products (sector 11), transport and communications (sector 20) and households reduce individually their CO_2 equivalent emissions by 20%.

The results show that by applying the reductions in the emissions of the sectors that pollute most I would succeed in reducing total CO_2 equivalent emissions between 23% and 26%, which would enable us to comply with the agreement signed by the European Union. Despite these positive effects to the atmosphere, the economic impacts would be very distorsioning and very assymmetric individually on the different agents involved. Although it may at first seem that some measures are not very favourable for households and for certain production activities which would be obliged to reduce significantly their production levels, in the long term they would in fact be extremely beneficial for the Catalan economy and society at large.

ISBN:978-84-693-0717-5/DL:T-442-2010

6.2. - Future Research Directions

Finishing a thesis does not mean finishing the research work. What it really means is that it has been completed the initiation into the wider world of research work, since when you are in the process of writing it new questions arise which may or may not be related to what you are working on, and different options for future research suggest themselves. [128]

Before anything else, it is important to say at this point that I believe it to be indispensable to make future improvements to databases since their role within the simulation process is primordial, given that the parameters of a model are obtained from its contents. If new information is available in future, I shall be in a position to improve my matrices through the inclusion of more complete and more recent data.

The first line of research is related to the first chapter, in which I give a brief introduction to computable general equilibrium models, to the different phases that make up the process of producing any general equilibrium model, and the advantages and limitations of this type of models, in addition to introducing the subject of computable general equilibrium models applied to the environment. I had at first intended to include an applyed general equilibrium model in the thesis, but finally I decided to finish the thesis and to construct the model later, when more time would be available. Through the construction of a computable general equilibrium model applied to the environment I will explore the empirical viability of a double dividend for the economy of Catalonia. The model will be calibrated on the basis of the social accounting matrix for the Catalan economy for 2001, which I presented in chapter 2. With this objective in mind, I shall then go on to analyse the effects of an ecological tax on the

[128] "Ending up a thesis is one thing, finishing a research (if possible at all) is another. Answers raise new questions, solutions define new problems, results call for a generalization or a sharpening, assumptions for a relaxation, gaps need to be filled up, and loose ends are to be tied up. Of course, this holds also for the present research". (Dietzenbacher, 1991, pp.266-267). Or "When you are almost finishing typing your thesis and you reach this part of the work, you feel it is difficult to deal with it. You have to think about the direction(s) of your future research when you have not finished this one yet. However, when I read the last paragraph I realized that it is true. Finishing a thesis is really different from finishing a research. A careful and critical look back at the finished chapters can show you how to continue with your research in the near future (Serrano, 2008, pp. 193)".

UNIVERSITAT ROVIRA I VIRGILI
MULTISECTORIAL MODELS APPLIED TO THE ENVIRONMENT:AN ANALYSIS FOR CATALONIA
Laia Pié dols
ISBN:978-84-693-0717-5/DL:T-442-2010

allocation of resources and the volume of emissions of greenhouse effect gases.

It would also be very interesting to use input-output methodology to analyse the relationship between economic and environmental variables through techniques based on economic-environmental trade-offs. In order to calculate the income-pollution trade-offs, I would take as an indicator of income the sectorial value added in relation to the cost of the factors and of the employment-pollution trade-offs, as Vicente Alcántara does in his doctoral thesis (1995).

In the context of energy analysis, Karunaratne (1989) proposed an alternative focus based on trade-offs between energy and the economic variables under analysis. I shall apply this method to emissions of greenhouse effect gases. This method could be an alternative to Rasmussen's coefficients with regard to the determination of key sectors of emission in relation to a specific objective.

The method of calculation of elasticities of production-demand and production-value added is to be found in the work of Pulido and Fontela (1993). Although the presentation of this aspect focuses on showing the usefulness of the relationships between vertical and horizontal coefficients, as presented by Miller and Blair (1985), in future research work I shall use the method of calculation employed by Vicent Alcántara (1995) to obtain the elasticity of emission/demand, perfectly extendable to obtaining the elasticity of emissions with respect to other economic variables, which represents an alternative approach for measuring the environmental impact of economic activity.

It would also be interesting to examine the technique for determining a key sector, which then makes it possible to produce a first approach to an analysis of the role of the various production sectors of the economy in relation to the objective of the study. The use as a technique of Rasmussen's indicators, which help to determine "key sectors" in a particular context, has been widely applied, although this focus is not

ISBN:978-84-693-0717-5/DL:T-442-2010

exempt from possible criticisms, among them those of Skolka (1986),[129] for example, or even Rasmussen himself (1956, pp. 132-144).[130]

These criticisms become widespread in the works of Chenery and Watanabe (1958) and of Hirschm (1958). The method I wish to propose is an adaptation of the energy analysis found in Alcántara's method (1995), and consists of an extension of the disaggregate calculation of the elasticity of production /demand proposed by Pulido and Fontela (1993, pp.82-84).

When I constructed the NAMEA, I observed that would be very interesting to analyze the relation that exists between the emission of CO_2 and the exports and the imports of the Catalan economy. In the last times, there have appeared several papers that summarize the literature on the relation that exists between the environment, the imports and the exports. Some of these papers are: Muradian and O'Connor (2001), Antweiler (1996), Muradian et al. (2002), Munksgaard and Pedersen (2001), Alcántara (1995), Duarte et al. (2002) and Sánchez-Chóliz and Duarte (2004).

Taking into account that to obtain economic development is necessary that an economy has a few good commercial relations with abroad, I plan to analyze if the levels of pollution of the Catalan economy could be affected by changes in the commercial patterns and, in addition, if the Catalan economy affects the atmospheric pollution in a more global level. And finally, my future work will analyse if part of the pollution generated in Catalonia is through the fault of his own needs or, alternativelly, it is if related to the requirements that exist abroad.

In summary, I will analyse the sectoral impacts that Catalan international trade relations have on present levels of atmospheric pollution.

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[129] Skolka's criticism (1986), quoted by Pulido and Fontela (1993, pp. 133) was perhaps one of the strongest.

[130] Rasmussen himself warns that it is not possible to give a single definition of "key sector", stating that this will depend rather on the problem to be dealt with. After proposing criteria for the designation of key sectors on the basis of employment and imports, he concludes as follows: "It is possible to consider other definitions of key sectors which are appropriate to other problems, but these observations are sufficient to direct attention towards the importance of the input-output model".

ISBN:978-84-693-0717-5/DL:T-442-2010

This will be studied by using an input–output framework and the concepts of vertical integration. Since the vertical integration will allow to define the pollution value of a good as the direct and indirect pollution generated, I will be able to observe better the relations that exist between the pollution, the imports and the exports.

In chapter five, when I analysed the relative index of emissions for each endogenous account, I realized that consumers have the greatest responsibility for the total of carbon dioxide (CO_2) equivalent emissions in Catalonia, since they produce 20.560% of the total. For this reason I think that it would be very interesting to analyse the evaluation of CO_2 equivalent emissions in relation to demand and household consumption, and in particular to analyse the distribution of household expenditure on different goods (the patterns of consumption), technological change or the intensity of emissions, for the total CO_2 equivalent emissions in the Catalan economy during the 1994-2001 period. To carry out this analysis I shall use the methodology of structural decomposition analysis (SDA).[131] This method of decomposition, defined by Rose and Chen (1991) as "the analysis of economic change by means of a set of comparative static changes in key parameters in an input-output table", has been used on various different occasions for the study of changes in energy consumption, CO_2 emissions and the generation of other polluting elements, as can be seen in Hoestra and Van der Berg (2002), De Haan (2001), Wier (1998), Rormose and Olsen (2005), Alcántara and Duarte (2004), Roca and Serrano (2007), Llop (2007) and Sánchez, Duarte and Mainar (2007).

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[131] In the work of Rose and Casler (1996), a detailed and exhaustive revision of the bibliography is given, and in the work of Dietzenbacher and Los (1998) an examination is made of some of the problems which frequently appear in the empirical application of the techniques of structural analysis.

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