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Designing Public Policies

An Approach Based on Multi-Criteria Analysis and Computable General Equilibrium Modeling

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Para mis padres y para Sara
F.J.A.

To my father, Manuel
M.A.C.F.

To my dear flat-mates Carlos, Javier and Puelcio
C.R.

Foreword

This monograph provides a novel approach to the evaluation of economic policy by combining two different analytical strategies. On the one hand, the computable general equilibrium (CGE) analysis, a standard tool mostly used to quantify the impact of economic measures or changes in the structural data of the economy. On the other hand, the multiple criteria decision-making (MCDM) approach, an optimisation technique that deals with problems with more than one objective. Typically, CGE is well suited for the analysis of the interactions of multiple agents from the point of view of a planner single objective. Combining this technique with the MCDM approach allows developing models in which we find many interacting agents and a decision maker with several objectives.

The contribution of this work is partly methodological and partly applied. It provides a framework for the analysis of this type of problems, as well as a series of applications in which the strength of the approach is made clear. The consideration of environmental problems, as a specific field in which this technique of analysis can be used, is particularly well chosen. The environmental concern keeps growing steadily and has already become an issue in most of the standard economic decisions. It is therefore extremely important to find systematic ways to introduce such a concern in the models with which we evaluate the impact of policy measures. This work is a relevant addition to the stock of knowledge from that perspective and will become a standard reference for the field. The authors have already proven their skills on those topics in a number of internationally renowned contributions. So the reader is in good hands to travel along these matters.

Antonio Villar
Professor of Economics
Universidad Pablo de Olavide

Preface

Almost eighty years ago the British economist Lord Robbins proposed what is now his famous and universally accepted definition of economics in his classic book *Nature and Significance of Economic Science*[1]:

> "Economics is the science which studies human behaviour as a relationship between ends and scarce means which have alternative uses".

Robbins' definition was not, however, readily accepted at first and raised many controversies. In fact, several epistemological issues underlying this definition have been discussed since its conception. Backhouse and Medema[2] offer a recent and lucid discussion about the controversies, as well as the slow acceptation of Robbins' definition.

Two main issues derive from this definition. The first is that scarcity is the primitive concept underlying any type of economic problem. The second is that, to some extent as a consequence of the scarcity issue, economics aims to deal with scarcity in the best possible way. Technically speaking, economics attempts to "optimize" the existing scarcity. In short, as Intriligator[3] states, "economic problems" can be expressed as particular cases of "mathematical optimization problems". The underlying optimization problem can be undertaken within an environment devoid of institutions (a "Robinson Crusoe economy") or within an environment with very dense institutions (the "current global economy"). But at the two opposite poles or in any intermediate state, the "economic act" is analytically speaking "an optimization act".

According to the above ideas, it is reasonable to accept that economics strongly depends on the state-of-the-art of current mathematical optimization theory. In this

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[1]Robbins LC (1932) An essay on the nature and significance of economic science. Macmillan, London.

[2]Backhouse RE, Medema SG (2009) Defining economics: the long road to acceptance of the Robbins definition. Economica 76: 805–820.

[3]Intriligator MD (1971) Mathematical optimisation and economic theory. Prentice-Hall, Englewood Cliffs, New Jersey.

sense, we should stress that economics is today generally underpinned by a classic optimization theory. This type of theory postulates the optimization (maximization or minimization) of an objective function that is assumed to represent the preferences of the economic agents (e.g., utility for a consumer, profits for a producer, etc). On the other hand, the optimization process is subject to a set of constraints being met. This can be understood as a representation of the economics side of scarcity (i.e. budget restraint, technology of a production process, etc).

Given this close connection between economics and optimization theory, it is worthwhile investigating what effects a change in the underlying mathematical optimization paradigm might have on economic science. Such a shift in the optimization paradigm has occurred in the last 40 years or so, with the slowly evolving of the Multiple Criteria Decision Making (MCDM) paradigm. The main purpose of this book is to analyse some potential effects of this shift of paradigm on an important branch of the economic analysis: the design and assessment of public policies. We will show throughout the book how this branch of economics can be considerably revitalized by formulating and solving the basic problems of this discipline within the MCDM paradigm. Thus, the acceptation of this new paradigm as a framework for economic policy implies new challenges, but also more realistic formulations, as well as more pragmatic solutions to the design of public policies especially when environmental and traditional economic criteria are considered together.

The MCDM paradigm has been developed mainly within the field of operational research/management science (OR/MS). Although it has been used to address many economic problems, it has not been fully incorporated yet into the core of economic thinking, and it remains unknown to many economists. Therefore, we would like to stress that our effort could be useful for re-building bridges between economics and operational research/management science (OR/MS). This connection takes place, first, through the extensive application of MCDM to a classical economic problem, such as the design and evaluation of economic policies. And second, our work establishes another connection between OR/MS and economics in the sense that we address policy design problems by combining MCDM techniques with structural economic models.

From the economics side, we need some analytical representation of the main economic mechanisms, such as production and consumption decisions, as well as markets for goods and inputs, to properly specify our policy design problems. Computable general equilibrium (CGE) models are useful for this representation of the economy. Such structures have been used extensively since the 1980s in the evaluation of public policies and other simulation exercises in both developed and developing countries. CGE modelling is especially attractive for policy-makers since, being consistent with standard economic theory, it can measure the effects of a specific change (e.g., a given policy) on the most significant economic variables such as prices, production levels, tax revenues, and income distribution.

The importance of the connection between economics and OR/MS was quite clear in the 1950s and 1960s, with important contributions by leading figures in economics like Arrow, Baumol, Dorfman, Hicks, Leontief, Samuelson, Solow, among others. However, this important tradition of linking economic problems with OR/MS almost vanished as of the early 1980s, which, in our view, is an important loss to both disciplines. We insist that our book can help to fill this gap. Thus, it is intended for postgraduate students and researchers of economic policy with an OR/MS orientation or of OR/MS with an economic policy orientation. In short, economic policy can be revitalized with new formulations and analytical procedures borrowed from the MCDM paradigm, whereas OR/MS can also be stimulated with the appearance of new interesting areas of application.

We are aware of the limits of our analysis. In fact, we only present initial and tentative procedures and solutions, but hopefully in a new and promising direction.

Seville — Francisco J André and M Alejandro Cardenete
Madrid — Carlos Romero
June 2010

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The work reported in this book has evolved gradually over five years of collaboration among the three authors. In this respect, there are a lot of beneficial intellectual influences that must be cited.

Francisco J. André came up with the idea of addressing macroeconomic policy making as a multicriteria problem after taking an extremely inspiring PhD course taught by Professor Carlos Romero at the Technical University of Madrid. The embryo of this idea was born when he was following the PhD program on economic analysis at the Complutense University of Madrid. He is indebted to many professors for helping him to develop an analytical vision of the economy. Of these, Professors Emilio Cerdá and Alfonso Novales deserve a special mention. This idea came to light after meeting Dr. Manuel Alejandro Cardenete at the Department of Economics of the Pablo de Olavide University of Seville, which provided a fruitful research environment.

Manuel Alejandro Cardenete thanks Professor Ferran Sancho from the Autonomous University of Barcelona for his patience and effort. Almost fifteen years ago he thought that helping this young graduate student to learn applied general equilibrium models might be of some use. Even today he still assists him with his research, although the relationship is now more than just professional. He would also like to thank Professor Jose Maria O'Kean from the Pablo de Olavide University of Seville and Professor Geoffrey J.D. Hewings from the University of Illinois at Urbana-Champaign for highlighting important points throughout his academic career.

Carlos Romero would like to acknowledge the positive influence of the seminal works by the leading figures in the field – the late Abraham Charnes and William W. Cooper – on his learning and understanding of MCDM. He also would like to mention the influence of the works of and conversations with some of the "Pioneers of South Carolina", like James P. Ignizio, Ralph E. Steuer, Po-Lung Yu, Milan Zeleny, among others. Looking back, he is extremely grateful to all the researchers with whom he has had the privilege of publishing works over the last 35 years. Although it is impossible to list all the names, he would like to mention the beneficial influence of his mentor Professor Enrique Ballestero in the early stages of his career and the privilege it is to have the help and collaboration of researchers of the intellectual calibre of Dr. Diaz-Balteiro and Dr. González-Pachón.

But, apart from the intellectual influences, there are other more material and practical issues that have also been essential to the success of this research. First, we are bound to acknowledge that this project has been generously financed and supported by the Spanish Fundación BBVA foundation. This research has been part of a joint annual activities program between Fundación BBVA and the IVIE (Instituto Valenciano de Investigaciones Económicas) research institute. IVIE staff have kindly helped us with the edition and handling of the text.

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Ekonomiaz

Environmental Management

Journal of Agricultural Economics

Journal of the Operational Research Society

Regional Studies

Socio-Economic Planning Sciences

Last but not least, we would like to thank Rachel Elliott for the careful English editing of the manuscript. As we are not native English speakers, Rachel's help has been vital in preparing a manuscript in readable English. No meagre feat!

Contents

Chapter 1
General Framework: Policy Making as a Problem with Multiple Criteria

Abstract This chapter underlines some limitations of the traditional approach to public policy making. First, it is troublesome to find an expression for a social welfare function because of information requirements and the technical difficulties associated with the aggregation of preferences. Second, observed policy practice does not appear to be consistent with the existence of a well-defined social welfare function. On the contrary, policy design seems to be targeted to the improvement of economic performance as measured by a number of conflicting indicators. Based on this evidence, we set out to provide an alternative, more pragmatic approach to policy making. In this chapter we introduce a recent line of research that we have developed in which policy design is modelled as a decision problem with several objectives using multiple criteria techniques. This approach requires a structural model of the economy, such as a computable general equilibrium model, some multicriteria techniques to address the policy design problem and to identify the key set of policy instruments and policy objectives. All these elements are analysed and developed throughout the rest of the book.

1.1 Introduction

Traditional economic analysis builds on the principle that agents are considered to be rational. This idea is typically rendered as the assumption that they set out to optimize some objective function subject to some constraints. In this way, most economic problems can be expressed as particular cases of mathematical optimization (see for example Intriligator 1971). Thus, consumers are assumed to maximize their utility subject to their budget constraints, and firms are assumed to maximize their profits subject to technology and market environment constraints. This approach is appealing for at least two reasons. On the one hand, it looks to be a sound and logical way to think about decision making from a conceptual point of view. On the other hand, by resorting to optimization theory, it provides economic theory with a powerful and consistent analytical tool.

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Following this trend, the design of public policies has also been traditionally envisioned as an optimization problem. As a matter of fact, finding an optimal policy, in the sense of choosing the value of instruments to optimize some social utility or welfare function, has become a traditional economic problem (see, for example, Ramsey (1927); Kumar (1969); Holbrook (1972) or Chow (1973) for classical references). To apply this approach, it is necessary to specify the policy maker's objective, which is typically assumed to be the maximization of the utility function of a representative consumer.

This conventional approach to economic policy design has also been frequently applied to environmental policy modeling, envisioned as the correction of externalities and other market failures in order to achieve maximum economic welfare (see, for example, Pigou (1920), and Coase (1960), for pioneering works, Baumol and Oates (1988), for a classical comprehensive text or Xepapadeas (1997), for a more recent analysis).

Despite the theoretical and technical interest of this framework for policy design, its applicability is arguable for at least two sets of reasons. The first group has to do with the technical problems associated with the specification of the government's objective function. It is philosophically appealing to assume that the government sets out to maximize a function that aggregates the preferences of society as a whole, but it is very difficult to find such a function in practice. First, it is problematic because of the huge amount of information that would be necessary to summarize the preferences of society as a whole. Second, Arrow (1963) noted that it is very troublesome to aggregate ordinal preferences and preserve all desirable properties. Within a cardinal context, on the other hand, the aggregation of individual preferences into a collective preference is not so complex, but leads to another problem known as "interpersonal comparison of utilities" (see for example Keeney 1976). Arrow's ideas were the embryo of a long line of research called social choice, concerned with aggregating individual into social preferences. This has proven to be a rather tricky problem.

The second set of reasons why the traditional single-optimization approach to policy design is troublesome in practice has to do with its realism. In fact, it is difficult in real life to identify a single policy objective for the government (see, for example, Fair and Howrey 1996). Moreover, direct observation does not seem to support the claim that the government has a single policy target or a well-defined objective function. On the contrary, policy makers are typically concerned about a bundle of economic variables that represent the state and evolution of the economy from a macroeconomic point of view. These variables include indicators related to the real evolution of the economy, such as the growth rate or the unemployment rate, nominal indexes such as the inflation rate, indicators related to public accounts, such as public deficit or public debt, or the evolution of the foreign sector as measured by the foreign deficit. On the other hand, environmental variables, including the emissions of certain polluting substances or the depletion of some natural resources, are increasingly becoming a government concern. In this framework, policy making can be understood as an attempt to improve the performance of the economy as measured by all these indicators.

1.2 Methodological Proposal

In view of all this, the task of designing public policies can be understood as a decision problem with several policy goals or objectives. Moreover, these goals usually conflict with each other. From a purely economic viewpoint, an active employment policy is likely to raise inflation; giving positive incentives to consumer demand could be harmful to the foreign sector; an expansive fiscal policy could be positive for economic activity but negative for the public budget, and so on. In summary, it is not generally possible to find a policy that is beneficial for all the objectives at the same time. This point is particularly relevant when the environment is a key concern. Since economic activity requires the exploitation of natural resources and generates a lot of waste that has an impact on the environment (see, for example, Baumol and Oates (1988), or Meadows (2004)), an immediate conclusion is that there is a clear conflict between increased economic activity and environmental protection.

These basic observations are the starting point for our research. Our aim is to provide an alternative approach to policy design founded on economics but also operational and consistent with observed practice. We claim that, given the existence of multiple conflicting criteria, public policy design falls into the methodological framework known as multicriteria decision making (MCDM). This framework has been developed in the operational research/management science (OR/MS) literature and it provides several tools (such as multiobjective programming, compromise programming, goal programming and others) precisely to deal with decision problems involving multiple conflicting criteria or objectives. These techniques have been fruitfully applied to many economic and environmental problems. See, for example, Ballestero and Romero (1998) for an introduction to these techniques and their applications to economic problems or Romero and Rehman (1987) for a survey on the applications of MCDM to natural resource management. By resorting to this OR/MS approach, we are moving from a purely conceptual and theoretical view of policy design to a more pragmatic approach, based far more on empirical evidence.

In the 1970s some authors recognized that policy making was a multicriteria issue and made some attempts to connect multicriteria techniques with econometric models to output policy recommendations (see Spivey and Tamura 1970; Wallenius et al. 1978; Zeleny and Cochrane 1973). Nevertheless, this branch of work was not very influential in economics. One likely reason for this lack of impact is the Nobel Prize winner Robert Lucas' well-known 1976 critique of the use of estimated (reduced-form) econometric models to predict the effect of macroeconomic policies. The main idea is that the estimated equations of a reduced form econometric model reflect a combination of economic agents' behaviour and the prevailing policy framework. As a consequence, those equations are not valid for predicting the effects of a policy that is different from the one that was being implemented when the model was estimated. Therefore, if one wants to evaluate the effects of alternative policy settings, it is not suitable to use a reduced form model. What is needed is a structural model specifying behaviour functions for all the agents, guaranteeing that the policy variables are clearly separated from the underlying fundamentals of economics (i.e. the technological structure and the agents' preferences).

This book presents and extends a line of research that the authors have recently developed in which policy design is modelled as a decision problem with several economic criteria using MCDM techniques. The idea is to adopt a multicriteria approach connected to a structural economic model to deal with the design of economic policies. The methodological proposal underlying this line of research is outlined in Fig. 1.1.

The top box represents the government policy design problem. This problem is to choose the optimum value of the policy instruments, including fiscal policy, monetary policy, and others. Optimality is defined in terms of the policy objectives, which typically include the indicators that the government is concerned about, such as the evolution of aggregated production, the behaviour of prices, employment, public deficit, environmental impact and others. Given the existence of multiple conflicting policy objectives, we propose to address the policy design problem using MCDM techniques.

The bottom box represents a structural model of the economy that links the policy instrument values to policy objectives and is claimed to represent the basic economic mechanisms. The underlying assumption is that using such a model the government is capable of predicting the effect of public policies on the key economic variables. This structural model should include specifications of the technology, the behaviour of economic agents (consumers and producers) and the interactions between them.

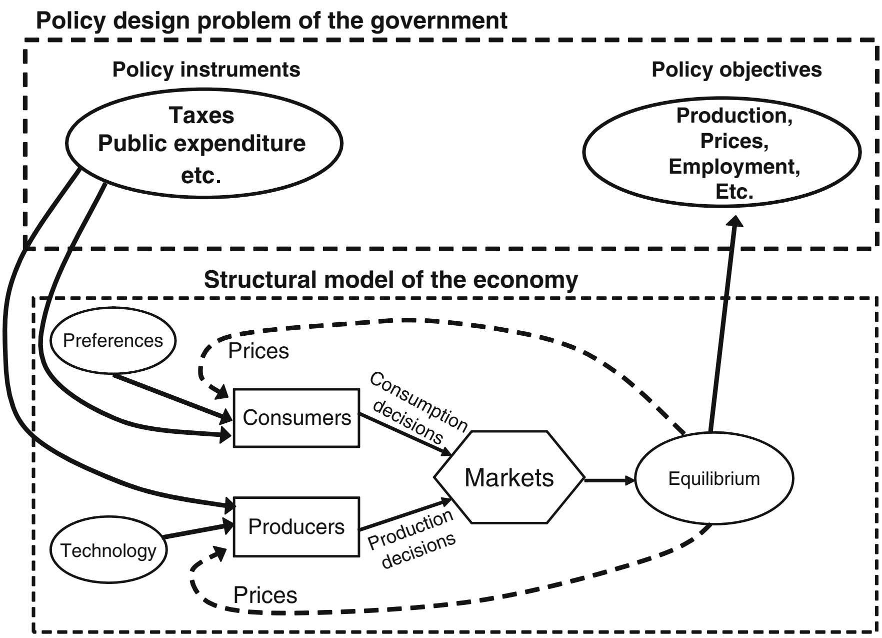

Fig. 1.1 Outline of the methodological proposal

These interactions give rise to the final prices and quantities exchanged at market equilibria and, as an aggregation of these prices and quantities, we get all the key macroeconomic variables representing the policy objectives.

It is worth noting that this procedure links OR/MS (by means of the MCDM techniques) and economics by means of the structural model. The purpose of this combination is twofold. On the one hand, we try to provide a methodology that is capable of dealing with real policy design problems and giving operational recommendations. But, at the same time, the structural model of the economy tries to guarantee that the predicted connections between the policy objectives and the policy instruments are consistent with economic theory. The use of this, rather than a reduced-form econometric model, is a crucial difference from the previously cited works by Spivey and Tamura (1970), Wallenius et al. (1978) and Zeleny and Cochrane (1973).

1.3 Elements of the Proposal and Structure of the Book

As discussed above, we need a structural model, i.e. an analytical representation of the system under analysis in order to use this approach. In this respect, all the applications developed in this line of research have been made using a computable general equilibrium (CGE) model. Specifically, in our applications, we use a CGE model calibrated for the Spanish economy.

Following in the CGE tradition, this model structurally disaggregates the activity sectors in the economy and market equilibrium, according to basic microeconomic principles. CGE modelling is especially attractive for policy makers, since, being consistent with standard economic theory, it is useful for measuring the effects of a specific change (e.g. a given policy) on the most significant economic variables such as prices, production levels, tax revenues, and income distribution. With the required adaptations, these models can also be employed to study the effects of policy measures on environmental variables. Chapter 2 presents a panoramic view of the history and the main elements of CGE models.

On the other hand, we need a MCDM technique to address the policy design problem. In this research we will focus on continuous multicriteria techniques, such as multiobjective programming, compromise programming and goal programming, although the key ideas could be perfectly compatible with discrete MCDM approaches. The selection of the specific technique is a decision that has to be made by the analyst or the policy maker depending on the features of the problem to be dealt with. In Chap. 3 we present key elements of the multicriteria paradigm and the specific issues of the (continuous) MCDM techniques that will be used in the remainder of the book.

To perfectly define the policy design problem, it is necessary to identify a relevant set of policy instruments and policy objectives. The selection of instruments and objectives is, to some extent, a discretional choice of the policy maker. Instruments should include those policy variables over which the government has a direct control and can be used to exert some influence on the economy. Typical examples include taxes, subsidies, monetary supply or interest rates. Policy objectives refer to those indicators the government is concerned about, the value of which it tries to modify by means of policy action, but it is not possible to control them directly. Generally speaking, policy objectives could include different economic, social or environmental indicators.

Thus, it is not possible to identify a set of policy instruments and policy objectives which is valid for all the cases. Rather, they should be carefully selected for each application depending on the concerns and degrees of freedom that the government has. For example, when analyzing the policy making of a member state of the European Monetary Union (such as Spain), it does not make sense to include the interest rate as a policy instrument, since this variable is not under the direct control of the Spanish policy. Nevertheless, it would be reasonable to do so if we are dealing with a country, such as the United States, having a more direct control over its own monetary policy. In the same fashion, the relevant policy instruments are different for a nation-wide or a regional policy setting. Similar considerations apply to policy objectives: the set of most important concerns for the government can vary from country to country, from one region to another within the same country, or even, in the same territory, the objectives could be different depending on the economic cycle or other social, economic or political circumstances.

In our case, we have tentatively chosen a simplified set of instruments and objectives which appeared to fit reasonably well real policy practice in Spain. Our aim here is not to identify “the best” set of instruments and objectives. Rather, we try to illustrate, in a simple and pedagogical manner, how our proposal could be applied in practice. A real-life application to policy making would probably require a more accurate selection of those elements. Concerning policy instruments, in the applications we are going to present in this book, we focus on fiscal policy, including public expenditure and taxes. Concerning policy objectives, in Chap. 4, we survey some earlier works applying our methodological proposal to design macroeconomic policies considering some purely economic objectives. These objectives include usual indicators such as economic growth, unemployment, inflation or public deficit. Moreover, in Chap. 4 we also set out a general framework for the whole line of research.

The next part of the book (Chaps. 5–8) aims to extend this line of research by including not only economic but also environmental policy objectives. The purpose is to set out a unified framework for the joint design of economic and environmental policies. In Chap. 5 we describe the CGE model that is used (with the required adaptations) in the applications presented in Chaps. 6–8. To address environmental as well as economic policy, the economic model needs to be extended to include environmental concerns. Specifically, we will focus on the reduction of pollutant emissions as an environmental objective. As environmental policy instruments, we add emissions charges on top of conventional fiscal policy.

Chapter 6 is based on an article by André and Cardenete (2008) and illustrates the use of multiobjective programming (MOP), which is a MCDM technique used to determine efficient policies in terms of economic and environmental criteria. Specifically, we focus on a two-objective application with an economic objective

–maximize economic growth- and an environmental objective –minimize CO_2 emissions. The possibility of enlarging the set of economic criteria is also discussed.

Chapter 7 illustrates the use of another MCDM technique: compromise programming (CP). In this chapter we discuss the possibility of reducing the size of the set of eligible policies by constructing the so-called *compromise set*. The compromise set is a subset of the efficient set having the property that all its elements are *as close as possible* to the ideal point taken as an anchor or point of reference. What we mean by "as close as possible" will be clarified in Sect. 7.3.6 and further developed in Chap. 7.

The third MCDM technique that has been used in this research is goal programming (GP). It is illustrated in Chap. 8, which is based on the article by André et al. (2009). In Chap. 8 we move from a conventional optimizing logic to a *satisficing* logic, as introduced by Simon (1955, 1957). Thus, we assume that, instead of trying to reach the optimal values of the objectives, the government aims to come as close as possible to certain targets or aspiration levels considered to be acceptable in the sense that they are satisfactory and sufficient (i.e. *satisficing*). This vision, which is workable thanks to the use of GP, is applied to a policy design problem with four economic objectives and three environmental objectives.

Throughout most of the book, we take a twofold, positive and prescriptive, approach to multicriteria policy making. It is positive, since it aims to offer a realistic vision of real policy making. And it is prescriptive in the sense that it aims to give policy makers useful recommendations for the task of designing public policies. In Chap. 9 we tentatively introduce an alternative approach to policy design. This approach is more in line with the conventional normative view of economic policy based on the construction of a social welfare function that represents the preferences of society. We come to the conclusion that, even if we take up such a normative viewpoint, MCDM is still a useful and fruitful approach.

Finally, Chap. 10 presents the main conclusions of this research, offers some discussion and some prospects for future investigation.

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Chapter 2
Economic Policy Using Applied General Equilibrium Models: An Overview

Abstract In the research presented throughout this book, a general equilibrium model serves to assess how the economy as a whole will react to any exogenous change. This chapter reviews general equilibrium theory and its transition to applied general equilibrium models. Specifically, we start by offering an overview of the theory of general equilibrium modelling from its origins and give a taste of how the theory evolved into applied models. We also review the key elements of an applied general equilibrium model, such as modelling production technology, consumers' behaviour, the activity of the public and the foreign sector and input markets. We also introduce the two basic techniques used to determine the numerical values of the model parameters – calibration and econometric estimation – as well as the identification of the benchmark equilibrium. The chapter concludes with a survey of some pioneering applications of general equilibrium models classified by fields and a critical appraisal of the major pros and cons of applied general equilibrium models today.

2.1 Introduction

As discussed in Chap. 1, this book presents a line of research that combines two analytical tools: applied general equilibrium modelling and multicriteria techniques. This chapter focuses on the first of these tools and reviews general equilibrium theory and its transition to applied general equilibrium models. The role of this type of model in our framework is to serve as an analytical description of the main economic driving forces that allows us to have an assessment of how the economy as a whole will react to any exogenous change.

In order to understand the philosophy underlying this modelling approach, in this chapter we look back at the theoretical origins of general equilibrium modelling and the main achievements in their development as fully applicable models. The remainder of the chapter is structured as follows. Section 2.2 gives an overview of the theory of general equilibrium modelling from its origins. Sections 2.3 and 2.4 give a taste of how this general equilibrium theory led to some attempts to translate these conceptual and theoretical ideas into applied models, resulting in so-called

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applied general equilibrium models or computable general equilibrium models. In Sect. 2.5 we review some of the most relevant analytical elements of the construction of an applied general equilibrium model. As we will discuss, building a general equilibrium model requires the specification of several parametric functional forms. Therefore, another important step in the development of these models is to determine the numerical values of the parameters involved in these functions. In Sect. 2.6 we discuss the two main approaches for determining such values: calibration and econometric estimation. Section 2.7 addresses another important step in general equilibrium applications: the determination of the model's so-called benchmark equilibrium. Section 2.8 presents a survey of some applications of computable general equilibrium models classified by fields. Section 2.9 concludes with a critical appraisal of the main current pros and cons of applied general equilibrium models.

2.2 An Overview of General Equilibrium Modelling

The historical origin of general equilibrium theory is to be found in the marginal utility or neoclassical school (school of economics active in the mid- to late nineteenth century). Based on the theory developed by this school, Gossen (1854), Jevons (1871) and Walras (1874) –who used mathematical notations– and Menger (1871) –who did not– took the first steps to develop general equilibrium theory. The most effective and outstanding researcher in this group is L. Walras. Walras can be considered the father of the theory.

General equilibrium's simplest problem lies in the analysis of exchange economies. In this type of economy, the demanders' budget constraint is determined by their initial resource endowment and the price vector. The individual demand function is the optimal response of the individual consumer to the given price system. The market demand function is obtained by aggregating individual functions, and market equilibrium emerges when we find a price for which the addition of net demands equals zero. This idea was already present in classical economic theory expressed as "supply should match demand". Although Cournot (1838), in his discussion of international money flow, and Mill (1848), in his arguments on international trade, had already sensed this point, we owe its expression as a set of mathematical equations to Walras (1874).

Some years later, Pareto (1909) defined a property of market equilibrium. Under the assumptions that goods were perfectly divisible and utility functions were differentiable, if every consumer made an equilibrium allocation of goods, an infinitesimal change in this allocation would not affect the utility levels if it did not affect the budget restriction levels. The so-called Pareto optimum could occur in competitive equilibrium, but it would require more severe conditions. The first theorem for developing this question was set out by Arrow (1951).

The following step in the development of general equilibrium theory was the introduction of production into a static framework. Producers were assumed to minimize production costs given the market prices. Market equilibrium was defined as a situation in which, given a price vector, supply matched demand. Walras considered a productive sector with a single good, and Hicks (1939) generalized this model to include more than just one output.

Earlier on Cassel (1918) had already developed a model with a productive sector, understood as a set of potential linear activities. He applied a simplified Walrasian model that preserved demand functions and production coefficients, but did not deduce the demand functions from the utility functions or preferences. The model was generalized by Von Neumann (1937) to allow for production in a spatial context.

A little later, Koopmans (1951) made a more complete and sophisticated analysis, creating a model explicitly introducing intermediate products. But the general linear model of production was not good enough to deal with the choice of activities as a cost-minimizing process, given the price vector and the quantities. Cost minimization had to be replaced by a condition according to which no activity could provide profits and no activity could suffer any losses in competitive equilibrium. This was exactly the condition used by Walras to initially define production equilibrium in a model with fixed production coefficients. This condition was first used in a general production model by Von Neumann (1937) and was called the Von Neumann law for production activities models.

Meanwhile an alternative productive sector model was being developed. This model emphasized producer organizations or firms rather than activities or technology. The equilibrium condition in the productive sector was that each firm maximized its profits, calculated as the value of the input–output combination over its production potential, given the input and output prices. This vision of production, specified in a partial equilibrium context by Cournot (1938), was implicit in the work of Marshall (1890) and Pareto (1909). It was further specified in a general equilibrium context by Hicks (1939) and especially in the Arrow and Debreu (1954) model.

The Arrow and Debreu's model (1954) is the one we can identify as the "first complete general equilibrium model". It formally demonstrated the existence of equilibrium with a productive sector formed by enterprises. Each enterprise had a set of production possibilities based on the resources it owned. The productive sector reached equilibrium when each enterprise chose the input–output combination of its set of technical possibilities that maximized profits at market prices. This was also the first model to directly include Walras-style preferences through demand-side hypotheses.

More or less simultaneously, McKenzie (1959) built another formal general equilibrium model. It formalized Walras' theory and used a linear production model. McKenzie proved the existence of equilibrium in this model through hypotheses made on demand functions rather than directly on preferences. It considered a linear technology instead of a set of enterprises. It was a generalized form of Wald's model (1951), omitting the structure of production, and the key hypothesis stated that demand functions satisfied the so-called "weak axiom of revealed preference".[1]

[1]For a full exposition of this axiom, see Wald (1951), pp. 370–379.

The spirit of static equilibrium analysis was to choose a time period that was short enough to avoid a big distortion of reality and suppose that all transactions would conclude within that period. This type of analysis had been developed by Walras, Hicks and Arrow–Debreu, although Arrow and Debreu explicitly dealt with inter-temporal planning, of both consumers and producers.

Walras' approach to static equilibrium was absolutely suitable only when everything remained constant: technology, tastes, resources and maybe even capital and population growth rates. Therefore, static comparisons had to be made as comparisons between the different stages.

Hicks (1939) considered the possibility of analysing equilibrium not from a static perspective, but, over time, assuming agents' present price expectations remained unchanged in the future.[2]

A number of authors tried to solve this problem. One was Radner (1972). His solution was to assume perfect forecasting, considering that all the agents had unchanged price expectations. Only a finite number of events could happen each time. From the point of view of the given market, the key events were the sequences of states of nature that could possibly occur over time. For each sequence, the agents correctly anticipated their corresponding price sequence. Rational expectations were implicit in this equilibrium model, where all agents had the same available information.

The trouble with this model, that is, admitting that the agents may behave differently from how they are expected to, has served other authors to demonstrate the non-existence of equilibrium; see, for example, Green (1977) and Kreps (1977).

Hick's model was naturally developed by Grandmont (1977), among others. Grandmont assigned each agent an expectation function that provided a distribution of probabilities on future prices and possibly other relevant variables as well. Therefore, assuming that each consumer had a criterion for choosing the optimum plan according to his or her expectations, the model would determine the excess demand as a function of current prices. Equilibrium would thus be reached if the market were cleared at the given prices.

Theorems on the existence of static equilibrium have been developed and demonstrated for many special cases, particularly for perfectly competitive economies where production is not taken into account and the number of periods is finite. The application of a fixed-point theorem (like the one developed by Brouwer)[3] completes the proof that a price system causes market clearing if every excess demand function equals zero. Despite these achievements, there are also some problems with this theory, as we will now see.

The most remarkable oversights in Walras' static equilibrium theory have been –and probably still are– the analysis of the demand for assets and saving for future consumption. For this reason, one of the main lines of general equilibrium theory development is the introduction of money. Money performs several economic

[2]This type of expectation is called "adaptive expectations" and is usually found in texts by Walras and Hicks.

[3]See, for example, Kehoe (1989), pp. 79–82.

functions, being a means of exchange, an asset or a numeraire. Authors such as Grandmont and Younes (1972) and Grandmont (1977) proved the existence of equilibrium in monetary models.

In order to prove monetary equilibrium, a hypothesis, similar to previous assumptions for the same purpose of limiting price expectations, like Green's conjecture (1973) was needed to prove the existence of a temporal equilibrium in non-monetary economies. The hypothesis was that, on a finite temporal horizon, the expected set of prices that resulted from all possible choices between current prices was assumed to be positive. Then, if all consumers had expectations that satisfied this and the previous model's hypotheses, a temporal equilibrium would also exist in this case.

This review of the main contributions to general equilibrium theory would not be complete without a reference to temporal equilibrium with infinite horizon. Let us remember that the Arrow–Debreu general equilibrium model (1954) had a finite number of periods, events and goods. The main objection to the finite number of goods constraint was that it required a finite horizon and there was no natural way to choose the end of the period.

Two types of models were developed to solve this problem, leading to an infinite number of goods. One model has an infinite number of living consumers. Each consumer could be considered a descendant of a series in an undefined future. This way, consumers living in the present period have an interest in the goods of all periods. This model is called an overlapping generation model. It was first proposed and analyzed by Samuelson (1958). Later on it was rigorously developed by Balasko et al. (1980) and by Wilson (1981).

The second model, introduced by Peleg and Yaari (1970), was a competitive general equilibrium model with a finite number of consumers and an infinite number of goods. Peleg and Yaari presented an exchange model without production. It was Bewley (1972) who produced a competitive general equilibrium model that included production with an infinite number of goods. It represented a generalized form of the existence theorem developed by McKenzie (1959) in the case of many goods, retaining the hypothesis of a finite number of goods.

We can conclude this review by saying that Walras' theory was the most complete and detailed general temporal equilibrium model ever developed. It is really remarkable in that it was also the first formal general equilibrium model. Walras was able to build a model that jointly determined money, production, saving level, capital goods and services prices and the interest rate. Obviously, the further developments summarized here added to and improved the original version.

2.3 From General Equilibrium Theory to Applied General Equilibrium

The step from the theoretical to the applied dimension took place between 1930 and 1940, when there was debate surrounding the feasibility of calculating Pareto optimal resource allocations for a socialist economy that was suitable for use by planners (see

Von Mises 1920; Hayek 1940; Robbins 1934; and Lange 1936). Leontief's *input–output analysis* was the next development (Leontief 1941). This was actually the most decisive step in the attempt to put Walras' theory on track towards an empirical dimension and to definitely align it with economic policy making.

Later on, the linear and non-linear planning models of the 1950s and 1960s, based on works by Kantorovitch (1939), Koopmans (1947) and others, were seen as an improvement of the input–output techniques through the introduction of optimization and as the first attempt to develop an applied general equilibrium.

In the 1950s, attention switched from a derivation of comparative statics to demonstrating the existence of equilibrium. Wald (1951) had already defended Walras' law and had provided the necessary proofs to demonstrate the existence of equilibrium. The use of differential calculus, topological analysis and the theory of convexity allowed authors like Arrow and Debreu (1954) and others to demonstrate the existence of equilibrium in very general models. The main mathematical tool that they used was, as mentioned earlier, Brouwer's fixed-point theorem.

Scarf (1973) developed a computational algorithm to find fixed points that satisfied the conditions of Brouwer's fixed-point theorem. This algorithm could be used to calculate equilibrium in economic models. Many of the first general equilibrium models used this algorithm for problem solving. Some of today's models are still based on that method, although faster variations developed by Merril (1971), Eaves (1974); Kuhn and McKinnon (1975), Van der Laan and Talman (1979) and Broadie (1983) are also used. Of these, Merril's variation is the one most often applied. Newton-type methods or local linearity techniques can be implemented as well. Even though convergence is not guaranteed, these methods can be as quick, if not quicker than Scarf's.

Another approach, implicit in the work of Harberger (1962), was to use a linearized equilibrium system to obtain an approximate equilibrium and, in some cases, to improve the initial estimator through multi-stage procedures so that approximation errors are eliminated. This method was also adopted by Johansen (1960), and improved by Dixon et al. (1982), de Melo and Robinson (1980), among others. It was they that developed the first applied general equilibrium models as such.

2.4 What Is an Applied General Equilibrium Model?

Reproducing the question posed by Shoven and Whalley (1984), we can say that an applied general equilibrium (AGE) or computable general equilibrium (CGE) model is an analytical representation of all the transactions in a given economy in such a way that it is possible to connect each element of the model with some observed empirical data.

The idea is to have an instrument that is capable of describing numerically how the economy behaves and reacts to different external shocks while being consistent with standard economic theory. As we will discuss later on, these models have been traditionally used to analyze the effects of changes in economic policies, such as the imposition of a tariff or quota on imported goods, the granting of export subsidies and income tax changes. They are equally useful for studying the impact of price rises or supply cuts of imported goods like petroleum, the effects of unexpected drops in the supply of goods or a greater regulation of the industrial sector, for example.

The basic elements of an applied general equilibrium model include the modelling of the behaviour of both consumers and producers, plus as many markets as factors, goods and services as are to be considered. Also, they usually account for the public sector, since one of the most common applications of this type of models is to evaluate certain public policies. In the next section we present a brief description of the main elements of a CGE model.

2.5 Main Elements of an Applied General Equilibrium Model

The first indispensable step in the process of clearly defining the problem to be analyzed is to choose the model's type, features and detail level. Analysing the impact of, say, income tax on households has nothing to do with examining the effects of a change in custom duties and tariffs on international trade although both of these events can be addressed in a general equilibrium setting. The first case would require a lot of details about the characteristics of domestic economies, as compared to the second case, where we would probably have to put more emphasis on the different productive sectors trading in foreign markets. Therefore, the type of problem we want to analyze will indicate the necessary degree of disaggregation and the economic sectors whose functions we must specify the most.

No matter what type of problem we set out to analyse, though, we must, in any modelling process, always bear in mind the following specifications:

- The number and type of goods (consumer goods, production goods, primary factors, etc.).
- The number and type of consumers (possibly classified by income, age, qualifications, tastes, etc.).
- The number and type of firms or productive sectors (simple or joint production; type of revenues of the production functions; technological development; etc.).
- The characteristics of the public sector (attitude of the government as demander or producer; fiscal system; budget, etc.).
- The characteristics of the foreign sector (related enterprises and sectors; degree of international integration; established tariffs and custom duties; etc.).
- Concept of equilibrium (with or without unemployment; with or without public and/or foreign deficit, etc.).

The choice of these specifications will output the particularities of the model to be used. On the other hand, the theoretical refinement of the model will also be affected by practical constraints such as information availability. In other words, an

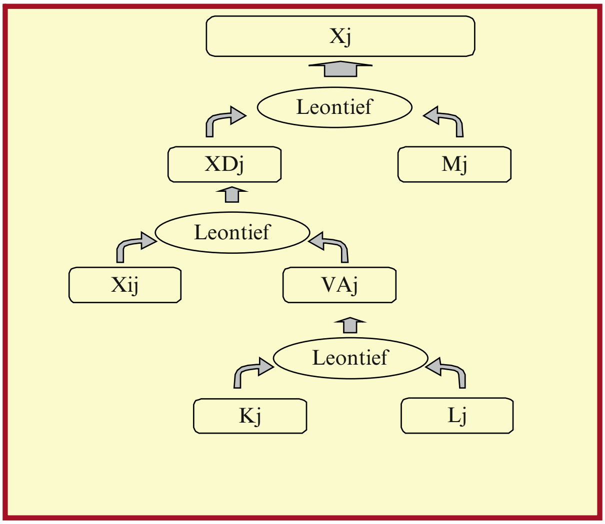

Fig. 2.1 Typical structure of a nested production function (Leontief technology)

applied general equilibrium model involves a trade-off between the researchers' intent to faithfully represent the economy's structure and the *ad hoc* constraints set by the available statistical information.

In the remainder of this section we present a discussion of all these elements.

Production: Production technology is usually represented by a so-called *nested production function*. Figure 2.1 shows a simple example of such a function. In this example, the domestic (or internal) production of sector *j* (denoted as *XDj*) uses production inputs, which typically include intermediate outputs from the other sectors (*Xij*) and primary factors (labour, *L*, and capital, *K*). Primary factors are combined using some production technology to provide the value added by each sector, VA_j. Total production Q_j is the result of combining domestic production Xd_j with imports, M_j, through a specific function usually conforming to Armington's (1969) hypothesis to simplify the analysis. This hypothesis considers that the analyzed country or economy is small enough as not to have an influence on foreign trade. In Fig. 2.1, Leontief-type technology is assumed to be used at all the nesting levels. Even so, this general structure allows for different production functions at each level. Producers are assumed to maximize their profits and this maximization results in supply functions of each good.

Public Sector: If we intend to undertake a study focused on policy making, the model should include some hypothesis about how the government makes such decisions. The government taxes economic transactions, thus collecting tax revenues and influencing the consumer's disposable income. It also makes transfers to the private sector and demands goods and services from different productive sectors *j*. The difference between its revenues and its outlays represents the balance (surplus or deficit) of the public budget *PB* according to the following identity:

$$\text{PB} = \text{Revenues} - \text{Public expenditures}, \tag{2.1}$$

where both income and expenditures are measured in monetary terms. Expenditure is the aggregation of (the nominal value of) public consumption and transfers made to the private sector. In the applications that we present in this book, the government activity (public expenditure and taxation) is perceived by economic agents as exogenous and by the government as decision variables.

Foreign Sector: In the model we will present in Chap. 5, the rest of the world is aggregated in a single foreign sector account. In principle, though, different accounts could be considered, for example, to represent trade with European countries and other foreign countries. Let us denote the foreign sector balance (deficit or surplus) by *ROWD*:

$$\text{ROWD} = \text{Imports} - \text{Exports} - \text{Net Transfers}. \tag{2.2}$$

If we are focusing on domestic issues and the foreign sector is not a key concern of the analysis, a common simplifying assumption (which we will adopt in our general equilibrium model) is to take the level of activity of the foreign sector as fixed. This is consistent with the small country hypothesis in the sense that the rest of the world is not affected by any domestic change introduced in our country.

Consumers: Final demand comes, first, from non-consumer demand sectors, investments and exports and, second, from household consumer goods demand. In general, there are *n* possible types of goods identified by their productive sectors, and there is usually one or more representative consumers (perhaps grouped by categories according to income source, income level, activity type, etc) who demand consumption goods. Each consumer has initial endowments and a set of preferences. The available consumer income not used for consumption is savings. The representative consumer's purchases are financed mainly by revenues from the sale of the initial factor endowments. The representative consumer's disposable income (*YDISP*) is calculated by adding up all capital and labour earnings, plus transfers received and minus the direct taxes for which his or she is liable:

$$\text{YDISP} = \text{Labour Income} + \text{Capital Income} + \text{Transfers} - \text{Direct Taxes} \tag{2.3}$$

The consumer's objective is to maximize some utility function, U, which depends on consumer goods CD_j and savings SD subject to the budget constraint:

$$\max U(CD_1, \ldots, CD_n, SD)$$

$$s.t. \sum_{j=1}^{n} p_j CD_j + invp \cdot SD = YDISP. \tag{2.4}$$

where n is the number of available goods, p_j denotes the price of consumption good j (j =1, .., n) and *invp* the price of investment goods. Demand functions are derived for each good from (4). Market demands are the result of adding up each consumer's individual demands. Note that market demands are price dependent and, they are also continuous, non-negative, homogeneous of zero degree and satisfy Walras' law.

Savings/Investment: The so-called *savings-driven models* are normally used for investment and savings. These are models on which the closure rule defines the behaviour of investment and that can tally the model's equation system depending on how investment is defined. Usually, investment is taken to be exogenous, savings are determined by the decision of the public sector, the foreign sector and of consumers to maximize their utility and deficits, and public sector and foreign sector investment are left to be determined endogenously according to the following accounting identity:

$$INV = PB + SD \cdot pinv + ROWD, \tag{2.5}$$

where *INV* is the aggregated nominal value of investment.

Input Markets: As for the inputs markets, labour and capital demands are calculated assuming that firms minimize the cost of producing value added. Concerning inputs supply, it is common to assume in the short term that total capital supply is inelastic (as we will do in the model presented in Chap. 5), although more complex specifications could also be used. Labour supply is normally a difficult element to deal with. One problem we face here is that CGE models are built on the assumption that all markets clear in equilibrium. On the other hand, one of the aims of applied work is to reproduce reality as closely as possible. This implies the recognition of unemployment. But such recognition is inconsistent with the equilibrium assumption, since unemployment means an excess supply of labour (and, hence, labour market imbalance). In Chap. 5 we will introduce a simple way to solve this problem.

Once all these elements have been specified, it is time to apply the equilibrium hypothesis. The idea is to assume that markets tend to equilibrium in the sense that supply equals demand in all markets as long as consumers and producers make optimal decisions. Solving the model means finding equilibrium, while allowing relative prices, productive sector activity levels (and perhaps public and foreign deficits) to operate as endogenous variables in equilibrium fitting. From a computational point of view, finding the equilibrium implies solving a system of equations. The complexity of this system is model dependent but must include, at least, the supply functions (one for each output and input), the demand functions, the market clearing conditions and all the relevant accounting identities.

The zero degree homogeneity of the demand functions and the linear homogeneity of profits in relation to the prices mean that only relative prices are significant; the level of absolute prices does not have any impact on the resulting equilibrium. Therefore, equilibrium is characterized by a set of relative prices and by certain production levels in each industry where market demand equals supply for all goods. The assumption that producers maximize their profits means that, in the case of constant scale revenues, no activity offers positive economic profits at market prices.

It is obvious that there is no just one general equilibrium model, but as many models as different combinations of decisions there are to be made (number of sectors, functional forms, etc). The choice of the specific functional forms usually depends on how elasticities are used in the model. The method most often applied is to select the functional form that best accounts for the key parameter values (like price and income elasticities) without damaging the model's feasibility. This is the key reason for perfectly identified functional forms, like Cobb–Douglas, constant elasticity of substitution (CSE), linear expenditure system (LES), Translog, Leontief's generalized and other flexible forms, being used.

2.6 Parameter Specification

Having solved the first problem (model specification), we now face the next obstacle of calculating the values of the parameters involved in the above functional relations, an essential step towards the use of this type of models for simulation purposes. A great deal has been written on the numeric specification procedures needed before calculating the model. We can divide the main ways of specifying these values into two groups: determinist calibration processes and econometric estimates.

2.6.1 Calibration Processes or Numeric Instrumentation

The most often used procedure is the so-called calibration method or numeric instrumentation.[4] We assume that the studied economy, empirically represented by a statistical database, is at an initial equilibrium, usually called "reference equilibrium". The model's parameters are then calculated so that the model reproduces the empirical data as an equilibrium solution for the model.

It is assumed that the reference data represent an equilibrium for the studied economy, and the required parameter values are then calculated using the agents' optimization conditions. If these conditions are not enough to identify the model, some of the parameter values –usually elasticities- are specified exogenously, until the model is identified. These values are normally based on existing databases and, every now and then, on additional estimates.

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[4]Work by Mansur and Whalley (1984) perfectly reflects the procedure called calibration. Meade and Stone (1957) researched the disaggregation of national accounts for sectorial surveys. Also St-Hilare and Whalley (1983) designed a database to develop a general equilibrium model.

In practice, the data used for calibration are taken from national accounts or provided by governmental institutions. These data (flows of goods, services and revenues for a specific or reference period) must be gathered and arranged so that they are operational. The most consistent way to do this is through a database known as the social accounting matrix (SAM). A SAM includes the data corresponding to the transactions between firms, consumers' initial endowments and the amounts of goods and consumer goods they demand, the sectorial decomposition of the value added for the different productive sectors, taxes and transfers between the government and private agents, the economy's transactions with the foreign sector, etc. Figure 2.2 shows the standard structure of a SAM.

A SAM database needs to be consistent, which means that it has to be compatible with the different statistical sources. This is not a trivial requirement since there are usually many inconsistencies across databases. For example, the value of gross domestic product (GDP) may not be the same in the national accounts as in the input–output tables; consumer expenditure in the national accounts may be different from the data provided by the input–output tables and the Household Budget Survey, etc. Compatibility of the information sources is achieved through hierarchization. Input–output tables are usually placed at the top of the hierarchy.

This calibration procedure has generated as much interest as criticism. The main pitfall is that it provides no statistical test of the model's specification since the calculation procedure is deterministic. This procedure with calibration processes is quite the opposite to econometric work that usually simplifies model structure to achieve greater richness in statistical terms. The pursuit of economic model perfection may have a negative impact on its statistical properties.

	PRODUCTION	***PRODUCTIVE FACTORS***	***INSTITUTIONAL SECTORS***	***CAPITAL***	***FOREIGN SECTOR***
PRODUCTION	*Intermediate consumption*		*Public sector and households consumption*	*Gross capital formation*	*Exports*
PRODUCTIVE SECTORS	*Value added payments to the factors*				
INSTITUTIONAL SECTORS	*Taxes on activities, goods and services*	*Revenue allocation from the factors to the institutional sectors*	*Current transfers between the institutional sectors*	*Taxes on capital goods*	*Transfers from the rest of the world*
CAPITAL		Consumption of fixed capital	*Savings of the institutional sectors*		*Foreign savings*
FOREIGN SECTOR	*Imports*		*Transfers to the rest of the world*		

Fig. 2.2 Standard structure of a social accounting matrix. *Source*: own elaboration

2.6.2 Econometric Estimates

An alternative way to specify parameter values in a general equilibrium model is through econometric estimation. Although this procedure is probably more common in economics, it is not the procedure generally adopted for applied general equilibrium models, where calibration is typically the norm.[5]

Despite the development of calculation methods to resolve non-linear general equilibrium models, especially in the aftermath of Scarf's research (1973), econometric methods[6] to estimate unknown parameters describing preferences in each model have not evolved at the same rate. Econometric estimations are not typically suitable for large-scale CGE models because this procedure requires a lot of calculations. On the other hand, econometric estimations are perfectly valid for some small-scale general equilibrium models.[7]

We can conclude that, even if the calibration method is less precise, it has the advantage of needing fewer data, observations and calculations. The econometric approach, although more powerful in terms of accuracy, is sometimes unfeasible due to the effort required to estimate all the parameters, each of which demands a great many observations. This is best summarized by Lau's statement:

> ...Thus, it is ideally suited (calibration) in which data are scarce and a quick answer is required. It is a useful shortcut for a modeller in a hurry.[8]

2.7 Benchmark Equilibrium

Once the functional forms of all the economic agents in the model have been defined and calibrated, we have to set the *benchmark equilibrium* or starting point equilibrium. The idea is to replicate the observed economy in such a way that the model reproduces a state of equilibrium where the supply and demand functions of all goods are obtained as the solution to utility and profit maximizing problems – see Fig. 2.3. The outcome will be a vector of goods and factor prices, levels of activity and tax revenues that satisfy the above conditions. Once the model has been calibrated, it can be used to simulate the effects of some proposed change, like a new policy to be implemented. The new equilibrium of the model can be seen as a

[5] Mansur and Whalley (1984). See also Jorgenson (1984).

[6] For a review of the main CGE models developed from stochastic estimates, see Jorgenson (1984).

[7] Mansur and Whalley (1984) discuss the estimates for a classic pure exchange economy, with or without production, and go on to then explain an estimation system for simple general equilibrium models.

[8] Lau (1984), p. 136.

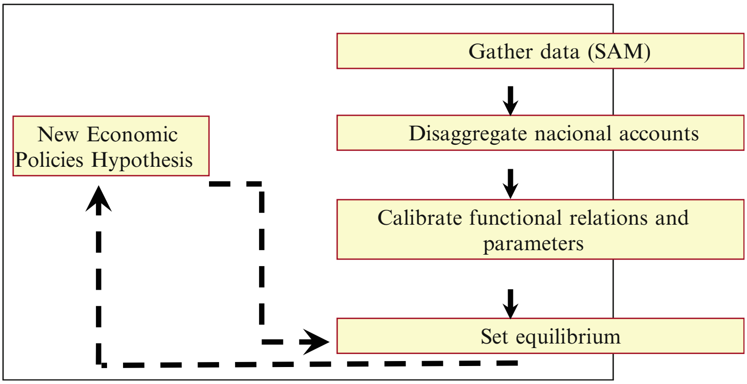

Fig. 2.3 Process of building an applied general equilibrium model. *Source*: own elaboration

prediction of the effect of this change on the most significant economic variables: prices, output levels, government revenues, and the new income distribution among the consumers.

Summing up, a general equilibrium models first establish the behaviour of a typical individual consumer, who, subject to physical and economic restrictions, aims to maximize his or her utility. The demand curves are thus determined for the different goods. Then, once all the individual demands of all goods have been aggregated, a market demand is obtained for each good, service or production factor. Afterwards the individual supplies of all firms are determined, assuming that they maximize their profits subject to technical and market constraints. And, finally, the individual supplies of each good are aggregated. Once the supplies and demands of each good have been obtained, we can investigate and find out if there is one or more prices on each market that equal aggregate supplies and demands. This will determine a price vector that will clear all the markets in the economy. Each agent will have obtained the individual demands and supplies to his or her maximum satisfaction, since the price vector is compatible with the decentralized decisions made by the agents. From this point of equilibrium, we will be ready to simulate and analyse the effects of the different policies applied. This outline of a general equilibrium model assumes, as is traditional, that the economy is modelled under the hypothesis of perfect competition. In Sect. 2.8g) we discuss some developments of related models under imperfect competition.

Standard *software* capable of completely fitting the data, calibration and equilibrium calculation sequence is available. GEMODEL, GEMPACK and, especially, GAMS, with all their different *solvers*, or problem-solving algorithms adapted to the different model necessities (database sizes; multiregional, dynamic or static models, etc.) are the most widespread. The problem nowadays is not so much a matter of resolving equilibrium as, as in other fields of economic theory, but collecting data in order to specify the parameters and finding economists with the skill to actually specify the model.

2.8 Main Applications of Applied General Equilibrium Models

One of the biggest strengths of general equilibrium models is their capacity to explain the consequences of major changes in a particular sector in relation to the economy as a whole. The consequences of a change in an economic policy are frequently analysed assuming that changes are small and using linear approaches based on relevant elasticity estimates. If the number of sectors is small, two-sector models can be used as in international trade theory. However, in a disaggregated model where several changes take place, there is no option but to resort to the construction of numerical general equilibrium models to study the economy.

A survey of the pioneering applications of general equilibrium modelling reveals the main areas where applied general equilibrium models have had a greater impact.

(a) Fiscal Policy Analysis

In the field of taxation, from the early two-sector models by Harberger (1962) and Shoven and Whalley (1977), we have moved on to modelling on a greater scale. (See Piggott and Whalley (1977) for Great Britain; Ballard et al. (1985) for the United States; Kehoe and Serra-Puche (1981) for Mexico; Keller (1980) for Holland and Piggott (1980) for Australia, among others.) This is the area where general equilibrium economic modelling has been more widely adapted and developed.

(b) Trade Policy Analysis

The analysis of general equilibrium applied to the study of trade policies has revolved around the issue of protectionism and its impact on economic efficiency and well-being. Trade models can be divided into two big groups. On the one hand, there are small economy models (closed economies), whose main characteristic is price endogeneity. On the other, there are large-scale economic models (open economies) that incorporate the assumption of price exogeneity in all trade goods.

Noteworthy, among others, are the global general equilibrium models developed by Deardorff and Stern (1986) and Whalley (1985b). They were used to evaluate political options in the GATT negotiation rounds. Dixon et al. (1982) attempted large-scale modelling in Australia. This has been used by governmental bodies to evaluate several commercial options in that country. Also, a group of models developed by the World Bank for different countries (Dervis et al. 1982) has provided information for decision-making processes in borrowing countries, as well as for trade liberalization options for several developing countries.

(c) Migratory Policy Analysis

Applied general equilibrium models are also used to study population movements. They may adopt a purely urban perspective, as King (1977) did, or a regional perspective, as was the case of Kehoe and Noyola's analysis (1991) of the Mexican economy. Kehoe and Noyola (1991) analysed the effects of alternative fiscal policies on emigration from rural to urban areas.

(d) Interregional Policy Analysis

These instruments have also analysed the impact of interregional policies. Take the work by Jones and Whalley (1986), for example. They developed a regional model for Canada that emphasizes issues related to partial labour mobility.

Serra-Puche (1984) developed a similar model for the Mexican economy, and Ginsburgh and Waelbroeck (1981) another for the Indian economy.

(e) Agricultural Policy Analysis

Good examples of general equilibrium models applied to the design of agricultural policies are the works by Keyzer and Wim (1994), who analysed food policies in Indonesia, or Parikh's treatise (1994) on Indian agrarian policies. Parikh (1994) focused on the public distribution system (PDS) according to which the government provides and offers some first necessity goods (rice, sugar, oil, flour and petrol) at below the market prices. Golden and Knudsen (1992) studied the effects of trade liberalization on agriculture.

(f) Stabilization Policy Analysis

The adverse external shocks experienced by most developed countries since the early 1980s, with falling exports, foreign trade losses, high interest rates and debt increments due to US dollar appreciation, led, together with the decrease of trade bank profits, to drastic adjustments. Subsequent adjustment programmes were designed mostly separately by the IMF and the World Bank.

Characteristically, these programmes placed an emphasis on both demand- and supply-side measures. Demand-size measures were to reduce short-term depressions, and supply-size polices provided for greater efficiency through structural adjustments. The two components of the strategy (stabilization and structural adjustment) were not separated, partly due to the dimension of the required adjustments.

Macromodels and standard general equilibrium models proved unsuitable for analysing the problem. The elevated aggregations of macromodels tend to consider the movement of resources between sectors and classes. On the other hand, money is neutral in standard general equilibrium models, and it only affects relative prices. There is no theoretically satisfactory way to study inflation, nominal wage rigidity or nominal exchange rate policies with traditional general equilibrium models. For this reason, some economists have developed so-called "general equilibrium financial models". They try to integrate money and financial assets into the multi-sector and multi-class structure of general equilibrium models. Despite these efforts, there is no consensus yet on the introduction of money and financial assets into general equilibrium theory. Authors like Lewis (1994), who studied the case of Turkey, and Fargeix and Sadoulet (1994) for Ecuador, have contributed to this line of study.

(g) Modelling Under Conditions of Imperfect Competition

The analysis of policies based on classical economic theory is underpinned by the hypothesis of an existing competitive equilibrium. We know that, in reality, competitive equilibrium does not always occur, and, consequently, there are monopolistic markets, oligopolies, monopolistic competitions, externalities, scale economies, etc. –in other words, markets with different degrees of imperfection.

Economists developing general equilibrium models have certainly not overlooked this reality and have tried to include this range of situations in their modelling. Take for example, Negishi's work (1961). Negishi (1961) first suggested that partial equilibrium analysis must be extended to general equilibrium analysis in the theory of monopolistic competition. Radner (1968) developed a general equilibrium model under conditions of uncertainty. Krugman (1979) studied a product differentiation model, trying to bring applied general equilibrium analysis closer to reality. Dixon (1987) analysed the possibility of imperfect competition within the macroeconomic framework of general equilibrium. Bonanno (1990) defended the development of a general equilibrium theory that included imperfect competition. De Melo and Roland-Holst (1994) studied South Korea's multi-sector general equilibrium model and examined if import tariffs and export subsidies in this model could be combined to promote the development of sectors with scale revenues and oligopolistic behaviours. Ginsburgh (1994) developed the model in a monopolistic scenario, and, finally, Brown et al. (1996) researched the existence of general equilibrium models for economies with incomplete assets markets.

(h) Inter-temporal Exchange Modelling

All the above analyses have one aspect in common: they take only the past and present into account for decision making. The resulting models are static. By dealing with exchange decisions inter-temporally, the models to move onto dynamic ground. Examples of such work are the writings by Benjamin (1994) on investment expectations in Bolivia, Cameroun and Indonesia; Blitzer et al. (1994) on the impact of restrictions on coal extraction in Egypt; Mercenier and Sampaïo de Souza (1994) on the structural adjustment of the Brazilian economy; and Berthelémy and Bourguignon (1994) on North–South-OPPP relationships.

(i) To Conclude. Some Recent Related Applications

This brief review of the origins of applied general equilibrium models has revealed one of the most important strengths of this approach. Indeed, AGE models are so versatile that they can be accommodated to a wide array of fields. Moreover, their use has spread to specific areas where there was no previous room for global analyses and where almost no formal works on impact measures had yet been developed. A presentation of the *state of the art* can be found in Kehoe et al. (2005).

One of the fields, particularly closed to our own research, in which CGE models have been successfully applied in recent times is environmental policy. Examples of environmental applications of CGE models include André et al. (2005), O'Ryan et al. (2005), Schafer and Jacoby (2005), Nijkamp et al. (2005), Kremers et al. (2002), Böhringer et al. (2006) or Springer (2003). The main methodological novelty of our work with respect to this literature is the combination of CGE models with multicriteria techniques.

2.9 Conclusions: Advantages and Disadvantages of Applied General Equilibrium Models

Despite the notable development of applied general equilibrium modelling over the last few years, this methodology is not without limitations. These limitations are due to its methodological basis –quite a common occurrence in economics and particularly inherent to any kind of modelling.

The main problem stems from the endemic difficulty of combining theory and reality. Applied general equilibrium models need an empirical basis for their calculation. This basis must reflect reality as faithfully as possible and at the same time be simple enough to be manageable. A list of the main problems with modelling follows[9]:

1. The model: choosing the model's functional forms, elasticity type, tax treatment, etc., is the first obstacle the researcher has to face when modelling a specific economy.
2. Disaggregation: the next problem is to disaggregate the model. Disaggregation and its degree of detail will give strength and credibility to the results of the simulation.
3. Data and parameter values: the model's data and parameters pose the next obstacle. In practice, it is not feasible to use econometric techniques to estimate the parameters that define the different functions in the model because so many estimates are needed. Models have been constructed with more than 20,000 parameters: it is an almost impossible task to estimate all of these parameters econometrically. The construction of a database that is consistent with reality (the so-called SAM) to later on define a general equilibrium that meets the conditions to be met by the model is the most frequently used technique. In some cases, it is complemented with econometrically estimated information. Although it may look like the easiest way to solve the problem, the construction of the SAM is by no means a simple exercise due to the great amount of statistical sources needed for its elaboration.
4. Model verification and validation: another important problem associated with this methodology is the lack of statistical tests to confirm the validity of the model specifications. Most general equilibrium models are calibrated from a database for a specific year. For this reason, except for simple tests to analyse the sensitivity of certain parameters included in the model, econometric procedures cannot be used to test the model's validity.
5. Transmission of the outcome: finally, there is an added problem with applied general equilibrium modelling. This problem has to do with the actual application rather than the construction of the model. The need to make the model as rich as possible contrasts with the simplicity required to explain the model to the people who are to use it for decision making, that is, the policy makers. This is a common obstacle with large-scale econometric models, and the effort to faithfully and easily convey the structure of the model becomes a sometimes unassumable challenge.

Everything that we have said so far leads to the conclusion that applied general equilibrium models are mostly discretionary, where it is the researcher that sets the model constraints and solutions during development. In contrast, their main

[9]See Whalley (1985b).

advantage is that they clearly bridge theoretical economic policy analysis and application. The present developmental lines of applied general equilibrium analysis cover[10]:

1. The reduction of model size by disaggregating precisely those sectors that are interesting for applied analysis. This means smaller and more specific models. Along these lines, the development of regional analyses appears to be one of the most important steps taken in the last few years.
2. The development of econometric general equilibrium models, where models define and estimate the behaviour of consumers or producers in a more complex way. This line of study analyses general equilibrium systems from the point of view of econometrics. Parameters will thus be more appropriately obtained and there will be more feasible chances of validating the models.
3. The definition of models so they can perceive gains or losses in well-being from the distortions generated in the model.

Finally, and apart from actual modelling, there is a line of action being developed that has to do with research group cooperation. The need to have a good command of general equilibrium theory, programming, databases, as well as to be familiar with parameter estimation, to have a sound knowledge of the range of taxation and institutional figures and to be able to interpret the results are forcing research efforts to focus on research groups that can cover all of these areas rather than on single researchers that develop the entire model from start to finish alone.

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[10]See Whalley (1985a).

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Chapter 3
Basic Aspects of the Multiple Criteria Decision Making Paradigm

Abstract In this chapter we present the basic elements of the second analytical tool that we use in our research: multiple criteria decision making (MCDM). It stresses the aspects most related to the design of public policies. MCDM has been designed to overcome two of the key limitations of the traditional approach: (1) the difficulty of characterizing preferences by a single criterion and (2) the fact that rigid constraints are not always a realistic representation of feasibility for decision makers. We start by introducing some basic concepts underlying the MCDM methodology, as well as a general distance function that provides a unifying framework for all the MCDM techniques that will be used in the book. The chapter focuses on continuous MCDM techniques, starting with the generation of efficient solutions by multiobjective programming. Then we introduce compromise programming, which aims at providing solutions with a minimal distance from the ideal point. The third approach is goal programming, which is based on a Simonian satisficing logic rather than on a conventional optimization logic. We also discuss the advantages and disadvantages of different MCDM approaches within a policy making context and give a brief historical overview of MCDM.

3.1 Introduction

This chapter addresses our second analytical research tool: multicriteria decision making (MCDM). The role of this tool in our framework is to provide a set of instruments for the policy makers to be able to formulate and solve decision problems in which the decision variables (in our case, the policy instruments) are chosen in an optimal way, where optimality is defined according to different conflicting criteria (in our case, the policy objectives).

Although this book targets researchers in economics and management science/ operational research (MS/OR) with a basic knowledge of MCDM, it also seeks to be a self-contained text. For this reason, we present the logical structure and operational basis of the most promising MCDM approaches for the design and

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assessment of economic and environmental policies. Although readers with a basic knowledge of MCDM can skip this part and go on directly to the next chapters, they are advised to skim through this material, chiefly to form an idea of some initial and intuitive connections between MCDM and the economic policies analysis field.

The structure of the chapter is as follows. In Sect. 3.2, we recall the basic elements of the traditional decision paradigm and discuss how this approach can be enriched by shifting to a MCDM framework. In Sect. 3.3 we introduce some fundamental concepts and definitions underlying the MCDM methodology. Section 3.4 presents a general distance function based upon a family of p-metrics. This function provides a unifying framework for all the MCDM techniques that will be used throughout this book. Section 3.5 discusses the generation of efficient solutions by means of the MCDM approach known as multiobjective programming. Section 3.6 introduces compromise programming. Compromise programming is a technique aimed at providing solutions with a minimal distance from the ideal point. Section 3.7 presents an alternative approach to the traditional optimizing view of decision making. This approach is based on a Simonian satisficing logic and is operationalized through goal programming. In Sect. 3.8 we discuss the advantages and disadvantages of different MCDM approaches. Section 3.9 gives a brief historical overview of MCDM developments. Finally, Sect. 3.10 presents some concluding remarks.

3.2 The Traditional Decision Paradigm and the MCDM Approach

The traditional general choice theory framework or paradigm has the following elements and characteristics:

(a) A decision maker (DM), that is, an individual or a group of individuals recognized as a single entity.
(b) The existence of limited resources, in other words, the classic economic idea of scarcity. Scarcity generates the constraints of the decision-making problem. The set of decision variable values meeting the constraints establish what is technically known as the feasible or opportunity set.
(c) A criterion function that reflects or is assumed to reflect the DM preferences, by attaching a number to each element of the feasible set.

Different mathematical techniques are used to arrive at the feasible point for which the criterion function achieves an optimum value (e.g. maximum profit, minimum cost, etc.). The feasible point represents the "best" or "optimum" solution. This type of protocol or paradigm underpins any decision-making problem defined in any disciplinary field. A few examples taken from economics will illustrate this idea.

In consumer theory, the opportunity set that determines the feasible baskets is defined by the budget constraint. In this case, the criterion function is given by the utility function that represents consumer preferences. Thus, the "optimum" solution is given by the feasible basket for which the utility function achieves a maximum value.

In production theory, the feasible or opportunity set is given by the production surface or technology of the underlying process. The point of the production surface achieving a maximum profit is the "optimum" production plan.

Within a mathematical programming framework, the classic logic of choice works in a similar direction. In this context, the feasible or opportunity set is in fact given by the value of the decision variables meeting the constraints of the problem. The "optimum" solution corresponds to the feasible point for which the objective function (i.e. the criterion function) achieves an optimum value.

In short, the traditional choice theory paradigm is logically quite sound and internally coherent. However, from the point of view of external coherence or empirical content, this theoretical framework has at least two important drawbacks that may deviate its functioning from actual decision-making processes. These two problems are:

1. In many real life economic or other situations, the DM preferences are not well defined by a single criterion but by a broad set of criteria of very different nature.
2. Defining the feasible or opportunity set by rigid constraints that rule out any type of violation is rather unrealistic. Indeed, in many cases some relaxation of certain constraints would not in fact seriously affect the quality of the solution, and could markedly improve the performance of the criterion function. In short, the violation of the right-hand side of a constraint is a weakness that should be penalized, but is not, generally, an impossibility.

The above considerations clearly show how DMs in many cases do not make their decisions based on a single criterion but rather on several different types of criteria. Also, economic "scarcity" is not well defined in real life by a set of absolutely inviolable constraints. For these reasons, management science/operational research researchers have developed over the last 40 years an alternative decision-making paradigm in order to more accurately account for the reality of the decision-making processes. This paradigm has been named multiple criteria decision making (MCDM). This chapter outlines the main features of this paradigm, emphasizing those aspects most related to the design of public policies. MCDM will be the groundwork for the basic purpose of this book: the proposal of operational methods for the joint design of economic and environmental policies.

3.3 Some Basic Concepts and Definitions

Before we explore the logical and analytical aspects of the MCDM paradigm, readers need to understand the following concepts and definitions.

3.3.1 Attributes

This concept refers to the DM's values regarding some decision-making problem. These can be measured independently of the DM's desires (objectivity condition) and can, in many cases, be expressed as a mathematical function of the underlying decision variables. For example, the inflation rate, the economic growth rate or the unemployment rate can be seen as attributes of economic policy design, whereas pollutant emissions is an example of an attribute within the context of an environmental policy.

3.3.2 Objectives

They represent directions for improving the attributes under consideration. There are two directions for improvement. One can be interpreted as "more is better" and implies a maximization process; the other can be interpreted as "less is better" and implies a minimization process. Minimize the inflation rate or SO_2 emissions or maximize economic growth are typical examples of objectives within a public policy context.

3.3.3 Aspiration Levels or Targets

They represent an intermediate concept on the way to defining what a goal is. Aspiration levels or targets are acceptable levels of attainment for any of the attributes considered by the DM. In other words, they are figures that the DM considers satisfactory and sufficient; that is, in Simonian terms, "satisficing" figures.

3.3.4 Goals

Combining an attribute with a target, the concept we get is a goal. Thus, if a government wants an economic policy to yield an economic growth of at least 3%, we have a goal. At this point, it is necessary to establish the difference between traditional constraints and goals. From a mathematical point of view both are inequalities. The difference lies in the meaning attached to the right-hand side of the respective inequalities. If we are speaking about constraints, the right-hand sides must necessarily hold, otherwise we get infeasible solutions, whereas, in the case of goals, the right-hand sides represent DM desires or aspirations that may or may not be achieved. The concept of goal and its link with the Simonian "satisficing" logic will de clarified in Sect. 3.7 of this chapter presenting the goal programming approach.

3.3.5 Criterion

This term comprises the above three concepts, that is, the attributes, objectives and goals of a DM for a particular decision-making problem. Therefore, the term MCDM refers to the general framework or paradigm for analysing decision-making problems involving different attributes, objectives and goals.

Let us specify the above ideas with the help of a simple example. Within an economic policy context, economic growth is an attribute, economic growth maximization is an objective and the attainment of an economic growth of at least 3% is a goal. Also, whatever the type of problem addressed, economic growth is an economic policy design criterion.

In mathematical terms, an attribute can be represented as a function of the vector $\boldsymbol{X}$ of decision variables, that is,

$$f(X).$$

An objective will be represented by the maximization or the minimization of the above function, that is,

$$\text{Max} f(X) \text{ or } \text{Min} f(X).$$

Finally, a goal corresponding to the achievement of a target $\hat{f}$ is represented as

$$f(X) + n - p = \hat{f},$$

where n is called the negative deviation variable, i.e. the quantification of the under-achievement of the goal, and p is the positive deviation variable, i.e. the quantification of the over-achievement of the goal. The meaning and primary role of goals and deviation variables will be explained in detail in Sect. 3.7 of this chapter.

3.3.6 Pareto Optimality

This concept has been fruitfully transferred from economics to MCDM by simply substituting the criterion entity (MCDM) for the person entity (economics). Therefore, the Pareto efficient or optimal solutions are feasible solutions such as no other feasible solution can perform equally or better for all the criteria under consideration and be strictly better for at least one criterion. In short, a Pareto optimal solution is a feasible solution for which an improvement in the value of one criterion can only be achieved by degrading the value of at least one other criterion. For instance, increasing economic growth may imply increasing SO_2 emissions. Obviously, all the MCDM techniques aim to obtain solutions that are at least optimal in the Paretian sense defined above.

3.3.7 Trade-Offs Among Criteria

The idea of Pareto optimality leads to the concept of trade-offs between two criteria. This concept measures what level of achievement of one criterion has to be sacrificed in order to gain a unit improvement in the other criterion. Trade-offs are good indicators for measuring the opportunity cost of one criterion in terms of another one. Also, these figures are crucial for the design and evaluation of any economic and environmental policy. The MCDM method known as multiobjective programming, which is presented in Sect. 3.5 of this chapter, can, to some extent, be considered as a procedure for determining or approximating the trade-off surfaces among criteria.

3.3.8 Payoff Matrix

The elements of this matrix are obtained by optimizing each of the objectives separately and then computing the value of each objective at each of the optimal solutions. Hence, this is a square matrix with a dimension equal to the number of criteria under consideration. The payoff matrix is a useful device, since it reports how much conflict there is between the objectives under consideration. The elements of the main diagonal of this matrix are referred as the "ideal point", since they represent the optimum values for all the objectives. The worst element of each column of the payoff matrix is called the "anti-ideal point". The "ideal point" and the "anti-ideal point" will play an essential role as reference points in the compromise programming approach to be presented in Sect. 3.6.

3.4 A General Distance Function Based Upon a Family of *p*-Metrics

The purpose of this section is to find a common root for the different MCDM approaches that will be used throughout the book. We will show how all the approaches to be used can be thought of as a special case of the following distance function model (Romero 1985):

$$Min \left[\sum_{i=1}^{q} W_i^p \left| \frac{\hat{f}_i - f_i(X)}{K_i} \right|^p \right]^{1/p} \tag{3.1}$$
$$s.t.\ X \in F,$$

where:

$i = 1 \ldots, q$ represents the set of criteria involved in the decision-making process.

$f_i(\boldsymbol{X})$ = mathematical expression of the ith criterion as a function of a vector of decision variables.

$\hat{f}_i$ = aspiration level or target for the ith criterion.

f_i^* = ideal value for the ith criterion, that is, the value achieved when the ith criterion is optimized, without considering the other criteria (e.g. elements of the main diagonal of the respective payoff matrix).

f_{i*} = anti-ideal value for the ith criterion, that is, the value achieved by the ith criterion when the other q−1 criteria are optimized without considering the ith criterion (e.g. worst value for each column of the payoff matrix).

K_i = normalizer factor attached to the ith criterion, for instance, the range for each criterion (i.e. $K_i = f_i^* - f_{i*}$).

p = metric characterizing the distance function, that is, a real number belonging to the interval $[1,\infty]$.

$\boldsymbol{F}$ = feasible set.

W_i = weighting parameter that represents the importance of the *i-th* criterion.

The type of distance function model (3.1) was introduced in the MS/OR literature by Yu in 1973. Yu demonstrated that the solutions obtained by minimizing (3.1) have useful economic and mathematical properties, such as feasibility, uniqueness, symmetry, etc. Before going any further, note the following points about (3.1). First, without loss of generality, it has been assumed that all the criteria are of the "more is better" type, that is, the corresponding objective functions are maximized. However, if there were criteria of the "less is better" type, multiplying the mathematical expression of the respective attribute by minus one maintains the monotone decreasingness of (3.1). Second, in most real scenarios, criteria are measured in different units and normally they have very different absolute values. For this reason, the criteria should be normalized. This is done in model (3.1) with the help of a normalizer factor K_i. Finally, notice that (3.1) is a general-purpose model, but can be straightforwardly interpreted in terms of economic policy. Thus, $f_i(\boldsymbol{X})$ will represent the generic ith policy criterion, and $\boldsymbol{X}$ the vector of policy variables.

Metric p plays a key role. Yu (1973) demonstrates that metric p in the context of distance function (3.1) acts as a "balancing factor" between the maximum average achievement of all the criteria (that is, for $p = 1$) and the maximum discrepancy or individual regret (that is, for $p = \infty$). Thus, for $p = \infty$, only the maximum deviation counts, and then model (3.1) is structured as follows:

$$\begin{aligned} & Min\ D \\ & s.t \\ & W_i \left| \frac{\hat{f}_i - f_i(X)}{K_i} \right| - D \leq 0 \quad \forall i \\ & X \in F, \end{aligned} \tag{3.2}$$

where D represents the maximum deviation.

As the p-metric is so crucial, it is tempting to calculate model (3.1) for different values of the metric. In this way, different solutions can be obtained by trading off the maximum average achievement against the maximum discrepancy. However, this type of strategy implies very serious computational difficulties, as expression (3.1) is not smooth. Because of these serious computational problems, a similar (albeit, in general, not equivalent) model to distance function (3.1) has been proposed. This alternative offers a relatively easy way to trade off average achievement against maximum discrepancy. The structure of this new model is

$$\begin{aligned} & Min (1-\lambda) D + \lambda \sum_{i=1}^{q} W_i \left| \frac{\hat{f}_i - f_i(X)}{K_i} \right| \\ & s.t. \\ & W_i \left| \frac{\hat{f}_i - f_i(X)}{K_i} \right| - D \leq 0 \quad \forall i \\ & X \in F \quad \lambda[0,1], \end{aligned} \tag{3.3}$$

where λ is a control parameter. With λ = 1, we get the solution of maximum aggregated achievement for metric $p = 1$. With λ = 0, we get the solution of minimum discrepancy or minimum regret for metric $p = \infty$. With intermediate values of control parameter λ, we get compromises or trade-offs between these two opposite poles (maximum aggregated achievement and minimum disagreement), if they exist. Note that model (3.3) is still non-smooth due to the existence of absolute values. Nevertheless, it is written now in a more convenient way and, based on this specification, we will be able to derive in the next sections several formulations easy to compute.

3.5 Multiobjective Programming: The Generation of the Pareto Frontier

Multiobjective programming (MOP), also called vectorial optimization, comes up against the problem of simultaneously optimizing a set of objectives subject to a set of constraints. It is impossible to simultaneously optimize all the objectives unless all the objectives are complementary. In this case, we have a single- rather than multiple-criteria problem. For this reason, MOP tries to establish or approximate the set of Pareto efficient solutions in the sense defined in Sect. 3.3. Formally, a MOP problem has the following structure:

$$Eff(X) = \left[f_1(X), \ldots, f_i(X), \ldots, f_q(X) \right], \tag{3.4}$$

where *Eff* means the search for the Pareto efficient solutions to a maximizing or minimizing problem.

There are several procedures for tackling problem (3.4), that is, for determining the Pareto efficient set or frontier. One of the most operational and fitting procedures, known as the weighting method, can be straightforwardly derived from model (3.1). Thus, the substitutes in (3.1) $p = 1, \hat{f}_i = f_i^*$, and $W_i/K_i = \alpha_i$, α_i being an arbitrary parameter without preferential or normalizing meaning, we have

$$\begin{aligned} & Min \sum_{i=1}^{q} \alpha_i (f_i^* - f_i(X)) \\ & s.t.\ X \in F. \end{aligned} \tag{3.5}$$

It is obvious that model (3.5) is tantamount to

$$\begin{aligned} & Max \sum_{i=1}^{q} \alpha_i f_i(X) \\ & s.t.\ X \in F. \end{aligned} \tag{3.6}$$

Model (3.6) represents what is known as the weighting method for generating Pareto efficient set of solutions (see, e.g. Cohon 1978, Chap. 6). In fact, it is demonstrated that if parameters α take non-negative values ($\boldsymbol{\alpha} > \mathbf{0}$), then different points of the Pareto efficient set or frontier can be obtained by modifying the value of parameters α. In short, for each set of values of these parameters, model (3.6) provides an extreme (corner) efficient point.

There are other methods for determining the Pareto efficient frontier, like the constraint or the multicriteria simplex method. The constraint method can be considered as a sort of dual of the weighting method (Cohon 1978, Chap. 6). The multicriteria simplex method finds all the extreme (corner) points by moving from one extreme point to an adjacent point by a simplex "pivoting" operation. This method is theoretically appealing, but requires an enormous amount of computer time, and is, consequently, of very limited practical interest (Evans and Steuer 1973; Steuer 1995).

The computational burden of the weighting method and the constraint method is not as big as that of the multicriteria simplex method, but it is not negligible either. Thus, the implementation of the weighting method requires R^{q-1} computer runs of the respective model, q being the number of objectives and R the number of values for the parameters $\boldsymbol{\alpha}$.

For the reasons discussed above, MOP is a very useful device for determining the Pareto efficient frontier for problems with two or three objectives. However, for higher dimension decision-making problems, MOP can only obtain rough approximations of the Pareto frontier. Within the context of some problems related to the design of public policies, the number of objectives under consideration is very limited (two or three). As we will see in Chaps. 5 and 6, MOP is a powerful tool for determining the Pareto frontier in such applications.

3.6 Compromise Programming: Approximation to an Ideal Solution

Compromise programming (CP) was proposed by Yu (1973) and Zeleny (1973, 1974). See also Yu (1985). This MCDM approach is underpinned by the following axiom of choice:

Alternatives that are closer to the ideal are preferred to those that are farther. To be as close as possible to the perceived ideal is the rationale of human choice. (Zeleny 1973, p. 174).

This axiom could be formally stated as

$$f^1 \mathbf{P}\, \mathrm{f}^2 \Leftrightarrow D\left(f^1, f^*\right) < D\left(f^2, f^*\right)$$

$$f^1 \mathbf{I}\, \mathrm{f}^2 \Leftrightarrow D\left(f^1, f^*\right) = D\left(f^2, f^*\right),$$

where **P** and **I** are the traditional preference and indifference relations, and $D(f^i, f^*)$ measures the topological distance (i.e. according to a given metric) between solution f^i and the ideal point f^*. In short, CP aims to establish the efficient point or the portion of the Pareto efficient frontier nearest to the ideal point. Let us now look at how a general CP model can be straightforwardly derived from the general model (3.1) by implementing some simple parameter specifications. Thus, substituting $\hat{f}_i = f_i^*$, and $K_i = f_i^* - f_{i*}$ in (3.1), we have

$$\begin{aligned} & Min \left[\sum_{i=1}^{q} W_i^p \left(\frac{f_i^* - f_i(X)}{f_i^* - f_{i*}} \right)^p \right]^{1/p} \\ & s.t.\ X \in F. \end{aligned} \tag{3.7}$$

Model (3.7) is a classic CP formulation. Note that the absolute value sign of (3.1) has been eliminated, since $f_i^* \geq f_i\,(\boldsymbol{X})$ for every i, as f_i^* is the ideal value. Two particular cases of (3.7) are especially relevant. For $p = 1$, model (3.7) becomes

$$\begin{aligned} & L_1 = Min \sum_{i=1}^{q} W_i \frac{f_i^* - f_i(X)}{f_i^* - f_{i*}} \\ & s.t.\ X \in F. \end{aligned} \tag{3.8}$$

For $p = \infty$, the general CP model (3.7) or model (3.1) for the above parameter specifications (i.e. $\hat{f}_i = f_i^*$, and $K_i = f_i^* - f_{i*}$) becomes the following optimization problem:

$$\begin{aligned} & \mathrm{L}_\infty = \mathrm{Min}\, D \\ & s.t \\ & W_i \frac{f_i^* - f_i(X)}{f_i^* - f_{i*}} - D \leq 0 \quad \forall i \\ & X \in F. \end{aligned} \tag{3.9}$$

L_1 and L_∞ optima represent two best compromise solutions. L_1 corresponds to the efficient point nearest to the ideal for metric $p = 1$ and implies a minimum average disagreement (see Sect. 3.3), whereas L_∞ corresponds to the efficient point nearest to the ideal for metric $p = \infty$ and implies the minimum maximum disagreement (see Sect. 3.4).

To calculate other best compromise solutions, we would, on the face of it, need to solve model (3.7) for values of metric p belonging to the open interval $(1, \infty)$. This entails the use of complex non-linear algorithms. However, this is not necessary in practice. In fact, Yu (1973) demonstrated that for two-criteria problems best compromises L_1 and L_∞ define a subset of the Pareto efficient frontier, known as the compromise set. The other best compromise solutions fall between the L_1 and L_∞ solutions. In short, solutions provided by models (3.8) and (3.9) are enough to establish the bounds of the compromise set for two-criteria problems. Moreover, Ballestero and Romero (1991) demonstrated that under very general conditions, again within a two-criteria context, the unknown utility optimum lies within the bounds of the compromise set. In conclusion, the CP model has very good properties for two criteria and, as such, will be extensively used in the following chapters. It should also be noted that although these nice properties do not hold for scenarios involving more than two criteria, solutions L_1 and L_∞ do bound the compromise set under very general conditions. These conditions basically require a convex feasible set limited by a differentiable hypersurface (Blasco et al. 1999). Such conditions usually hold in any economic scenario generally and economic policy situation in particular.

Note also that if we want to trade off solution L_1 against L_∞, we can resort to a formulation such as is proposed by model (3.3).Thus, this model within a CP context (i.e. $\hat{f}_{\mathrm{i}} = f_i^*$, and $K_i = f_i^* - f_{i*}$) becomes

$$\begin{aligned}
& Min(1-\lambda)D + \lambda \sum_{i=1}^{q} W_i\left(\frac{f_i^* - f_i(X)}{f_i^* - f_{i*}}\right) \\
& s.t. \\
& W_i\left(\frac{f_i^* - f_i(X)}{f_i^* - f_{i*}}\right) - D \leq 0 \quad \forall i \\
& X \in F \quad \lambda[0, 1].
\end{aligned} \tag{3.10}$$

Compared with model (3.7), model (3.10) is much easier to compute. In fact, if the mathematical structure of the q objectives considered is linear, then model (3.10) implies a linear programming formulation. For this reason, it is tempting to resort to model (3.10) instead of model (3.7) to trace out the compromise set. However, André and Romero (2008) have demonstrated that, although both formulations are seemingly similar, the actual equivalence only holds for two-criteria cases when the Pareto frontier is differentiable. Therefore, the solutions provided by both models are generally different. Despite of that, model (3.10) is a straightforward procedure for quantifying the trade-offs between minimum average disagreement and minimum maximum disagreement. This is very useful within an economic policy context, as we will see in the following chapters, especially within an environmental context.

3.7 Satisficing Logic and Goal Programming

The MOP and CP approaches work very well for problems of moderate size, involving two or three criteria. However, when we are dealing with the joint design of economic and environmental policies, the number of constraints, decision variables and especially criteria could be very large. For this type of scenario, and for pragmatic reasons, MOP and CP should give way to other MCDM approaches like goal programming (GP).

Charnes et al. (1955) and Charnes and Cooper (1961) developed the embryo of GP. GP was initially devised for addressing "constrained regression" problems, as well as for dealing with constraint incompatibilities within a linear programming context. Later on, GP was developed as a powerful and flexible decision-making tool for addressing MCDM problems.

Like any other decision-making approach, GP can be underpinned by different philosophies. Given the type of problems analysed in this book, perhaps the most fruitful philosophical underpinning for GP is Simonian "satisficing" logic (Simon 1956; Ignizio 1976). From an analytical point of view, a satisficing philosophy within a GP context implies that DM behaviour is explained by the minimization of the non-achievement of the respective "satisficing" goals. A general setting for a GP model can be derived from model (3.1). Thus, we introduce the following change of variables in model (3.1) (see Charnes and Cooper 1977):

$$n_i = \frac{1}{2}\left[\left|\hat{f}_i - f_i(X)\right| + (\hat{f}_i - f_i(X)\right] \tag{3.11}$$

$$p_i = \frac{1}{2}\left[\left|\hat{f}_i - f_i(X)\right| - (\hat{f}_i - f_i(X)\right]. \tag{3.12}$$

By adding (3.11) and (3.12), and by subtracting (3.12) from (3.11), we have

$$n_i + p_i = \left|\hat{f}_i - f_i(X)\right| \tag{3.13}$$

$$n_i - p_i = \hat{f}_i - f_i(X). \tag{3.14}$$

Therefore, according to (3.13) and (3.14), general model (3.1) is structured as follows:

$$Min \left[\sum_{i=1}^{q} W_i^p \left(\frac{n_i + p_i}{K_i}\right)^p\right]^{1/p} \tag{3.15}$$

$$s.t.$$

$$f_i(x) + n_i - p_i = \hat{f}_i \quad \forall i$$

$$n \geq 0,\ p \geq 0$$

$$X \in F.$$

Model (3.15) is an Archimedean GP formulation. Normally, the objective function of the model in a GP context is called the achievement function. Note that, when the ith goal derives from a "more is better" attribute, deviation variable n_i is unwanted and deviation variable p_i is wanted, hence only variable n_i appears in the achievement function. On the contrary, when the ith goal derives from a "less is better" attribute, n_i is wanted and p_i unwanted, then only deviation variable p_i appears in the achievement function. Finally, the DM wants neither under-achievement nor over-achievement, both deviation variables must appear in the achievement function.

Several GP variants can be obtained for different values of metric p. Thus, for $p = 1$, model (3.15) becomes

Achievement function:

$$\begin{aligned} & Min \left[\sum_{i=1}^{q} W_i \left(\frac{n_i + p_i}{K_i} \right) \right] \\ & s.t. \\ & f_i(x) + n_i - p_i = \hat{f}_i \quad \forall i \\ & n \geq 0, p \geq 0 \\ & X \in F. \end{aligned} \tag{3.16}$$

Model (3.16) is referred to as weighted GP, since it minimizes a weighted sum of the unwanted deviation variables. It is easy to check that the maximization of a separable additive utility function in the q goals considered underlies this GP variant (Romero 2001).

By setting $p = \infty$ in (3.15), the model becomes the following optimization problem (Romero 1991):

Achievement function:

$$\begin{aligned} & \text{Min}\, D \\ & s.t. \\ & W_i \left(\frac{n_i + p_i}{K_i} \right) - D \leq 0 \quad \forall i \\ & f_i(x) + n_i - p_i = \hat{f}_i \quad \forall i \\ & n \geq 0, p \geq 0 \\ & X \in F. \end{aligned} \tag{3.17}$$

Model (3.17) is referred to as the MINMAX (or Chebyshev) GP model, minimizing the discrepancy D of the most displaced goal with respect to its target. The philosophy underlying this GP variant is the maximization of a MINMAX utility function that minimizes the maximum deviation (Tamiz et al. 1998).

From a utility perspective, the WGP and Chebyshev solutions given by models (3.16) and (3.17) can be said to represent two opposite poles. Thus, the WGP solution provides the maximum aggregate achievement (*maximum efficiency*), while the Chebyshev option provides the most balanced solution between the achievement of different goals (*maximum equity*). The first solution (WGP pole) can be extremely biased towards or against the achievement of some of the goals, whereas the second (Chebyshev pole) can provide poor aggregate performance across the different goals.

Obviously, there is a clear preferential link between the WGP model given by (3.16) and the model providing the L_1 bound of the compromise set given by (3.8). In the same way, there is a strong preferential link between the Chebyshev GP model given by (3.17) and the model providing the L_∞ bound of the compromise set given by (3.9). Hence, it is worthwhile looking for a formulation similar to model (3.10) able to trade off aggregate achievement against balanced achievement within a GP context. We can undertake this task by establishing a linear convex combination of models (3.16) and (3.17) or, equivalently, by implementing the change of variables (3.11) and (3.12) in model (3.10). Either way, we arrive at the following formulation known as Extended GP (Romero 2004):

Achievement function.

$$
\begin{aligned}
& Min(1-\lambda)D + \lambda\left[\sum_{i=1}^{q} W_i\left(\frac{n_i+p_i}{K_i}\right)\right] \\
& s.t. \\
& W_i\left(\frac{n_i+p_i}{K_i}\right) - D \leq 0 \quad \forall i \\
& f_i(x) + n_i - p_i = \hat{f}_i \\
& n \geq 0, p \geq 0 \\
& X \in F.
\end{aligned}
\tag{3.18}
$$

Control parameter λ plays a similar role as in model (3.10). Thus, if $\lambda = 1$, we obtain a WGP model, whereas, the Chebyshev GP model is reproduced for $\lambda = 0$. In short, control parameter λ weights the importance attached to the minimization of the weighted sum of unwanted deviation variables. For values of control parameter λ belonging to the open interval (0,1), we get intermediate solutions between the two GP options considered, if they exist. In short, model (3.18) again trades off aggregate achievement against balanced achievement, now within a GP context.

Let us now introduce the last GP variant applicable to the design of economic and environmental policies. This variant is called lexicographic GP (LGP). The achievement function of a LGP model is made up of an ordered vector whose dimension is equal to the Q number of pre-emptive priority levels defined in the model. Each component of this vector comprises the unwanted deviation variables of the goals placed at the corresponding priority level. Thus, we have (Lee 1972; Ignizio and Perlis 1979):

Achievement function:

$$\text{Lex min a} = \left[\sum_{i\in h_1} W_i(\frac{n_i+p_i}{K_i}),\ldots,\sum_{i\in h_r} W_i(\frac{n_i+p_i}{K_i}),\ldots.,\sum_{i\in hQ} W_i(\frac{n_i+p_i}{K_i})\right]$$
$$s.t.$$
$$n \geq 0 p \geq 0$$
$$X \in F, \tag{3.19}$$

where h_r means the index set of goals placed at the rth priority level.

We seek to find the lexicographic minimum of vector **a**, that is, the ordered minimization of its components. So, the first component of **a** is minimized, then the second component of **a** is minimized subject to the non-degradation of the minimum value of the first component obtained previously and so on. Note that a LGP model implies a non-compensatory preference structure in the sense that there are no finite trade-offs among goals placed at different priority levels (Debreu 1959, pp. 72–73). This type of assumption is actually very strong, but also useful when we are mixing economic with key environmental criteria, as we will see in Chap. 8.

GP is a flexible and pragmatic approach, especially suitable for addressing complex decision-making problems. However, when GP is applied mechanically, some bad and unexpected results can be obtained. This problem is known as "critical issues in GP" (Romero 1991). These critical issues should be addressed properly in order to avoid poor modelling practices. A thorough analysis of this problem is beyond the scope of this chapter. However, the critical issue related to the possible non-efficiency of a GP solution is of crucial importance especially given the purpose of this book. Let us introduce the basic aspects of this problem.

A standard GP formulation can produce inefficient solutions, which is totally undesirable. In the 1980s, this led to serious arguments against this approach. However, these criticisms were simply making a mountain out of a molehill. It has in fact been demonstrated how GP models can, through minor refinements of the approach, assure the generation of efficient solutions.

Hannan (1980) proposed a test to check whether or not a GP solution is efficient. The method can also establish the whole set of GP efficient solutions. Masud and Hwang (1981) demonstrated that, in order to assure efficiency, it is enough to add an additional priority level to the GP model's achievement function, maximizing the sum of the wanted deviation variables. Tamiz and Jones (1996) proposed a very general procedure for distinguishing the efficient from the non-efficient goals. This procedure can also restore the efficiency of the goals detected as non-efficient. Caballero et al. (1996) developed procedures for generating efficient GP solutions for non-linear and convex models. Finally, Tamiz et al. (1999) extended the issue of efficiency to integer and binary GP models.

In conclusion, the GP model's potential for generating an inefficient solution is not a real problem nowadays, since modern GP approaches can quite easily find a way to solve this type of problem.

3.8 Is There a Best MCDM Method for Economic Policy Design?

Having discussed a number of MCDM approaches, one might wonder what the best MCDM method is. There is no easy answer to this question, because, as shown below, each method has its strengths and weaknesses.

Let us start by evaluating the different MCDM methods in terms of computational burden. In this respect, GP is the most efficient as it requires a single "computer run". On the contrary, within a MOP context, the approximation of the efficient set by any generating technique requires a number of "computer runs" that grows almost exponentially with the number of objectives involved. In CP, and for two-criteria cases, only two mathematical programming models (one for the $p = 1$ metric and the other for the $p = \infty$ metric) have to be solved to obtain the bounds of the compromise set. However, this strategy implies ignoring the remainder of the efficient set, and this can lead to an important loss of information.

Let us now evaluate the different MCDM methods in terms of the amount of information and precision required from the DM. In this respect, GP is the least attractive approach. In fact, within GP, the DM has to provide precise target values, weights, pre-emptive ordering of preferences, etc. In this respect, MOP is at the opposite end of the scale, as no knowledge of the DM's preferences is required to build the model. In CP, we only need information on the weights attached to the discrepancies between each criterion and their ideal values in order to approximate the compromise sets for different values of metric p.

Finally, looking at the information that the model provides to the DM, GP with only a single solution is clearly worse than the other techniques. Although a post-optimality sensitivity analysis can mitigate this problem, the fact remains that GP provides rather meager information compared with either MOP or CP.

The efficient set generated by MOP models provides very useful information for analysing any decision-making problem. In fact, this set represents the transformation curve or production possibility frontier for the objectives under consideration. This MOP strength is especially noteworthy when there are only two objectives. In this case, the transformation curve can be shown graphically. However, moderate size MOP problems can generate an enormous number of extreme efficient points. Indeed, Steuer (1994) reports results from a simulation of MOP problems where models with 40 constraints, 50 decision variables and 5 objectives generate almost 3,000 efficient extreme points! Of course, this is an undesirable situation because the DM is swamped with undue information that is of no help for decision making.

Evidently, these points do not lead to a definitive conclusion about which MCDM approach is better than another. This result is not surprising, since each MCDM method is based on different philosophies. This makes their comparison extremely difficult if not meaningless. A pragmatic attitude towards this matter would be to accept the fact that the relative advantages and disadvantages between the MCDM approaches largely depend upon the characteristics of the problem situation. Thus, it is impossible to use MOP for a decision-making problem with many attributes, say, for example, seven, and a complex continuous set (several hundred constraints and decision variables), whereas a problem with these characteristics is quite manageable within a GP framework. On the other hand, if the problem being modelled involves two or three attributes, a not overly complex constraint set and the DM does not feel very confident about the target values, then other MCDM approaches should be preferred to GP. In short, as Ignizio (1983), p. 278) says "there is not now, and probably never shall be, one single 'best' approach to all types of multiobjective mathematical programming problems". Actually the main features of the problem situation will lead the analyst towards the "best" approach from an analytical point of view. We will see in the following chapters how, within the context of the design and assessment of economic and environmental policies, the specific features of the different problems analysed point us to the most suitable MCDM method.

3.9 A Historical Summary: The "Pioneers of South Carolina" or the Influence of the "Young Turks"[1]

In this section, we briefly describe the history of MCDM and chronicle its evolution from the basic seminal ideas up to the current powerful framework. The MCDM movement's originator was possibly Koopmans (1951), who established the concept of efficient or non-dominated vector. This crucial concept was later on developed in a paper by Kuhn and Tucker (1951) obtaining the optimality conditions for the existence of non-dominated solutions. From another perspective, the article by Charnes, Cooper and Ferguson, which first introduced the basic idea of goal programming and was published in 1955 in the *Management Science* journal, can also be considered another seminal work in the development of the MCDM paradigm within the context of a constrained regression problem (Charnes et al. 1955).

During the 1960s, the above ideas evolved slowly. Zadeh (1963) and Marglin (1967) developed some multiobjective approaches and Charnes and Cooper (1961) and Ijiri (1965) extended the initial concept of goal programming chiefly in the direction of lexicographic optimization, etc. Despite these worthwhile efforts, however, there was not a lot of enthusiasm for MCDM during the 1960s. The crucial moment or turning point for MCDM was October 1972 when the First International Conference on MCDM was held at the University of South Carolina.

At the conference held in South Carolina around 200 delegates presented more than sixty papers. The actual pioneers of the MCDM movement attended this historical conference. They were young scientists in their thirties presenting results

[1] This section relies heavily upon the paper by Caballero and Romero (2006).

derived from their PhD dissertations. Besides these young scientists some big figures in OR/MS also attended and contributed to this memorable conference. A non-exhaustive list of the “Young Turks”[2] would include, among others names, Dyer, Ignizio, Ijiri, Keeney, Steuer, Yu and Zeleny. And among the big names were Churchman, Evans, Fishburn, Roy and Zadeh. The contributions of these authors have had a huge seminal value. Many of these researchers are still active and “productive”, and their works are still highly cited.

The conference proceedings were published in a book edited by Cochrane and Zeleny (1973) and can be considered, in Kuhnian terms, as the acceptance of MCDM as “normal science”. One of the resolutions accepted at the South Carolina Conference was to set up the Special Interest Group on Multiple Criteria Decision Making. This was to become the International Society on Multiple Criteria Decision Making in 1979. It is currently has 1,500 members from 90 countries. The Special Interest Group, first, and the International Society later, have organized an international congress every 2 years. The last conference held in Chengdun (China) in June 2009. Other international societies on MCDM are the EURO Working Group on Multicriteria Decision Aid formed in 1975, the European Special Interest Group on Multicriteria Analysis (ESIGMA) formed in 1985 and the Multiobjective and Goal Programming (MOPGP) group formed in 1994. MOPGP also organizes a biennial conference. The last MOPGP conference was held in Sousse (Tunisia) in May 2010.

Since the “Pioneers of South Carolina” conference, an impressive number of papers on the subject of MCDM have been published chiefly in OR/MS journals. Nowadays, it is difficult to find an issue of any of these journals that does not include a paper on the theoretical or applied aspects of MCDM. Similarly, several journals have published special issues focusing entirely on the subject of MCDM. A non-exhaustive lists includes *Agricultural Systems, Annals of Operations Research*, *Computers and Operations Research, European Journal of Operational Research, Large Scale Systems, Management Science, Mathematical and Computer Modelling, Naval Research Logistics, Regional Science and Urban Economics, Socio-Economic Planning Sciences, Water Resources Bulletin, etc.*

The categorical success of the MCDM paradigm and sociological support from the scientific community led to the appearance of the *Journal of Multi-Criteria Decision Analysis* in 1992. The rationality of a journal focusing specifically on the subject of MCDM is perhaps questionable. In fact, the journal’s appearance is implicit acceptance of there being two decision-making contexts (single and multiple criteria). Even so, as a leading member of the multi-criteria movement states (Zeleny 1982, p. 74): “No decision-making occurs unless at least two criteria are present”. Hence, single objective decision making can be said to be just an old paradigm superseded by the new MCDM approach. The “old” approach or

[2]The term “Young Turks” usually refers to a group of young intellectuals, including John Maynard Keynes. They were graduate students at King’s College, Cambridge, who in the early twentieth century led a protest movement aiming to change the Victorian norms ruling the King´s.

paradigm can be reduced to a particular case of the "new" paradigm. At any rate, the growth of MCDM over the last 30 years is unparalleled in the decision sciences or any neighbouring field. Thus, a paper by Steuer et al. (1996) categorized more than 1,200 papers published in refereed journals with an MCDM audience. More recent surveys, such as Ehrgott and Gandibleux's research (2002), shows that not only has this trend continued, but it has actually strengthened.

3.10 Some Final Remarks

The MCDM paradigm can be likened to a two-sided coin. The first side represents a decision-making situation with an infinite number of decision alternatives, normally characterized by a set of mathematical constraints. The basic aspects and methods belonging to this side of the coin have been covered throughout this chapter.

The other side of the coin would be a decision-making situation with a discrete number of feasible solutions to be assessed according to a finite set of criteria. This chapter has not dealt with this side of the coin. The reason for this strategy is the focus of the book, that is, the design and assessment of economic and environmental policies. In fact, the MCDM approaches devised for addressing continuous problems (i.e. problems with an infinite number of feasible solutions) are very fruitful for dealing with this type of problems. On the other hand, the approaches devised for dealing with discrete problems (i.e. with a finite number of feasible alternatives) are not especially relevant in the economic policy field. For this reason, this chapter has not covered some well-known approaches that are widely used for dealing with discrete MCDM problems, like multi-attribute theory (MAUT) or the analytic hierarchy process (AHP).

We adopt a non-conventional format for presenting the different MCDM methods to be used in the book. In fact, all the presented methods derive from (i.e. are particular cases of) a general distance function based on a generic p metric. We take the view that this type of presentation based upon a unifying approach has some important advantages. They include:

(a) The proposed unified approach stresses similarities between MCDM approaches. This can lead to increased clarity and precision in future dialogues, helping to reduce divisions among the advocates of different approaches. Thus, the general distance function framework can be a useful expository tool for introducing readers to MCDM steering clear of the common presentation based upon a completely disconnected "pigeon hole" system of methods.
(b) It would appear to be helpful for practitioners to be aware that, whatever MCDM model they are building, they are actually formulating a particular case (*secondary model*) of a p-metric distance function model (*primary model*). This gives a better understanding of the linkages between several approaches.
(c) The distinction between efficient solution (maximum aggregated achievement) and balanced solution (minimization of maximum disagreement) is especially

relevant within an economic policy context. This type of conceptual distinction, as well as the possibility of quantifying trade-offs between both types of achievement is very clear and operational within the proposed distance function model. We will see in the following chapters how this matter is especially useful and relevant for the design and assessment of economic and environmental policies.

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Chapter 4
Multicriteria Economic Policies: General Ideas and Some Previous Experiences

Abstract As discussed in Chap. 1, the traditional approach to optimal economic policy, although theoretically robust and elegant, is problematic in terms of realism and practical implementability. Our claim is that policy design can be seen as a problem with multiple conflicting objectives, and our proposal is to address policy design combining MCDM techniques with a general equilibrium model. The argument is twofold: this combination provides a more realistic representation of real policy making and it can provide useful recommendations to decide how to use policy instruments in practice. This chapter presents a general setting to outline how to represent policy design as a multicriteria decision problem. Moreover, it also reports three previous applications of our methodological proposal for policy design with economic objectives. The first application uses multiobjective programming to identify efficient policies in terms of economic growth and inflation. The second application employs compromise programming (CP) to reduce the size of the eligible set of policies by focusing on efficient policies that are also as close as possible to the ideal point. The last application is performed at the regional level with data from Andalusia, and its aim is to determine the efficient configuration of subsidies across activity sectors.

4.1 Introduction

As discussed in Chap. 1, the optimal economic policy design is typically represented by assuming that the government aims to maximize some social welfare function. We also argued that, although this approach is theoretically robust and elegant, its realism and implementability in practice is somewhat problematic. First, the construction of a single welfare function to represent the preferences of all society is challenging due to the huge information requirements and the difficulties for aggregating individual preferences. Second, the aim of maximizing a single utility function does not match up with the observed policy-making practice,

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regarding the behaviour of the economic authorities. Rather policy makers appear to be concerned about a bundle of economic indicators that represent the state and evolution of the economy from a macroeconomic point of view and they try to design their policies to improve the performance of the economy as measured by these indicators. Therefore, policy design can be seen as a problem with multiple conflicting objectives.

In Chap. 3 we showed that the MCDM approach is designed to deal with decision-making problems with several conflicting objectives or criteria. The purpose of this research is to use this approach to deal with the design of public policies in connection with some structural economic model. The argument for using such an approach is twofold. First, we argue that, from a conceptual point of view, a multicriteria setting is a reasonable and realistic representation of how policy makers take their decisions in practice. Second, from a pragmatic point of view, MCDM techniques can be of considerable help to decide how to use policy instruments in practice.

In this chapter we present the basic elements of this methodological proposal and a summary of our previous research work combining CGE modelling and MCDM techniques to tackle policy design problems with multiple criteria. The applications presented in this chapter are confined to purely economic policy objectives. The rest of the book is aimed at enlarging this line of research by combining both economic and environmental criteria.

Section 4.2 presents a general setting to outline how to represent policy design as a multicriteria decision problem. Section 4.3 contains an application of multi-objective programming (MOP) to identify efficient policies in terms of economic growth and inflation. We construct the efficient frontier and compare it to the real observed situation. We conclude that the observed situation is strictly above the frontier and, therefore, displays some degree of inefficiency. We also come up with some policy recommendations to move towards the efficient frontier. Section 4.4 presents an application in which compromise programming (CP) is used with the same policy objectives as in the previous section. The idea is to reduce the size of the eligible set of policies by focusing on efficient policies that are also *as close as possible* to the ideal point. These first two applications deal with macroeconomic policy and are performed with nationwide Spanish data. Section 4.5 presents a regional application with data from Andalusia (a southern region of Spain). The aim is to determine the efficient configuration of subsidies across activity sectors. All three applications use 1995 data for Spain and Andalusia, respectively. Section 4.6 sets out the main conclusions of this chapter.

4.2 General Setting

Assume that the government has a vector X of policy instruments. Economic agents are assumed to act rationally in the sense that they choose the values for their decision variables to maximize their objective functions.[1] Consumers make consumption and saving choices to maximize utility, and firms decide their factor demand and goods supply to maximize profits. Assume there are *m* economic agents in the economy, and each agent *h* (*h=1,..., m*) has a vector, denoted as z_h, of decision variables. Agent *h* decides the value of z_h to

$$\begin{array}{ll} \max & u_h(z_h, z_{-h}, X) \\ \text{s.t.} & z_h \in R_{h,} \end{array},$$

where R_h is the feasible set for the decision variables of agent *h*. In general, the satisfaction level of agent *h*, u_h, may depend on the agent's own decisions, the decisions (denoted as z_{-h}) of the other agents, and the value of the policy variables. For example, the profit of a firm depends on its own strategy, competitor strategy, consumer behaviour and the taxes they have to pay.

Let $\mathbf{z}_h(z_{-h}, X)$ denote the optimal response of agent *h*, i.e. the (feasible) value of the agent's decision variables maximizing u_h given the value of z_{-h} and *X*. Once the value of *X* is fixed, the interaction among agents provides the *equilibrium* value of all the decision variables for all agents, denoted as $z^*(X) =(z^*_1 (X), \ldots z^*_m (X))$. In equilibrium the following conditions must hold:

$$\begin{array}{c} z^*_h(X) \in \mathrm{z_h}(z^*_{-h}, X) h = 1, \ldots, m \\ z^*(X) \in R, \end{array} \tag{4.1}$$

where *R* is a set determined by feasibility constraints for the whole economy (in a standard economic model, this includes the equality between demand and supply for all markets).

Typically, the policy objectives are given by a set of relevant macroeconomic variables, which, in turn, are calculated after applying some aggregation rule to z^*. For example, the Gross Domestic Product (*GDP*) results from the aggregation of outputs from all firms, the consumer price index (*cpi*) results from the weighted average of the prices of all goods and services, and so on. Assume the government is interested in *K* macroeconomic aggregates denoted as $Z_1, \ldots, Z_K$ and resulting from z^* according to some aggregation rules:

$$\begin{array}{l} Z_1 = Z_1(z^*(X)) \\ Z_K = Z_K(z^*(X)). \end{array} \tag{4.2}$$

If a planner knows the response functions of all the agents, using (4.1) he or she can predict the equilibrium of the economy for every value of *X* and, using the aggregation in (4.2), he or she can get the values of the policy objectives as a

[1]For simplicity's sake, we assume that each economic agent has a single well-defined objective. Therefore, they act in a single-criterion way, and the government is the only entity considered to make multicriteria decisions.

function of X. If there were a single policy objective, the optimal design of the economic policy would result from solving the following problem:

$$\begin{gathered} \underset{x}{Opt}\ Z \\ s.t.(1),(2) \\ X \in F, \end{gathered}$$

where *Opt* means the search for optimal solutions in a maximizing sense when "more is better" (for example, economic growth) or a minimizing sense when "less is better" (for example, inflation) and F is the feasible set. The feasible set is determined by all the constraints imposed on the policy variables (for example, fiscal pressure should not be too high, public expenditure should be between given boundaries, and so on). In practice, there are typically several policy objectives, all with a trade-off, and, therefore, government policy making is a multicriteria problem.

For practical purposes, the implementation of this approach requires the following elements:

1. The identification of relevant policy criteria as measured by specific macroeconomic variables.
2. The determination of the policy instruments and the feasible range for those instruments.
3. A structural model including behaviour functions for economic agents from which it is possible to calculate the equilibrium of the economy and the value of policy objectives as a function of policy instruments.
4. A reliable database in order to find the parameter values of the model by some estimation or calibration procedure.
5. Some multicriteria technique to be applied in order to handle the decision problem.

Concerning points 1 and 2, the policy objectives in the two first applications that we will present in this chapter are growth and inflation, and the policy instruments taxes and public expenditure. In the third application, the policy instruments are government subsidies, whereas the policy objectives include one macroeconomic objective (total output) and sectorial objectives defined by the profitability of some key activity sectors. In Chaps. 6–8 we will explore the use of this framework for the joint design of economic and environmental policy, including pollutant emissions as a policy objective and emissions charges as a policy instrument.

Regarding point 3, our proposal is to use a computable general equilibrium model (CGE) as specified in Chap. 2 of this book. In the three applications reported in this chapter, we have used slight variations of the same CGE model. In Chap. 5, we present an adapted and enlarged version of that model to include environmental together with economic criteria. For reasons of space, we do not present the model used for the above applications here. For more information about the model, see Chap. 5, André and Cardenete (2009a, b) and André et al. (2008).

With respect to point 4, the models have been calibrated using Spanish data for all the applications presented in this book. We have used a national social accounting matrix (SAM) in all the applications reported in this book, except for the application presented in Sect. 4.5, which uses a regional SAM.

As regards point 5, the decision maker or the analyst should choose the most suitable multicriteria techniques depending on the characteristics of the decision-making problem to be handled. In this book we will illustrate the use of some of the most traditional continuous decision tools, such as multiobjective programming, compromise programming and goal programming.

4.3 Building Efficient Policies in Terms of Growth and Inflation

As a first example of our methodology applied to policy design with multiple criteria, in this section we present an application assuming that the government is concerned about just two policy objectives: growth and inflation. Also, we assume that the aim of the government is to determine the set of efficient policies in terms of these two criteria. The material presented in this section is based on André and Cardenete (2009a).

4.3.1 Preliminaries

To define the policy design problem, we first need to choose the policy objectives. In this case we focus on real economic growth (denoted as γ) and inflation (denoted as π), since the balance between these variables is an ongoing and substantial challenge in real macroeconomic policy-making. Economic growth is calculated as the annual rate of change of real *GDP,* whereas inflation is measured as the annual rate of change of the *cpi*:

$$\gamma = \frac{GDP_{1995} - GDP_{1994}}{GDP_{1994}} \cdot 100 \qquad \pi = \frac{cpi_{1995} - cpi_{1994}}{cpi_{1994}} \cdot 100$$

GDP_{1994} and cpi_{1994} are exogenously available (Source: INE, Spanish Statistical Institute), whereas equilibrium values for 1995 are endogenously determined by our CGE model (see Chap. 5). Real GDP is calculated as the total value of outputs from all sectors at constant prices. A policy X providing (γ, π) is said to be efficient if there is no other feasible policy (say, X') providing (γ', π') such that $\gamma' \geq \gamma$ and $\pi' < \pi$ or $\gamma' > \gamma$ and $\pi' \leq \pi$ see the concept of Pareto efficiency introduced in Sect. 3.3).

Concerning the policy instruments, we focus on fiscal policy. Fiscal policy encompasses public expenditure in each activity sector and the average tax rates applied to every sector, including indirect taxes (social security contributions paid by employers, tariffs and value-added tax) as well as direct taxes (social security contributions paid by employees, and income tax).

Moreover, the following constraints were imposed to increase the realism of the exercise. First, the maximum variation of all policy instruments with respect to their values in the benchmark situation (denoted as X_0) was limited to at most 20%, i.e. $0.8\, X_0 \leq X \leq 1.2\, X_0$. Second, both the overall tax revenue and public expenditure must each be equal to their values under the same benchmark conditions, although the cross-sectorial composition was allowed to vary.

4.3.2 Identifying the Set of Efficient Policies

As a first step, we obtain the payoff matrix, as defined in Sect. 3.3, and that is shown in Table 4.1. The first row lists the values for growth and inflation obtained when growth is maximized without taking inflation into account, whereas the second row presents the results that follow from the inflation-minimizing exercise. If the policy-maker was concerned with only growth, he or she could implement an expansive policy resulting in a high growth rate, $\gamma = 3.62\%$ (denoted in bold as the ideal value) compatible with a high inflation rate of $\pi = 6.59\%$. On the other hand, by implementing a deflationary policy, it would be possible to eliminate inflation and actually realize a deflation of 6.76% (denoted in bold as the minimum attainable value for inflation), together with a negative growth rate of $\gamma = -9.69$.

Note that the first solution implies a rather high growth rate, thus representing a desirable policy outcome. Nevertheless, such a solution is probably unacceptable in practice as it would be accompanied by an excessively high inflation rate. On the other hand, the second solution is likely to be seen as entirely undesirable for two reasons. First, it implies the existence of a growth recession. Second, policy-makers are typically not interested in deflation, but rather in a low inflation rate, e.g. 0.5–1.0%, to ensure stability. In what follows, we will thus take 0.5% as the minimum reasonable inflation rate, with the resulting "acceptable range" being [0.5, 6.59].

By maximizing the growth rate subject to $\pi = 0.5$, we determined that the highest compatible growth rate would be $\gamma = 1.57$. Table 4.2 shows the ideal solutions for both policy objectives when considering our stated lower bound for inflation.

Table 4.1 Solution of single-criterion problems

	γ Econ. growth (%)	π Inflation (%)
Max γ	**3.62**	<u>6.59</u>
Min π	<u>−9.69</u>	**−6.76**

Bold figures represent the ideal values and underlined figures anti-ideal values for each objective

Table 4.2 Payoff matrix with a lower bound for inflation

	γ Econ. growth (%)	π Inflation (%)
Max γ	**3.62**	<u>6.59</u>
Min π bound	<u>1.57</u>	**0.50**

Bold figures represent the ideal values and underlined figures anti-ideal values for each objective

We use the so-called *constraint method* introduced in Chap. 3 to construct (an approximation of) the efficient set of policies. This method involves constructing a grid of the feasible values of π, i.e. [0.5 to 6.59]. The number of points in the grid depends on how accurate the analysis is to be. In our case, 10 values appear to be sufficient to provide a good approximation of the efficient set. Let π_n denote one specific value of π in the grid. For each of these values, we then solve the problem:

max γ

subject to: $\pi \leq \pi_n$,

and all the equations of the CGE model.

Figure 4.1 maps these calculations for the Spanish economy in 1995 showing the ideal and anti-ideal solutions. We refer to the polygonal connecting all the efficient solutions as the *efficient frontier*. Any combination above this frontier can be considered as inefficient, as it entails either a higher inflation rate for the same growth rate (if compared with its vertical projection onto the frontier) or a lower growth for the same inflation rate (when compared to the horizontal counterpart in the frontier). All the combinations below the frontier are infeasible.

The slope of the efficient frontier can be understood as the policy *trade-off* or opportunity cost among objectives. Clearly, this slope is always positive, but it is not constant in absolute terms. Indeed, the frontier can be roughly divided in two parts: the bottom segment (with *low* values of growth and inflation), and the top segment (with *high* values of both variables). The bottom segment slopes less than the top segment. This means that, if the growth rate is high, it takes larger increments in inflation to attain additional points of economic growth. Alternatively, if the inflation rate is low, it would be more costly in terms of lost growth to achieve additional reductions than otherwise.

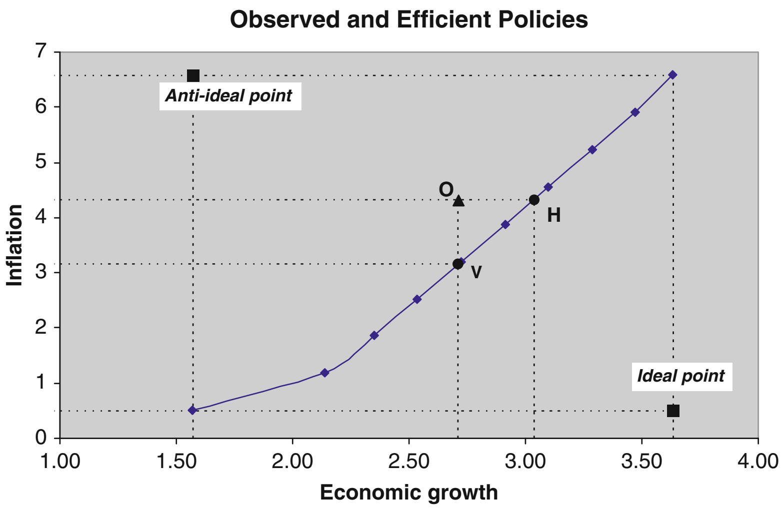

Fig. 4.1 Projecting the observed policy on the efficient frontier

4.3.3 Testing the Efficiency of Observed Policies

In Fig. 4.1, point O shows the observed growth and inflation rates in Spain in 1995: $\gamma = 2.71\%$, $\pi = 4.3\%$ (Source: INE, Spanish Statistical Institute). These results can be understood as the consequence of the policy implemented in 1995 by the Spanish government. Since this point lies strictly above the frontier, the policy is somewhat inefficient in terms of the selected objectives. Note that point H ("horizontal projection") provides the same inflation rate with a strictly higher growth rate (specifically, $\gamma_H = 3.02$, $\pi_H = 4.3$), whereas point V ("vertical projection") provides the same growth rate with a strictly lower inflation rate ($\gamma_V = 2.71$, $\pi_V = 3.15$).

To determine in which direction(s) the (fiscal) policy should be reformulated to improve the results in terms of efficiency, we solve two optimization problems. The first maximizes γ subject to $\pi \leq 4.3$ (observed inflation). The second minimizes π subject to $\gamma \geq 2.71$ (observed growth). Solving these formulations is equivalent to projecting point O onto H and V, respectively.

The results of these exercises are shown in Table 4.3. The column headed *Observed* shows the values of the policy instruments (public expenditure[2] and taxes by sector) under observed conditions (resulting from calibration). The columns headed *Point H* and *Point V* present the changes that should be applied in order to move from the observed situation (O) to H and V, respectively. In each case, the column labelled *Value* displays the value of each instrument, whereas *Change* displays the rate of change with respect to the observed situation.

Values in the H column can be seen as recommendations for increasing growth (while keeping inflation unchanged), whereas the V-values are directed at reducing inflation (while keeping growth as observed). The following section classifies the policy recommendations.

4.3.4 Policy Recommendations

We can split the set of policy recommendations into two groups. The first would include those recommendations that appear to be efficiency-enhancing regardless of policy priority (growth or inflation). We label these as *general efficiency recommendations* (unshaded/white cells in Table 4.3). In this category, the model recommends a 20% increase in public sector expenditures for sectors 5 (Chemicals) and 6 (Machinery and Transport), and a slight reduction (−0.85%) for sector 9 (Services). One could conclude, therefore, that if the Spanish government wanted to increase the efficiency of its fiscal policy, it should spend more on Chemicals and

[2]Note that public expenditure in 1995 Spain only appeared to be positive in sectors 5, 6 and 9, and zero in the remainder. Since we imposed the constraint that there should be a variation of no more than 20% in all policy instruments compared with the observed value, the public expenditures in all sectors except 5, 6 and 9 were constrained to zero.

Table 4.3 Values of policy instruments (observed and projected)

	Sector	Observed[a]	Point H		Point V	
			Value[a]	Change rate[b]	Value[a]	Change rate[b]
Public expenditure	5	3,295	3,954	20.00	3,954	20.00
	6	119	143	20.00	143	20.00
	9	80,362	79,679	−0.85	79,679	−0.85
VAT	1	0.65	0.52	−20.0	0.52	−20.0
	2	1.30	1.04	−20.0	1.04	−20.0
	3	3.29	2.63	−20.0	2.63	−20.0
	4	2.28	1.82	−20.0	1.82	−20.0
	5	1.02	1.22	20.0	1.22	20.0
	6	1.42	1.71	20.0	1.71	20.0
	7	1.89	2.26	19.5	1.86	−1.7
	8	1.70	2.04	20.0	2.04	20.0
	9	3.61	2.89	−20.0	2.89	−20.0
Social security employers	1	11.17	8.94	−20.0	8.94	−20.0
	2	39.64	31.72	−20.0	31.72	−20.0
	3	36.22	28.98	−20.0	28.98	−20.0
	4	27.28	21.83	−20.0	21.83	−20.0
	5	32.33	32.73	1.2	29.57	−8.5
	6	28.52	34.23	20.0	34.23	20.0
	7	25.58	28.05	9.6	26.70	4.4
	8	23.28	27.94	20.0	27.94	20.0
	9	26.60	27.44	3.2	24.84	−6.6
Tariffs	1	0.15	0.15	0.0	0.15	0.0
	2	0.11	0.11	0.0	0.11	0.0
	4	0.57	0.56	−1.75	0.57	0.0
	5	0.56	0.66	17.85	0.56	0.0
	6	1.62	1.62	0.0	1.59	−2.2
	7	0.89	0.89	0.0	0.89	0.0
Income tax		10.29	10.75	4.5	11.47	11.5
Social security employees		6.50	5.17	−20.0	5.17	−20.5

Units: [a]Million euros for public expenditure, and average percentage rate for taxes; [b]percentage rate of change with respect to the observed value. In the columns "Point H" and "Point V", shaded cells represent objective-specific policy recommendations, whereas the white cells represent general efficiency recommendations

Machinery and Transport. Notably, these recommendations hold independently of what is the main focus of the policy: growth or inflation control.

In terms of VAT, the tax rates should decrease as much as possible within the feasible range for sectors 1–4 and 9, and increase as much as possible for sectors 5, 6 and 8. Further, social security contributions paid by employees and employers in sectors 1–4 should decrease by 20%, whereas those paid by employers should be increased in sectors 6, 8 and, to a lesser extent, in sector 7. Generally speaking, the model seems to suggest that taxation should be reduced in the less productive sectors (agriculture, extractives, energy or food) or those generating a lower value added (services), and increased in dynamic sectors such as machinery and transport, or construction.

A second set of policy recommendations *depends* on policy priority: maximizing growth (H) or minimizing inflation (V). We label these as *objective-specific* *recommendations* (shaded cells in Table 4.3). In general, the differences between the two policy strategies (H and V) appear to be rather small compared to their common features. First, note that there are policy-specific recommendations regarding taxes, but not public expenditure. The most notable differences arise in the social security contributions paid by employers in sectors 5 and 9, which should be higher in order to increase growth, and lower to reduce inflation. A similar thing applies to the indirect tax on consumption (VAT) in sector 7, and tariffs in sectors 4–6. Our analysis thus suggests that, by following each group of recommendations, the government could hereby increase efficiency while "fine-tuning" its policy in the desired direction (either growth or inflation control).

4.4 Towards the Ideal Point: Building Compromise Policies

Since the efficient set could be very large, it is a good idea in many situations to apply a more selective technique in order to reduce the number of eligible policies and get more precise policy recommendations. The application presented in this section is based on André et al. (2008). The proposal is to narrow down the set of efficient policies by focusing on the so-called compromise set. The idea is to select those policies that are efficient and are also as close as possible (in the sense that some distance measure is minimized) to the ideal point. This summary of the above article illustrates here the use of compromise programming (CP) in policy design.

4.4.1 Preliminaries and Setting

Remember that the main analytical aspects of CP were reviewed in Chap. 3. As explained in Sect. 3.6, CP starts by defining the ideal point as a vector whose components are given by the optimum values of the objectives considered. Because the objectives usually conflict, the ideal point is infeasible, so the "most suitable" or "best compromise" solution is defined as the Pareto efficient solution closest to the ideal point. As it was explained in Sect. 3.6, depending on the topological metric used, a "compromise set" is established as the "most suitable set of solutions". Zeleny and Cochrane (1973) used the CP approach outlined above to address macroeconomic policy-making problems. The fact that their proposal did not catch on was perhaps due to the lack of connections between CP and the traditional utility maximization approaches used in economics. However, as reported in Chap. 3, some works have tried to approximate classic utility maximization and CP. Thus, Ballestero and Romero (1991, 1994) show that, under reasonable empirical conditions on the utility function for a two-criteria case, the compromise set can be interpreted as the part of the efficient set that maximizes the utility function.

By transferring these results to a macroeconomic policy-making scenario, the compromise set can be interpreted as a closed interval where the social preferences

Table 4.4 Payoff matrix problem in Sect. 4.4

	γ Econ. growth (%)	π Inflation (%)
Max γ	**3.07**	3.77
Min π	2.38	**2.36**

Bold figures represent ideal values and underlined figures anti-ideal values for each objective

are likely to be maximized. Moreover, according to Romero (2001), each point of the compromise set can be interpreted as a combination between optimum *policy efficiency* (i.e. maximum aggregate achievement of the different macroeconomic objectives) and optimum *policy equity* (i.e. maximum balance of achievement across the different macroeconomic objectives).

As in the paper presented in Sect. 4.3, this application focuses on real growth and inflation as policy objectives and fiscal policy as the set of policy instruments. In this case, the maximum variation of all policy instruments was limited to no more than 3% with respect to their values in the benchmark situation, i.e. 0.97 $x_0 \leq x \leq$ 1.03 x_0 (apart from the constraint that overall tax revenue and public expenditure must each be equal to their values under the same benchmark conditions). This explains why the results are not totally comparable with the outcomes of Sect. 4.3. Table 4.4 presents the payoff matrix of this two-criteria problem.

4.4.2 Obtaining the Compromise Set

According to the rationality underlying CP, one efficient alternative is preferred over another if and only if the first alternative is closer than the second one to the ideal point. In this way, several solutions (efficient macroeconomic policies in our context), can be obtained for different metrics *p*, by solving the following optimization problem:

$$Min\, L_p = \left[\left(\frac{\gamma^* - \gamma(x)}{\gamma^* - \gamma_*} \right)^p + \left(\frac{\pi(x) - \pi^*}{\pi_* - \pi^*} \right)^p \right]^{1/p}$$

Subject to the constraint set, where the constraint set is determined by the constraints placed on the values of the policy instruments and all the equations of the CGE model. In this formulation, we have implicitly assumed that the government is equally concerned about growth and inflation deviating from its ideal value so that both deviations are equally weighted when computing the distance. In any case, as explained in Chap. 3, different sets of weights can be set in order to represent government preferences over the two criteria considered. Different best compromise policies can be obtained by minimizing the distance function L_p. Figure 4.2 shows the best compromise policies for metrics 1, 2 and ∞, as well as an approximation to the efficient set. Table 4.5 shows the numerical values of these three macroeconomic policies.

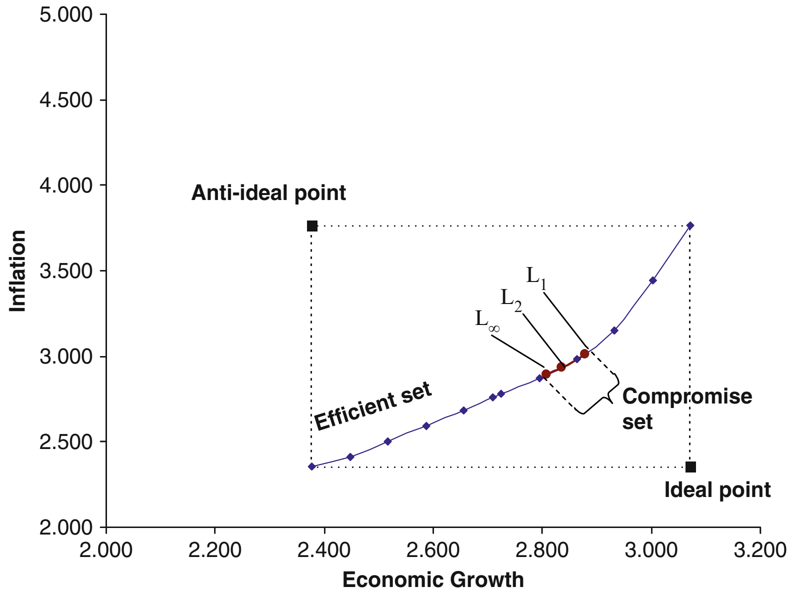

Fig. 4.2 Efficient policies and compromise programming

Table 4.5 Best-compromise solutions for metrics 1, 2 and ∝

	γ Econ. growth (%)	π Inflation (%)
L_1	2.88	3.01
L_2	2.84	2.94
L_∞	2.81	2.89

Table 4.6 Payoff matrix of restricted problem

	γ Econ. growth (%)	π Inflation (%)
Max γ	**3.07**	3.77
Min π	2.71	**2.76**

Bold figures represent ideal values and underlined figures anti-ideal values for each objective

4.4.3 Reducing the Size of the Compromise Set

If the government finds that the above compromise set is still too wide to be useful as a policy guide, this set can be reduced using the so-called *displaced ideal* method. The idea is to include some information in terms of additional constraints. This procedure provides the so-called *displaced ideal* point which will be used as an anchor to get a new *displaced compromise* set (see Zeleny, 1974, 1976 for technical details about this method). Assume the government requires the growth rate to be at least 2.71% (which is precisely the observed growth rate in Spain in 1995). If we solve the resulting CP problem including constraint $\gamma \leq 2.71$, we get the new payoff matrix shown in Table 4.6. Thus, the new displaced ideal point is given by $\gamma = 3.07$

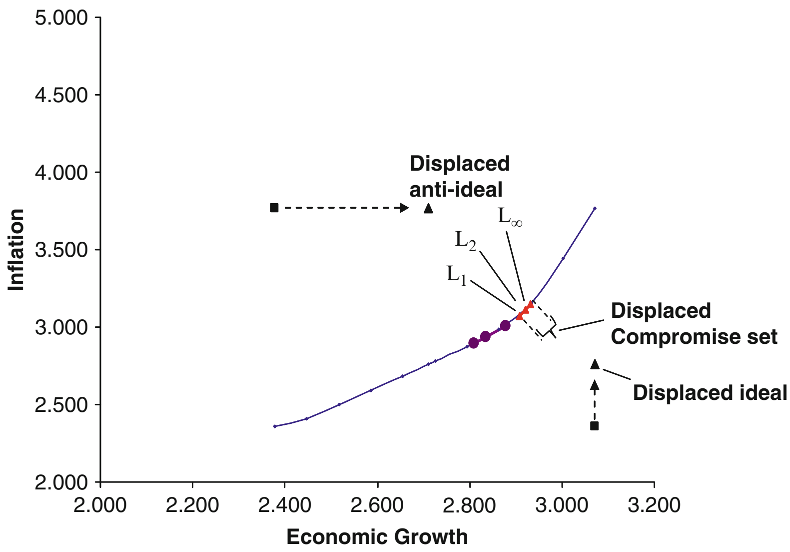

Fig. 4.3 Compromise set and displaced compromise set

Table 4.7 Best compromise policies when the ideal is displaced

	γ Econ. growth (%)	π Inflation (%)
L_1	2.91	3.07
L_2	2.92	3.11
L_∞	2.93	3.15

$\pi = 2.76$, and the new displaced anti-ideal point is given by $\gamma = 2.71$ and $\pi = 3.77$. These results, together with the new displaced compromise set, are illustrated in Fig. 4.3 and Table 4.7.

Note that the new compromise set has moved upwards and rightwards with respect to the original one, and it is smaller. Moreover, if we round to a single decimal place, the new compromise set is a single point. Compromise set uniqueness is very handy from a decision-making point of view, and the displaced ideal method proves to be a useful device for policy making. On the other hand, determining the displaced ideal has required additional information that, in many cases, is not easy for the public DM to provide.

4.4.4 Evaluating the Observed Policy

The real situation of the Spanish economy in 1995 is given by an economic growth of 2.71% and an inflation rate of 4.30%, as represented in Fig. 4.4. Here there are two crucial points to be made. First, as we have already concluded in Sect. 4.3, the observed situation is not Pareto efficient, since the model indicates that the same growth rate (2.71%) could be compatible with a much lower inflation rate (2.76%).

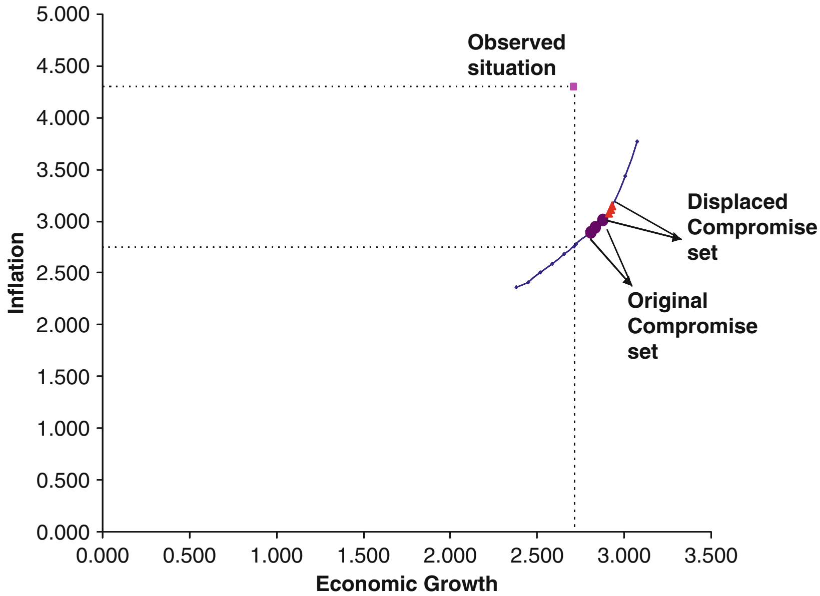

Fig. 4.4 Evaluating the observed situation

In other words, the observed policy is dominated by several policies placed on the frontier.

Second, and perhaps more importantly, the observed situation appears to be very far from the compromise set and the displaced compromise set. Therefore, the Spanish policy does not appear to be easily justifiable according to sensible preferences attached to both growth and inflation. Rather the policy appears to be almost exclusively aimed at maximizing growth irrespective of its impact on inflation. History appears to corroborate this interpretation. In fact, after the Spanish dictatorship (1936–1975), the situation of underdevelopment with respect to the rest of Europe made growth and development the main priority, causing very high rates of inflation for many years. This trend continued into the early nineties, as illustrated in Fig. 4.5. In the years following upon 1995, there was a more active anti-inflationist policy, mainly due to political pressure to meet the Maastricht requirements.

4.5 Designing Efficient Subsidy Policies in a Regional Economy

The two previous applications were rather similar in the sense that both were designed at the national level and focused on the use of fiscal policy to address two classical macroeconomic indicators such as growth and inflation. Nevertheless, the basic CGE-MCDM approach presented here for policy design is in principle applicable to many different policy settings.

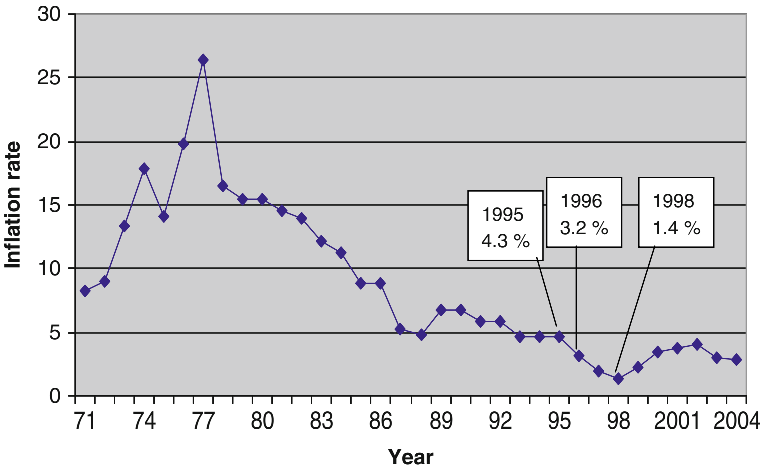

Fig. 4.5 Inflation rate in Spain

This section, which is based on the article by André and Cardenete (2009b), presents an application which differs from the previous ones on some important points. First, it is applied to a regional economy (specifically, Andalusia) instead of the whole country. A second difference is the set of policy instruments considered. Instead of focusing on taxes and total public expenditures, it deals with the use of subsidies to different production sectors. The third difference has to do with the kind of policy objectives considered. CGE models have the potential of providing a range of information disaggregated by activity sectors. In this application, we take advantage of this information wealth by including sectorial objectives on top of a typical macroeconomic indicator, such as aggregate growth. Specifically, the profitability of a key strategic sector for Andalusia such as agriculture is included as a policy objective. An additional contribution of this application is that we have also explored the possibility of enlarging our approach by addressing policy problems with more than two objectives and including some additional aggregate and sectorial variables. As in Sect. 4.3, the purpose is to find efficient policies and, therefore, we resort to multiobjective programming.

4.5.1 Preliminaries

Andalusia, a large region in southern Spain, has been designated by the European Union as an Objective 1 region (see Lima and Cardenete, 2007, for more information). Also, it is the Spanish region that has traditionally received the largest amount of public subsidies because of its economic situation, geographical extension and population. In Andalusia, a large number of sectors receive a net production subsidy.

Table 4.8 Productive sectors in SAM, Andalusia 1995

1. Agriculture	14. Vehicles
2. Cattle and forestry	15. Transport
3. Fishing	16. Food
4. Extractives	17. Manufacturing of textile and leather
5. Refine	18. Manufacturing of wood
6. Electricity	19. Other Manufactures
7. Gas	20. Construction
8. Water	21. Commerce
9. Mining	22. Transport y communications
10. Manufacturing of construction material	23. Other services
11. Chemicals	24. Sales services
12. Manufacturing of metal products	25. Non sales services
13. Machinery	

According to the 1995 social accounting matrix of Andalusia, all the activity sectors listed in Table 4.8, except sectors 3 (Fishing), 5 (Refine), 10 (Manufacturing of Construction Material), 21 (Commerce), 23 (Other Services) and 25 (Non Sales Services), received a positive net production subsidy (defined as the difference between subsidies and output taxes).

4.5.2 Stating the Policy Design Problem

Concerning policy instruments, we focus on the design of an efficient subsidy policy at the regional level. Therefore, we select as policy variables the net subsidy rates of those sectors that received a net subsidy in the benchmark situation. The subsidy rate is defined as the ratio of the net subsidy (total subsidy minus taxes on production) over the value of domestic output in the sector, i.e. the net subsidy per unit of domestic output.

To rule out policy recommendations being unrealistically far away from real applied policies, the following constraints were imposed on the policy instruments:

1. The sectors that were not subsidized, in net terms, in the benchmark situation (the observed values in Andalusia, 1995) are assumed to remain unsubsidized.
2. For the sectors that were subsidized in the benchmark situation, two bounds for the new (simulated) subsidy rate were set: the lower bound is zero (meaning that the subsidy is fully eliminated) and the upper bound is the observed value times 1.5 (meaning that the subsidy rate is increased by 50%).
3. The other policy instruments (VAT, income tax, public expenditure, etc.) were assumed to have the same value as in the benchmark situation.

Regarding policy objectives, two problems were studied. The first problem had two objectives, and the second, seven policy objectives.

4.5.3 A Bi-Criteria Problem: Output Variations Versus Agricultural Profit

As discussed earlier, the economic policy in Andalusia is, for several reasons, largely based on subsidies. The agricultural sector is one of the key activity sectors in Andalusia, and one of the sectors that have traditionally been strongly subsidized. Since the early eighties, this sector has received substantial funding from the European Community in an attempt to modernize and develop its activity.

Based on this observation, we start by stating a hypothetical problem in which the (regional) government is assumed to design its subsidy policy according to two objectives. The first objective is to foster the overall activity of the economy in real terms. This objective is represented as the maximization of output variation, as measured by the growth rate with respect to the benchmark situation and denoted by ΔQ. The second objective is to increase the profit of the agricultural sector in order to make this activity as profitable as possible. This objective is represented as the maximization of firm profit in the agricultural sector (as measured by the Gross Exploitation Surplus). For the sake of normalization, we will take, as an indicator, the growth rate of profit with respect to the benchmark situation, denoted as $\Delta\pi_{Agric}$. The rationale for selecting these objectives is that the government may be interested in promoting a key activity sector (such as agriculture) but, on the other hand, probably does not want to do it at the expense of damaging the economy too much as a whole.

Table 4.9 displays the payoff matrix of this two-criteria problem. The first row shows that the maximum attainable output increment is $\Delta Q^* = 1.99\%$. As a by-product of this policy, the profit of agricultural firms would experience a modest increment of 0.25%. The second row shows that (as a consequence of a different subsidy policy), it would be possible to increase the agricultural profit by 1.93%. Nevertheless, this policy would mean reducing the overall output of the economy by 0.74%.

Figure 4.6 shows an approximation to the efficient set that was constructed using the *constraint method* in a similar fashion to Sect. 4.3. The efficient points obtained by this procedure are denoted as $E_1, \ldots, E_{10}$. Table 4.10 displays the subsidy rate as a percentage of the value of production in the original benchmark situation (shaded column), as well as in each of the efficient points in Fig. 4.6. The first noteworthy point is that, throughout the frontier, the agricultural sector (sector 1) subsidy is unchanged at its maximum allowed value (50% greater than the value in the original situation) at all the points of the frontier. The conclusion that can be drawn from this result is that increasing the agricultural sector subsidy is a policy change that is consistent with increasing both agricultural profit and overall output.

Table 4.9 Payoff matrix output variations in terms of profit in agriculture

	ΔQ (%)	$\Delta\pi_{Agric}$ (%)
Max ΔQ	**1.99**	<u>0.25</u>
Max $\Delta\pi_{Agric}$	−<u>0.74</u>	**1.93**

Bold figures represent ideal values and underlined figures anti-ideal values for each objective

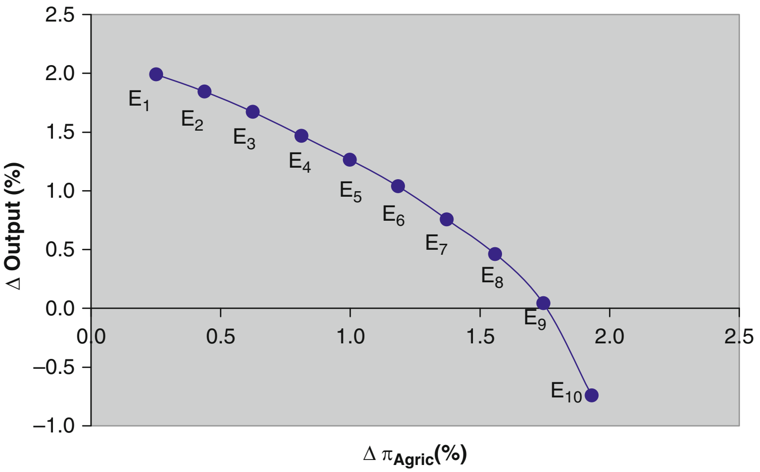

Fig. 4.6 Efficient frontier between output variation and agricultural profit

Table 4.10 Net subsidy by sectors in benchmark situation and at efficient points in the two-criteria problem

		Subsidy rate (%) at efficient point E_n									
Sector	Bench	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}
1	2.98	4.48	4.48	4.48	4.48	4.48	4.48	4.48	4.48	4.48	4.48
2	3.09	4.64	4.60	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64
4	36.22	54.33	54.30	54.33	36.92	7.89					
6	3.04	1.44		4.56	4.56	4.56					
7	7.97	11.95	12.00	11.95	11.95	11.95					
8	2.69	4.04	4.00	4.04	4.04	4.04	4.04	4.04	4.04	4.04	4.04
9	0.55	0.82									
11	9.51	14.26	14.30	14.26	14.26	14.26	14.26	14.26	14.26	14.26	
12	2.87	4.30	4.30	4.30	4.30	4.30	0.00	0.00	0.00		
13	19.66	0.00	2.60	29.49	29.49	29.49	29.49	22.84	0.89		
14	36.02	54.04	54.04	54.04	54.04	54.04	54.04	22.13			
15	5.67	8.50	8.50	6.25							
16	9.59	14.38	14.40	14.38	14.38	14.38	14.38	14.38	14.38	14.38	14.38
17	16.25	24.38	24.38	24.38	24.38	24.38	24.38	24.38	24.38	20.51	
18	5.90	8.85	8.80	8.85	8.85	8.85	0.55				
19	10.06	15.09	15.09	15.09	15.09	15.09	15.09	15.09	15.09		
20	3.64			0.30	1.08	1.96	3.77	5.47	5.47	5.47	5.47
22	5.08	7.61	3.80								
24	4.80										

Source: own elaboration

When moving from E_1 to E_{10}, the required value of the agricultural profit increases. Since the agricultural subsidy is already at its maximum feasible level, this profit increment can only be achieved by altering the value of other policy variables (in this case, by changing the subsidies of other sectors). The data in Table 4.10 illustrate that any of the efficient points displayed in Fig. 4.6 requires a

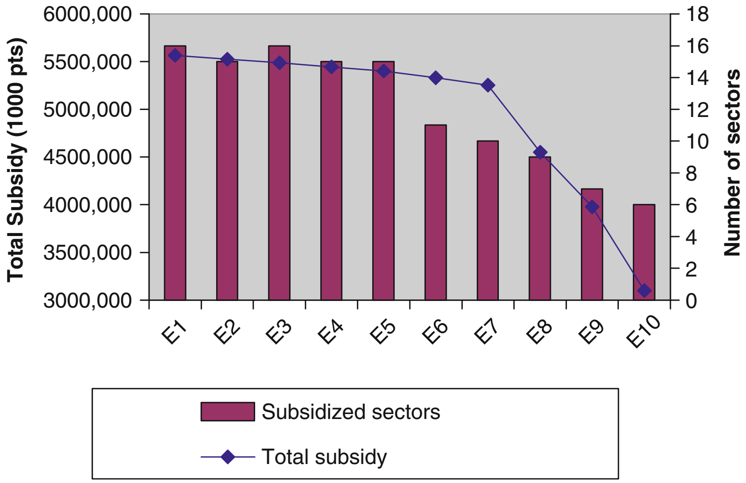

Fig. 4.7 Number of subsidized sectors and total amount spent on subsidies across efficient points in the bi-criteria problem

concentration of subsidies on fewer sectors. As a matter of fact, at any of the efficient points, the model recommends increasing the subsidy rate of sectors 2 (Cattle and Forestry), 8 (Water) and 16 (Food) to their maximum feasible levels. Note that these sectors are complementary and connected to agriculture. On the other hand, when moving from E_1 to E_{10}, the subsidies for many other sectors are eliminated.

Figure 4.7 is a summary of the general evolution of subsidies across the efficient points. It shows the number of subsidized sectors (bars) and the total net public expenditure in terms of subsidies (dotted line) across the efficient points shown in Fig. 4.6. Clearly, a higher required value for agricultural profit goes hand in hand with a reduction in the number of subsidized sectors and a smaller amount of expenditure on subsidies. This can be interpreted as follows: if one wants to benefit the agricultural sector and it is not possible to increase agricultural subsidies, one possible option is to increase the subsidies of sectors that are complementary to agriculture and eliminate the subsidies to other sectors. This way, agriculture receives the same treatment in absolute terms but a better treatment in relative terms (as compared with the other sectors).

4.5.4 A Problem with more than Two Criteria

To enlarge the scope of the discussion, we considered the possibility of the government being concerned about a larger number of criteria. To illustrate how to deal with this kind of setting, assume the government has two types of objectives: general economic objectives and strategic sectorial objectives.

Of the *general economic objectives*, it was assumed that the government is concerned, first, about the variation of output with respect to a benchmark situation (see previous section). Since the policy makers are supposed to aim at increasing social welfare, we include as an objective (the maximization of) compensating variation (*CV*). Compensating variation is a conventional welfare measure in monetary terms (see, for example, Mas-Colell et al., 1995, p. 82). We arbitrarily set $CV = 0$ in the observed situation. This way, $CV > 0$ (<0) means that, after implementing the analyzed policy combination, the consumers are better off (worse off) than before implementing it. The third objective is to minimize the public deficit (denoted as *PD*). The fourth objective is to minimize the unemployment rate (denoted as *u*).

Concerning the *sectorial objectives*, assume the government is particularly interested in ensuring the viability of some key strategic sectors. Assume these sectors are sector 1 (Agriculture), 20 (Construction) and 22 (Transport and Communications). Therefore, the government sets profit maximization (as measured by the gross exploitation surplus) of these sectors as policy objectives. For the sake of normalization, we focus on the profit increment of these sectors with respect to the benchmark situation, denoted as $\Delta\pi_1$, $\Delta\pi_{20}$ and $\Delta\pi_{22}$.

We solved seven single-criterion problems to obtain the payoff matrix for the policy problem (see Table 4.11). Looking at the matrix, we find that there are clear conflicts among objectives. Let us focus first on general macroeconomic policy objectives. It turns out that output variation, consumer welfare (as measured by compensatory variation) and unemployment minimization behave similarly in the sense that are not conflicting. Actually the optimization of the two first objectives provides almost the same solution, whereas unemployment minimization provides a very similar solution. On the other hand, all three of these objectives strongly conflict with public deficit minimization, since optimizing any of these objectives results in a public deficit well above the minimum attainable level and minimizing public deficit provides very poor results for output variation, consumer welfare and unemployment minimization.

Concerning sectorial objectives, as discussed above, maximizing the profitability of the agricultural sector (sector number 1) clearly conflicts with the objective of maximizing the increment of output, and we now find that it also conflicts with the maximization of compensatory variation and, to some extent, with unemployment minimization. The profitability of the transportation sector (number 22) conflicts even more clearly with output variation, consumer welfare and unemployment

Table 4.11 Payoff matrix of the seven-objective problem

	ΔQ	CV	−PD	u	$\Delta\pi_1$	$\Delta\pi_{20}$	$\Delta\pi_{22}$
Max ΔQ	**1.99**	7,871.61	108,396.95	33	0.25	3.94	0.48
Max CV	1.99	**7,871.61**	108,396.95	33	0.25	3.94	0.48
Max -PD	−4.08	−40,127.87	**72,773.80**	38	1.40	−1.52	0.99
Min u	1.98	7,811.18	108,360.29	**33**	0.26	3.73	0.47
Max $\Delta\pi_1$	−0.74	−11,709.20	96,890.17	33	**1.93**	2.49	−0.69
Max $\Delta\pi_{20}$	1.57	5,461.34	109,432.74	37	0.68	**4.80**	−1.18
Max $\Delta\pi_{22}$	−3.19	−32,366.48	79,293.65	34	0.53	−1.65	**2.72**

Δ Q, u, $\Delta\pi_1$, $\Delta\pi_{20}$ and $\Delta\pi_{22}$ are measured in %. CV and PD are measured in millions of euros
Bold figures represent ideal values and underlined figures anti-ideal values for each objective

minimization. On the other hand, any of these general objectives very clearly conflicts with the profitability of the construction sector (number 20). Finally, the profitability of construction and transportation seem to conflict very clearly with each other, and they all have a moderate degree of conflict with the agricultural sector (sector 1).

We now illustrate two alternative ways to obtain efficient policies: the previously used *constraint method* and the *weighting method* (see, Sect. 3.5). To apply the *constraint method*, we need to optimize one single objective while the remainder are kept as parametric constraints. To illustrate the technique, let all objectives except the one being optimized have an equal or better value than in the observed situation. The observed values (taken from official statistical sources) are:

$$\Delta Q = CV = \Delta\Pi_1 = \Delta\Pi_{2\tilde{0}} = \Delta\Pi_{22} = 0, PD = 110800.67, u = 33.9\%, \quad (4.3)$$

where PD is measured in millions of euros. Thus, the first candidate point is obtained by solving the following problem:

$$Max\,\Delta Q \quad (4.4)$$

subject to $CV \geq 0$, $PD \leq$ 110800.67, $u \leq$ 33.9,

$\Delta\Pi_1 \geq 0$, $\Delta\Pi_{20} \geq 0$, $\Delta\Pi_{22} \geq 0$,
all the equations of the model.

The solution of problem (4.4) is represented in the first row of Table 4.12. Note that this combination dominates the observed situation in a Paretian sense. In fact, not only does output increase with respect to the observed output, but also the compensating variation is larger, public deficit and unemployment are lower and the profits of all the target sectors are higher than in the benchmark situation. So, we conclude that, according to our setting, the observed policy displays some degree of inefficiency and it could be unambiguously improved with respect to the seven objectives considered here.

By making similar calculations for each objective, we get six more policy combinations, as shown in Table 4.12. Note again that the solution for the first two criteria (output variation and compensating variation) are identical. Moreover,

Table 4.12 Using the constraint method with respect to the observed situation

	Δ Q	CV	−PD	u	$\Delta\pi_1$	$\Delta\pi_{20}$	$\Delta\pi_{22}$
Max Δ Q	1.99	7,871.61	108,396.95	0.33	0.25	3.94	0.48
Max CV	1.99	7,871.61	108,396.95	0.33	0.25	3.94	0.48
Max -PD	0.75	655.03	105,104.28	0.34	0.80	3.30	0.37
Min u	1.74	7,172.33	109,274.53	0.33	0.27	4.01	0.58
Max $\Delta\,\pi_1$	0.53	363.16	108,395.84	0.34	1.38	3.19	0.00
Max $\Delta\,\pi_{20}$	1.73	6,594.76	108,992.69	0.33	0.47	4.40	0.00
Max $\Delta\,\pi_{22}$	0.40	461.90	110,794.67	0.34	0.00	2.57	1.33

Δ Q, u, $\Delta\pi_1$, $\Delta\,\pi_{20}$ and $\Delta\,\pi_{22}$ are measured in %. CV and PD are measured in millions of euros the solutions for these criteria are exactly the same as shown in Table 4.11. The reason is simply that the constraints imposed when solving problem (4.4) and the equivalent problem for compensating variation are not binding since the unconstrained optima shown in Table 4.11 dominate the observed situation for all the objectives. Nevertheless, the situation is different for the other rows in Table 4.12, since the unconstrained optimal values (in Table 4.11) do not meet the requirement that no objective should have a worse value than in the benchmark situation. This makes the constrained optima being different from the unconstrained ones.

A sufficient condition for the constraint method to provide efficient solutions is that all the parametric constraints are binding. Since this is not the case for some constraints, we cannot ensure that all the solutions shown in Table 4.12 are efficient, although they all Pareto-dominate the observed situation. At this point, we have at least two possibilities for finding solutions that are efficient for sure. The first is to continue using the *constraint method* and make the parametric constraints tougher by increasing the value of the "more is better objectives" (ΔQ, CV, $\Delta\pi_1$, $\Delta\pi_{20}$ and $\Delta\pi_{22}$) and/or decreasing the value of the "less is better" objectives (*PD* and *u*) until we find a solution for which all the constraints are binding at the same time.

The second approach is to use the so-called *weighting method*. This method, as was explained in Chap. 3, can be expressed as minimizing the following sum of normalized values of objectives:

$$\sum_{i=1}^{7} \omega_{fi} \frac{f_i^* - f_i}{f_i^* - f_{i*}}, \tag{4.5}$$

where f_i denotes the achieved value for objective i = 1,...7, where $f_1 = \nabla Q,\ldots$, $f_7 = \nabla\pi_{22}$ and each objective is normalized by subtracting the anti-ideal value and dividing by the difference between the ideal and the anti-ideal value (both of which are given in Table 4.12). For each f_i, the resulting ratio is bounded by construction between zero (when the objective is equal to the anti-ideal) and one (when it is equal to the ideal). This normalization eliminates units of measurement and means that the addition makes mathematical and economic sense. The coefficients ω_{γ_i} are preference parameters representing how concerned the policy maker is about each objective i. We illustrate the policy combination obtained with $\omega_{f_1} = \ldots = \omega_{f_7}$, meaning that the policy maker is equally concerned about all the objectives. The solution of the maximization of (4.5) with this set of weights is:

$$\Delta Q = 0.21\%, \quad CV = -23.49 \times 10^6€, \quad PD = 108{,}147.12 \times 10^6€, \quad u = 33.9\%,$$
$$\Delta\Pi_1 = 0.77\%, \quad \Delta\Pi_{20} = 1.12\%, \quad \Delta\Pi_{22} = -1.15\%.$$

This is an efficient solution by construction. By testing different combinations of weights we obtain different efficient solutions. These solutions may respond to different policy-maker preference configurations. Note that this procedure does not guarantee that all the criteria improve with respect to the observed situation. Actually, the solution found does not Pareto-dominates the observed solution in

1995 in Andalusia since some policy objectives improve and others worsen with respect to the observed situation.

4.6 Concluding Remarks

In this chapter we have reviewed three different policy design applications with multiple economic criteria. These applications serve to illustrate the potential of our MCDM-CGE approach from two points of view. First, from a conceptual perspective, it looks to be a sensible way to view and represent the concerns and the procedures actually followed by policy makers. Second, from an empirical perspective, MCDM techniques are capable of providing operational policy recommendations and, therefore, to decide how to use policy instruments in practice.

Concerning the selection of specific MCDM techniques, we have illustrated the use of two different approaches. The first one is multiobjective programming, which allows us to compute *efficient* policies. The rationale behind this approach is to assure that the policies that are applied by policy-makers are not Pareto dominated. Apart from its theoretical soundness, the practical relevance of this property is clear. The reason is that any policy would be more effective and better accepted by society insofar as it attains the set goals without being overly costly in terms of other relevant objectives.

On the other hand, we have discussed that, although efficiency is a desirable property, the set of efficient policies is typically too large to serve as a useful policy guide. The second MCDM technique we have applied is compromise programming. Compromise programming provides an additional criterion to reduce the set of eligible policies by minimizing the distance to the ideal point. Moreover, if the compromise set is still too large, there are additional tools, such as the displaced ideal method, capable of further refining the search for *optimal* policies.

The joint use of the techniques we are combining here (a CGE model and MCDM) provides several useful outcomes. First, we get a sensible array of values to be set as targets for the policy objectives, since it makes apparent sense that the policy-makers aim at getting at least efficient results and values that are as close as possible to the ideal point combination. Second, we get a framework to evaluate past or potential policies. Indeed, it is possible to compare the observed achievements with the efficient frontier and the compromise set to determine how well we are doing with respect to our theoretical possibilities; but it is also possible to simulate the results of any policy proposal and evaluate it in terms of efficiency and distance to the ideal. Finally, together with the efficient and compromise values of the policy objectives, we come up with a set of policy recommendations since our model tells us in which directions the policy should be reformulated in order to achieve each of the efficient or compromise points.

We also claim that our methodological proposal is straightforwardly applicable to very different policy settings. Thus, by presenting two nationwide applications and one regional application, we have shown that our CGE-MCDM framework is not restricted to a specific geographical framework. Moreover, the same methodological approach is compatible with different public policy configurations, such as, for example, the design of macroeconomic fiscal policies or the optimal structure of production subsidies.

Clearly, the modelling strategy is also compatible with purely macroeconomic criteria (such as growth or inflation) or with sectorial criteria (such as the promotion of selected key sectors). In this chapter, however, we have assumed that the policy maker is concerned about two economic policy objectives only. The purpose of the remainder of the book is to explore the use of this methodology for the joint economic and environmental policy design.

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Chapter 5
Building a CGE Model for Economic and Environmental Policies

Abstract To perform a joint analysis of economic and environmental policy (which will be done in the coming chapters), we need to build a model that includes information about both the key economic variables and the environmental impact of economic activity. In this chapter we introduce the standard structure of the CGE model (following the Walrasian tradition) that we use for this task. We present the technological structure, represented by a nested production function. Concerning consumer behaviour, we include a single representative consumer that makes decisions about consumption and saving while trying to maximize his/her utility function subject to a budget constraint. Pollutant emissions are introduced following a short-term approach according to which pollution intensity is assumed to be fixed. We provide for the possibility that the government imposes emissions charges on top of other taxes. The basic structure of the model is completed with a description of input markets, the foreign sector (whose behaviour is assumed to be exogenous) and the closure rule which links investment, saving and the public and foreign balances. We also introduce the main database used for the calibration process, which is Spain's social accounting matrix.

5.1 Introduction

In Chaps. 6–8 we will approach the joint problem of designing economic and environmental policies. Therefore, we will enlarge the analysis presented in Chap. 4 by including not only economic but also environmental instruments and environmental objectives.

The first element we need to do this is a model that, apart from the key economic variables, includes some information about the environmental impact of economic activity. This chapter shows the standard structure of the CGE model used in the following chapters. Moreover, we also introduce the database –social accounting matrix- used to calibrate the model in the applications described in the following

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chapters. A simplified and adapted version of this model was used for all the applications presented in Chap. 4.

The model that we present here follows the recent line of research by André and Cardenete (2009a, b) and André et al. (2008) extended to cover not only economic but also environmental objectives. In turn, all the models used in these works are based on a computable general equilibrium model developed by Cardenete and Sancho (2003). It is a CGE model conforming to the basic principles of the Walrasian equilibrium (see Chap. 2). Taxes and public sector activity are taken to be exogenous by consumers and firms, whereas they are considered as decision variables by the government. The model also includes a foreign sector, the activity level of which is assumed to be fixed in the sense that total imports and exports are not sensitive to the policy changes implemented by the government. This assumption is consistent with the small country hypothesis and a short-term approach to policy design.

The relative prices and the activity levels of the productive sectors are endogenous variables. The equilibrium of the economy is given by a price vector for all goods and inputs, a vector of activity levels, and a value for public income such that the consumer is maximizing his or her utility, the productive sectors are maximizing their profits (net of taxes), public income equals the payments of all economic agents, and supply equals demand in all markets.

The remainder of the chapter is structured as follows. Section 5.2 presents how production technology and firms' decisions are modelled. Section 5.3 describes consumer behaviour. In Sect. 5.4 we show how pollutant emissions and emissions charges are incorporated into the model. Section 5.5 describes the role of the government. The markets for production inputs are introduced in Sect. 5.6. Section 5.7 completes the presentation of the model equations by introducing the foreign sector and the closure rule. Finally, in Sect. 5.8, we present the database used for the calibration process.

5.2 Technology and Producer Behaviour

The model comprises 26 productive sectors matching the structure of the (aggregated) 2000 Social Accounting Matrix (SAM) of Spain, which is used to calibrate the model (Table 5.1). The production technology is given by a *nested production function*.

We assume that overall output of sector j is obtained from a Cobb–Douglas combination of domestic output and imports:

$$Q_j = \phi_j \cdot Xd_j^{\sigma_j} \cdot IMP_j^{1-\sigma_j}, \tag{5.1}$$

where Q_j is the total output of sector j measured in euros, Xd_j stands for domestic output of sector j, IMP_j represents imports of output from sector j, ϕ_j is the scale parameter of sector j and σ_j $(1 - \sigma_j)$ is the elasticity of total output with respect to

Table 5.1 Structure of productive sectors SAM Spain 2000

SAMESP00
1. Agriculture
2. Fishing
3. Coal
4. Oil and gas
5. Extractives
6. Refinery
7. Electricity
8. Gas and water
9. Distribution of gas
10. Food
11. Textile and leather
12. Wood
13. Chemical
14. Mining sector
15. Manufacture
16. Machinery
17. Vehicles
18. Building materials
19. Transport
20. Other manufactures
21. Construction
22. Commerce vehicles and oils
23. Commerce
24. Transports and communications
25. Other services
26. Services

Source: Cardenete and Fuentes (2007)

domestic (foreign) output. This specification is consistent with the so-called Armington hypothesis (Armington 1969), where domestic and imported products are taken as imperfect substitutes. Also, this hypothesis considers that the analyzed country is small enough so as not to have an influence on foreign trade.

The domestic output of sector j ($j = 1,\ldots,26$) is obtained by combining, through a fixed-coefficient technology, outputs from the other sectors and value added to represent the fact that materials are typically used in constant proportions and each activity usually renders (proportionally) the same value added. Analytically,

$$Xd_j = \min\left\{\frac{X_{1j}}{a_{1j}}, \ldots, \frac{X_{26j}}{a_{26j}}, \frac{VA_j}{v_j}\right\}, \tag{5.2}$$

where X_{ij} is the amount of commodity i used to produce commodity j, a_{ij} is the ijth (ith row, jth column) element of the social accounting matrix (SAM) and represents the technical coefficient measuring the minimum amount of commodity i required to get a unit of commodity j, VA_j stands for the value added of sector j and v_j is the technical coefficient measuring the minimum amount of value added required to produce a unit of commodity j.

In turn, value added is generated from primary inputs (labour and capital), combined with a Cobb–Douglas technology, to account for the (limited) possibility of substituting one for the other:

$$VA_j = \mu_j L_j^{\gamma_j} K_j^{1-\gamma_j}, \tag{5.3}$$

where μ_j is the scale parameter of sector j, γ_j is the elasticity of labour, L_j represents the amount of labour employed in sector j and K_j represents the amount of capital used in sector j.

5.3 Demand, Preferences and Consumer Behaviour

Final demand comes from investment, exports and consumer demand from households. Concerning consumer demand, our model includes a representative consumer that demands present consumption and saves the remainder of his or her disposable income (*YD*). In turn, the consumer's *YD* equals labour and capital income, plus transfers, minus direct taxes. Taking into account how taxes are computed in the Spanish tax system, this can be analytically expressed as

$$\begin{aligned} YD = {} & w\ L + r\ K + cpi\ TPS + TROW - DT(r\ K + cpi\ TPS + TROW) \\ & - DT(w\ L - WC\ w\ L) - WC\ w\ L, \end{aligned} \tag{5.4}$$

where w and r denote input (labour and capital) prices and L and K input quantities sold by the consumer, *DT* is the income tax rate and *WC* is the tax rate corresponding to the employees' social security payment. *TPS* stands for public sector transfers to the consumer (pensions, allowances, social benefits, unemployment benefits…) and *TROW* stands for transfers from the rest of the world to the consumer. Finally, *cpi* is the consumer price index.

The consumer's objective is to maximize his or her welfare, subject to his or her budget constraint. Welfare is obtained from consumer goods CD_j ($j = 1, \ldots, 26$) and savings *SD*, according to a Cobb–Douglas utility function:

$$\begin{aligned} &\text{maximize } U(CD_1, ..., CD_{26}, SD) = \left(\prod_{j=1}^{26} CD_j^{\alpha_j}\right) SD^{\beta} \\ &\text{s.t.} \sum_{j=1}^{26} p_j CD_j + p_{inv} SD = YDISP, \end{aligned} \tag{5.5}$$

where p_{inv} is an investment price index, and α_j and β represent the elasticities of utility with respect to the consumption of good j and savings, respectively. For the sake of normalization, it is assumed that $\sum_{j=1}^{26} \alpha_j + \beta = 1$.

5.4 Modelling Pollution Emissions and Emissions Charges

We focus on emissions obtained from production activities, and we adopt a short-term approach. Chapters 6 and 7 are confined to CO_2 emissions. In Chap. 8 we enlarge the analysis by including two new pollutants: NO_X and SO_X. The model can be straightforwardly adapted to include any arbitrary number of pollutants.

The production technology is assumed to be fixed, as is the pollution intensity of all the sectors. Let E_j^m denote emissions of pollutant m (where $m \in \{CO_2, NO_X, SO_X\}$) from activity sector j ($j = 1, \ldots, 26$). Then, we have the following equation, which assumes a linear relationship between production Q_j (measured in constant euros) and emissions:

$$E_j^m = \alpha_j^m \cdot Q_j, \tag{5.6}$$

where α_j^m measures the amount of emissions of pollutant m per unit of output produced in sector j. The technical parameter α_j^m accounts for the differences in pollution intensities across sectors. This formulation overlooks abatement or technical change possibilities by implicitly assuming that pollution intensity is given. In other words, firms can reduce emissions only by cutting down production. This simplification is perhaps not realistic in the long run, but it is consistent with a short-term setting, where technology is given and substitution possibilities are limited.

We account for the possibility that the government can impose an environmental tax of t^m euros per unit of emissions. As a consequence, each sector j pays T_j^m euros for its emissions of pollutant m, where

$$T_j^m = t^m \cdot E_j^m. \tag{5.7}$$

Note that the different pollution intensity across sectors means that the same tax on pollution implies a different economic burden with respect to output. Substituting (5.6) into (5.7), the tax to be paid by sector j can be written as

$$T_j^m = \beta_j^m \cdot Q_j, \tag{5.8}$$

where $\beta_j^m \equiv t^m \cdot \alpha_j^m$ is the tax rate of sector j in terms of euro paid per euro produced because of its emissions of pollutant m. Therefore, from the viewpoint of industry, the impact of an environmental tax is similar to that of a unit tax on output, where the more polluting industries have a higher tax rate. The tax will create a wedge between the price paid by consumers and the price received by firms. We can expect the equilibrium (consumer) price to increase and equilibrium quantity to decrease. The tax creates a negative incentive for production (and, hence, for pollution), which is particularly strong for more intensively polluting sectors. So, we can expect output to decrease more in those sectors. The final impact on total output, employment and prices will be the aggregation of all the sectorial effects.

Finally, the total amount of emissions of pollutant m, E^m, equals the sum of the emissions generated by all sectors:

$$E^m = \sum_{j=1}^{26} E_j^m. \tag{5.9}$$

5.5 The Public Sector: Taxes and Expenditures

The government sets taxes to raise public revenue, makes transfers to the private sector and demands goods and services from each sector, leading to the final balance (surplus or deficit) of the public budget. Tax revenue includes revenue raised by all, direct and indirect, taxes, including environmental taxes.

Beginning with indirect taxes, and based on the Spanish tax system, taxes on output, R_P, are calculated as

$$R_P = \sum_{j=1}^{26} \tau_j \left[\sum_{i=1}^{26} a_{ij} p_i Xd_j + \left(\left(1 + EC_j \right) wl_j + rk_j \right) VA_j \right], \tag{5.10}$$

where l_j and kj are the technical coefficients of labour and capital in sector j, τ_j is the tax rate on the output of sector j and EC_j is the social security tax rate paid by employees in sector j.

Social security paid by employers, R_{LF}, is given by

$$R_{LF} = \sum_{j=1}^{26} EC_j wl_j VA_j. \tag{5.11}$$

Tariffs, $R_{T,}$ equal

$$R_T = \sum_{j=1}^{26} tar_j rowp\ a_{rwj} \mathrm{Q_j}, \tag{5.12}$$

where tar_j is the tax rate on all the transactions made with the foreign sector j, a_{rwj} represents technical coefficients of commodities imported by sector j and $rowp$ is a weighted price index of imported and exported goods and services.

R_m stands for the revenue raised by the environmental tax on pollutant m, ($m \in \{CO_2, NO_X, SO_X\}$), and can be computed by the following equation:

$$R_m = \sum_{j=1}^{26} \beta_j^m (1 + \tau_j) \left[\sum_{i=1}^{26} a_{ij} p_i Xd_j + ((1 + EC_j) wl_j + rk_j) VA_j \right] + \sum_{j=1}^{26} \beta_j^m (1 + tar_j) rowp \cdot a_{rwj} \cdot Q_j, \tag{5.13}$$

where $\beta_j^m = t^m \cdot \alpha_j^m$ is the environmental tax rate for pollutant m on sector j, expressed in terms of euro paid per euro produced.

The value added tax revenue, R_{VAT}, is given by

$$\begin{aligned} R_{VAT} = & \sum_{j=1}^{26} VAT_j(1+\tau_j)(1+\beta_j^{CO_2}+\beta_j^{NO_X}+\beta_j^{SO_X}) \\ & \times \left[\sum_{i=1}^{26} a_{ij}p_iXd_j + ((1+EC_j)wl_j + rk_j)VA_j\right] \\ & + \sum_{j=1}^{26} VAT_j(1+tar_j)(1+\beta_j^{CO_2}+\beta_j^{NO_X}+\beta_j^{SO_X})rowp \cdot a_{rwj} \cdot Q_j, \end{aligned} \tag{5.14}$$

where VAT_j is the *ad valorem* tax rate on (domestic and foreign) commodity j.

Concerning direct taxes we have, first, the social security contribution paid by employers, R_{LC} , which is given by

$$R_{LC} = WC\,w\,L. \tag{5.15}$$

Income tax, R_I, is computed from

$$R_I = DT(wL + rK + cpiTPS + TROW - WC\,L\,w). \tag{5.16}$$

Total public revenue is denoted as R and determined by the seven categories of taxes specified above:

$$\mathrm{R} = \mathrm{R_P} + \mathrm{R_{LF}} + \mathrm{R_{LC}} + \mathrm{R_T} + \mathrm{R_m} + \mathrm{R_{VAT}} + \mathrm{R_I}. \tag{5.17}$$

Tax collected in each category depends on equilibrium prices and quantities and effective tax rates, calculated directly from the SAM as a quotient between the total tax revenues and the taxable income by each type of taxes.

The government also makes transfers to the private sector, *TPS*, and demands goods and services from each sector $j = 1,\ldots,26$, GD_j. *PB* denotes the final balance (surplus or deficit) of the public budget:

$$PB = TPS \cdot cpi + \sum_{j=1}^{26} GD_j \cdot p_j - R, \tag{5.18}$$

cpi being the consumer price index and p_j a production price index before value added tax (VAT) levied on all goods produced by sector j.

5.6 Markets for Production Inputs

Labour and capital demands are computed under the assumption that firms aim at maximizing profits and minimizing their production costs. In the capital market we consider that total supply is perfectly inelastic. In the labour market, we use the following approach to the labour supply. It shows a feedback between the real wage and the unemployment rate, related to the power of unions or other factors inducing frictions in the labour market (see Kehoe et al. 1995):

$$\frac{w}{cpi} = \left(\frac{1-u}{1-\bar{u}}\right)^{\frac{1}{\beta}}, \tag{5.19}$$

where u and $\bar{u}$ are the unemployment rates in the simulation (after any specific policy is implemented) and in the benchmark equilibrium (i.e. the observed value in 1995) respectively, w/cpi is the real wage and β is a flexibility parameter. This formulation is consistent with an institutional setting where the employers decide the amount of demanded labour and workers (represented by trade unions) decide the real wage, taking into account the unemployment rate according to (5.19). If labour demand increases (decreases), the unemployment rate u decreases (increases). Consequently, there are fewer (more) available workers, now enjoying more (less) bargaining power and enabling them to demand higher (lower) real wages. If, after simulation, employment remains unchanged, the real wage will be the same as in the benchmark equilibrium. Concerning the value of the flexibility parameter, it cannot be calibrated using the SAM, because this database does not include data about unemployment. For simplicity's sake, we take in our empirical exercises $\beta = 1$.

5.7 Foreign Sector and Closure Rule

There is only one foreign sector. It comprises the rest of the world. The balance of this sector, *ROWD*, is given by

$$ROWD = \sum_{j=1}^{26} rowp \cdot IMP_j - TROW - \sum_{j=1}^{26} rowp \cdot EXP_j, \tag{5.20}$$

where EXP_j denotes exports of sector j and the other elements of the equation have already been defined above.

Regarding investment and saving, this is a *saving driven* model. The closure rule is defined in such a way that investment, *INV*, is taken as exogenous, savings are determined by consumer decision and both variables are related to the public and foreign sectors by the following accounting identity:

$$\sum_{j=1}^{26} INV_j \cdot p_{inv} + DP = SD \cdot pinv + ROWD. \tag{5.21}$$

5.8 Databases and Calibration

The main economic data used to calibrate the model in Chaps. 6 and 7 come from the aggregated 2000 social accounting matrix (SAM) for Spain. This is the most recent officially available SAM for Spain. It comprises 38 accounts, including 26 productive sectors – see the details of disaggregation in the appendix – two inputs (labour and capital), a saving/investment account, a government account, direct taxes (income tax and employees' social security contribution) and indirect taxes (VAT, payroll tax, output tax and tariffs), a foreign sector and a representative consumer (see Cardenete and Fuentes 2007, for details on the SAM).

The values for the technological coefficients, the tax rates and the coefficients of the utility function are calibrated to reproduce the 2000 SAM as an initial or benchmark equilibrium for the economy. In the simulations, the wage is taken as numeraire ($w = 1$) and the other prices vary as required to meet equilibrium conditions.

In order calibrate the α_j^m coefficients of pollution intensity, we also use sector data for the considered pollutants. Specifically, we use data from the satellite accounts on atmospheric emissions published by the Spanish Statistical Institute (INE) and the Spanish Institute for Energy Efficiency and Diversification (IDAE) of the Spanish Ministry of Industry. In all our applications, all the calculations (including the calibration, but also the simulation and optimization exercises) are performed using GAMS software.

The data in a social accounting matrix (SAM) are mostly used to implement empirical multisectoral and computable general equilibrium (CGE) models. These are then used to perform economic analyses and policy simulations. Data quality and/or currentness are therefore of critical relevance for appraising and evaluating model results and making them more credible in the eyes of policy makers. Unfortunately, statistical offices do not produce timely and regular data of the kind needed in multisectoral modeling. Data collection and compilation is expensive, and quite often there is inevitably too big a time lag in the production and publication of official statistics.

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Chapter 6
Designing Efficient Policies in Terms of Economic and Environmental Objectives

Abstract The aim of this chapter is to determine efficient policies in terms of economic and environmental objectives. Efficiency is a particularly desirable property for policies when taking into account environmental concerns, since, on the one hand, any environmental policy will be better accepted if it does not imply big economic costs and, on the other hand, economic targets should be pursued with the minimum environmental impact. First, we present a two-objective problem, assuming that the government is only concerned about increasing economic growth and reducing CO_2 emissions. We conclude, as expected, that tougher environmental goals monotonically entail higher environmental tax rates. Indeed, if we want to cut down emissions by more than 1%, the model recommends setting the tax rate at its highest feasible value. Afterwards, we design a more complex and more realistic exercise by including additional economic objectives such as unemployment, public deficit and fiscal pressure. We find that there are some trade-offs across objectives which are by no means straightforward or even monotonic. The conclusion is that economic growth on its own cannot be considered as a sufficient indicator of all economic policy concerns, and a more accurate analysis requires explicitly including all key indicators.

6.1 Introduction

In this and the next two chapters, we move from policy making with just economic objectives to a framework where we address public policy design under the assumption that policy makers are concerned about both economic and environmental objectives. Thus, we extend the research approach presented in the earlier chapters by adding environmental concerns to the policy design problem.

The purpose of this chapter is to determine *efficient policies* in terms of economic and environmental objectives. As shown in Chaps. 3 and 4, a policy (i.e. a combination of the policy instruments) is said to be efficient if there is no other policy providing better value for some policy objective without being worse for any

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other policy objective. The main motivation for finding efficient policies is to attain each objective at the least possible cost for the other relevant objectives. As discussed in Chaps. 3 and 4, this is a very important property for economic policy in general. Nevertheless, it is especially significant when taking into account environmental concerns. On the one hand, any measure adopted to improve the quality of the environment will be easier to implement and better accepted by society if it does not imply a sharp reduction in economic growth, a large increase of the public deficit, a very high inflation rate and so on. On the other hand, another current policy mandate is to pursue economic targets with the minimum environmental impact.

As shown in Chap. 4, multiobjective programming (MOP) was used in André and Cardenete (2009a) to compute efficient fiscal policies in terms of economic growth and inflation (see Sect. 4.3) and in André and Cardenete (2009b) to determine efficient subsidy policies in a regional economy (see Sect. 4.5). In this chapter, we enlarge the scope of this approach by including environmental on top of economic concerns. Another novelty with respect to these articles is the fact that we use a more recent database. Specifically, we calibrate our CGE model (see Chap. 5) using the Spanish SAM at 2000 acquisition prices. This is the most recent officially available SAM for Spain (see Cardenete and Fuentes 2007, for technical details of the SAM). The material presented in this chapter is based on André and Cardenete (2008).

6.2 Setting the Policy Design Exercise

To fully define our policy design exercise, we need to choose the policy instruments and the policy objectives.

6.2.1 Policy Instruments

Regarding policy instruments, we focus on fiscal policy and we include an environmental tax. Briefly, we consider taxes and public expenditure as policy instruments. Concerning taxes, we assume that the government uses the average rate of the following taxes as policy instruments:

- Direct Taxes
  - Income tax
  - Employee social security contribution
- Indirect Taxes
  - VAT (allowing for a different tax rate in each activity sector)
  - Employer social security contribution (allowing for a different tax rate in each activity sector)
- Environmental Taxes
  - Tax on CO_2 emissions (as explained in Chap. 5)

Concerning expenditures, we consider that the government can decide the volume of public expenditure in each activity sector.

For the sake of realism, we also include some constraints on the feasible values of the policy instruments. Specifically, we assume that none of the instruments can vary more than 5% with respect to the real value observed in 2000. If we denote by X the vector of tax rates (excluding the emissions charge rate) and expenditures by sectors, and by X_0 the observed value of those variables in 2000, the set of constraints is

$$0.95X_0 \leq X \leq 1.05X_0.$$

On the other hand, public expenditure is allowed to vary up to 5% by sector, but total expenditure must be equal to the observed value in 2000 in order to rule out very unrealistic solutions in terms of the public budget. Concerning the emissions charge rate, we set a lower bound equal to 0 (meaning that pollution cannot be subsidized, although we account for the possibility of no tax being levied) and an upper bound equal to €0.02 per unit of pollution (kton/year of CO_2 emissions). The upper bound is set to prevent the tax burden being excessively high in terms of output.[1]

Concerning policy objectives, we present two different policy design exercises. The first (presented in Sect. 6.3) is a two-objective problem, assuming that the government is only concerned about two objectives. The first is to foster economic activity as measured by the yearly growth rate of the real gross domestic product (GDP), denoted as g_Q,

$$g_Q \equiv \frac{GDP_{2000} - GDP_{1999}}{GDP_{1999}} 100, \tag{6.1}$$

where GDP_{1999} is the gross domestic product of 1999, which is taken to be a given exogenous value. The GDP for 2000 is the result of aggregating output across sectors. Since GDP_{1999} is given, maximizing growth is equivalent to maximizing GDP_{2000}. We chose the growth rate since it is a more common indicator in practice.

The second objective is to reduce CO_2 emissions. Specifically, the policy objective that we include is the growth rate of emissions against the observed value in 2000 (the idea is to measure by how much we could reduce emissions through a policy change as compared to what was observed in reality, i.e. without making any change):

$$g_E = \frac{E - E_{obs}}{E_{obs}} \cdot 100, \tag{6.2}$$

[1]Specifically, when the environmental tax rate is set at its highest rate, the most polluting sector (which is sector 7, "Production and distribution of electricity") has an average tax rate of 8% in terms of output.

where E is the value of emissions resulting from the equilibrium of the model and E_{obs} is the observed 2000 value.

Later on (in Sect. 6.4), we look at a more realistic exercise by including some additional economic objectives, such as unemployment, public deficit and fiscal pressure.

6.3 Efficient Policies Regarding Growth and Emissions

As a first approach to the design of efficient policies, we assume that the government is concerned only about two policy objectives: increasing growth and reducing CO_2 emissions.

Table 6.1 shows the so-called *payoff matrix*, which is obtained by optimizing each objective separately. Remember that, in these optimization problems, apart from the constraint on the policy instruments, we include all the CGE model equations in order to guarantee that the solution is consistent with the model (i.e. that the observed values correspond to an economic equilibrium). We conclude that if the government designed its policy just to maximize growth, it would be possible to get a growth rate equal to 4.94%. Nevertheless, this policy would imply, as a side-effect, that CO_2 emissions would increase by 0.40% over the observed value in 2000.

If, on the other hand, the government put every effort into controlling pollution, it would be possible to reduce CO_2 emissions by more than 2% over the observed value. The economic consequence of this policy would be an economic growth rate of 3.45%, i.e. about 1.5 below the maximum feasible value (see the second row of Table 6.1). Therefore, we conclude that there is a conflict between both objectives in the sense that it is not possible to get the optimal value of both at the same time.

By comparing the value of the policy instruments in these two solutions, we conclude (as one might expect) that maximizing growth is consistent with fixing the environmental tax rate at its lower bound, zero. On the other hand, the emissions minimizing solution entails setting the highest possible value for this tax (€0.02 per kton/year of emissions). Moreover, the other indirect taxes (VAT and social security contributions) would have to be reduced to maximize growth or increased to minimize emissions. Additionally, both solutions entail increasing direct taxes (income tax and employee social security payments). Finally, the growth-maximizing solution requires shifting public expenditures to sector 17 ("vehicles") and

Table 6.1 Payoff matrix growth-CO_2 emissions

	g_Q, Econ. Growth (%)	g_E, Emis. Growth (%)
Max g_Q	**4.94**	<u>0.40</u>
Min g_E	<u>3.45</u>	−**2.16**

Bold figures represent ideal values and underlined figures anti-ideal values for each objective

minimizing emissions is consistent with increasing public expenditure in sector 25 ("other services"), which is one of the least polluting sectors.

The next step is to construct the set of efficient policies. As we know, the idea is to get any level of economic growth with the minimum value of emissions or, alternatively, to achieve environmental goals with the maximum feasible growth. We perform this task using the so-called *constraint method* by optimizing an objective while setting a parametric limit for the other one (see Sect. 3.5). In this case, we made a grid of ten values in the feasible range of g_E , which is given by the interval [−2.16, 0.40]. Let g_{En} ($n = 1,\ldots,10$) denote the nth value of the grid. For each of those values, we maximize growth by setting maximum emissions values no greater than g_{En}, i.e.

$$\begin{aligned} &Max\ g_Q \\ &s.t. \\ &g_E \leq g_{En} \end{aligned} , \qquad (6.3)$$

where, apart from the parametric restriction on g_{En}, we also need, as always, to impose the aforementioned constraints on the policy instruments and all the equations of the CGE model. By construction, each of these problems provides an efficient solution. The results of these calculations are shown in Fig. 6.1.

The first conclusion from Fig. 6.1 is that the relationship between both variables is monotonically increasing, i.e. the higher the level of emissions that the government is willing to accept, the higher the growth rate it can achieve. Or, symmetrically, tougher environmental targets imply lower growth rates.

As an additional insight, note that the slope of the efficient frontier is not constant. Indeed, the slope is higher for low values of emissions than for higher values. The interpretation of this result is that, as the government pursues higher

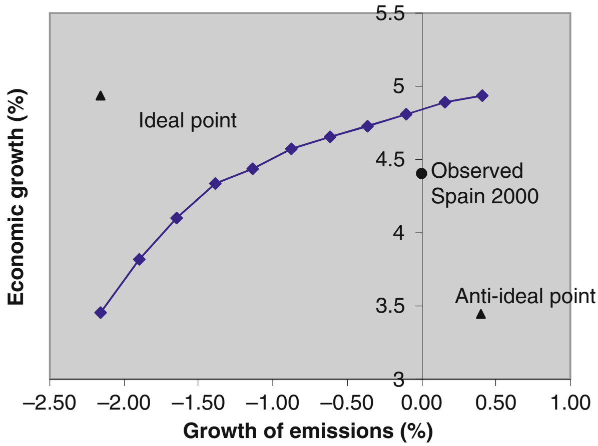

Fig. 6.1 Efficient policies (growth vs. emissions)

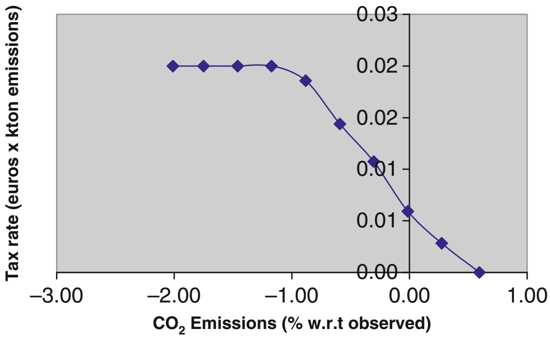

Fig. 6.2 Environmental tax across the efficient frontier

growth levels, the marginal cost in terms of additional emission increments is increasing. Or, symmetrically, setting tougher environmental goals entails increasing costs in terms of reductions in the growth rates.

Figure 6.1 also shows the observed combination of growth and emissions in Spain 2000, i.e. $g_E = 0$ (by construction) and $g_Q = 4.4$.[2] Note that the observed combination is strictly below the efficient frontier. This appears to suggest that the policy actually followed by the government could be improved in terms of efficiency if it were confined to the two policy objectives considered here. Actually, by choosing an alternative combination of the policy instruments, it would be possible to get about 0.4 additional points of growth with the same emissions. Alternatively, it would also be possible to get the same growth rate while reducing emissions by about 1% below the observed value.

Figure 6.2 shows the value of the emissions charge throughout the efficient frontier. As expected, tougher environmental goals monotonically entail higher environmental tax rates. As a matter of fact, if we want to cut down emissions by more than 1%, the model recommends setting the tax rate at its highest feasible value. Softer environmental goals are consistent with lower tax rates and, as the policy preferences move towards maximizing growth (while disregarding pollution), the optimal emissions charge tends to zero.

6.4 Efficient Policies with more than Two Criteria

In the previous section we have simplified the issue by assuming that the government is concerned with a single economic objective, namely, real growth. The aim of this section is to design a more realistic exercise by including some additional economic objectives. Specifically, we include unemployment, u (see Chap. 5), public deficit, *PD*, and fiscal pressure, *FP*, defined as total tax collections as a

[2]Source: INE, Spanish Statistical Institute.

Table 6.2 Payoff matrix with five objectives

	g_Q (%)	g_E (%)	u (%)	PD (€10^6)	FP (%)
Max g_Q	**4.94**	0.40	13.10	17,588	33.06
Min g_E	3.45	−**2.16**	15.28	24,545	34.84
Min u	4.94	0.40	**13.09**	17,680	33.05
Min PD	4.05	−0.79	14.41	**13,817**	34.84
Min FP	4.44	0.16	13.83	16,023	**32.96**

Bold figures represent ideal values and underlined figures anti-ideal values for each objective

percentage of GDP. We assume that the government aims to minimize the value of all these three objectives.

Table 6.2 represents the new payoff matrix with the added criteria. As before, each row shows the results of a single-criterion problem involving the optimization of a single objective and disregarding the others. As always, the numbers in the main diagonal (printed in bold type) are the optimal values of all each objective and altogether represent the so-called *ideal point*. In each column, the worst value for each objective (the minimum growth rate, the maximum increment in emissions, and so on) is underlined. All these values jointly represent the so-called *anti-ideal point*.

From Table 6.2 we can draw the following conclusions. Firstly, maximizing growth and minimizing unemployment (objectives 1 and 3) appear to be fully consistent with each other, since both single-criterion problems provide essentially the same solution (with negligible numerical differences). Therefore, there is the same degree of conflict between emissions minimization and economic growth (see Sect. 6.3) as there is between emissions minimization and unemployment minimization. Actually, minimizing unemployment entails 0.40% more emissions, whereas minimizing emissions leads to the worst possible value of unemployment, with more than 2% points above its ideal value. On the other hand, the second row shows that there appears to be severe conflict between emission minimization and all the economic objectives, since they all achieve their anti-ideal values.

A more detailed analysis reveals that the conflict between pollutant emissions and public deficit is not as straightforward as it may seem at first sight. At first, minimizing public deficit is compatible with a noticeable reduction of emissions (−0.79%). But if we try to get emissions down from this point to their minimum value, this additional effort will lead to a sharp increase in the public deficit up to €24,545 million, that is, more than a 70% increment over its ideal value. These results suggest that there is a non-monotonic relationship between the two variables. A similar conclusion is reached concerning the relationship between emissions and fiscal pressure. Figure 6.3 shows the behaviour of unemployment, public deficit and fiscal pressure at different points of the growth-emissions frontier shown in Fig. 6.1. Notice that, while the environmental goal gets softer (and the economic growth objective becomes more demanding) the unemployment results improve. Nevertheless, this movement does not have a uniform effect on public deficit and fiscal pressure.

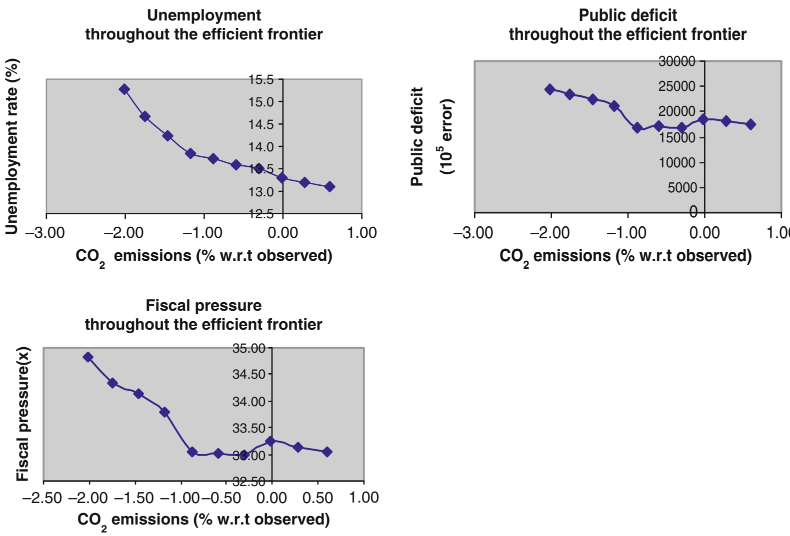

Fig. 6.3 Evolution of unemployment, public deficit and fiscal pressure throughout the efficient emissions / economic growth frontier

On the other hand, Table 6.2 also shows that there is some conflict among economic objectives. The most noticeable case is public deficit, the minimization of which reduces growth by almost 1 point below its ideal value, leads to an extra point of unemployment with respect to the minimum attainable value and, as one might expect, a high value of fiscal pressure.

To summarize, we can conclude that economic growth cannot be taken as a sufficient indicator of all policy makers' relevant economic objectives. Moreover, the relationships among different policy objectives are by no means straightforward. In order to get meaningful results in terms of all the objectives, they should all be explicitly incorporated into the policy design problems.

Enlarging the set of policy objectives necessarily increases the dimension and the complexity of the problem. Typically, the increased dimension also brings an exponential increment in the number of efficient solutions. Such a problem can be handled with different computational techniques. Our aim here is not to offer a systematic exploration of the efficient set, but simply to illustrate the use of alternative techniques that policy makers could use to find their own efficient solutions. Thus, we present two alternative ways to tackle this multiobjective problem. The first possibility is to again use the *constraint method*. This can be done by optimizing a single objective while the others are limited by parametrical constraints. As a first approximation, we will take the observed values in Spain 2000 for each of the objectives as parametrical limits:

$$g_Q = 4.4 \; g_E = 0\% \; u = 14.0\% \; PD = 15957 \text{ mill. } FP = 33\%.$$

Firstly, we solve the following problem

$$Max\ g_Q$$

$$s.t. \quad g_E \leq 0, u \leq 14.0, PD \leq 15,957, FP \leq 33 \tag{6.4}$$

and all the equations of the CGE model.

This involves maximizing growth while restricting the other objectives to get a value that is not worse than the observed values. After solving this problem, we get the following values for all the policy objectives (also shown in the first row of Table 6.3):

$$g_Q = 4.67 \ g_E = 0 \quad u = 13.48 \quad PD = 15,957 \quad FP = 32.86.$$

Note that this solution Pareto-dominates the observed situation, since we get, at the same time, a higher growth rate and lower unemployment and fiscal pressure, while pollutant emissions and public deficit are unchanged. The mere existence of this solution implies that the observed policy is inefficient with respect to these five objectives given the feasible set of policy instruments.

By doing similar calculations for each objective, we get the solutions shown in Table 6.3. The second row of this table shows that, with the same growth as observed in 2000, it would be possible to reduce emissions by about 1% below the observed value. Moreover, this solution would not imply any increment of public deficit and would provide, as by-products, a slight reduction in unemployment and fiscal pressure. Similar conclusions can be obtained from the other rows of Table 6.3.

These calculations provide a first approximation to the set of efficient policies. Nevertheless, as noted in Sect. 4.5, when using the constraint method, efficiency is guaranteed only if all the parametric constraints are binding on the solution. Although all the solutions in Table 6.3 Pareto dominate the observed situation, they all have some constraint(s) that is(are) not binding. Therefore, we cannot be sure that these solutions are efficient. A possible way to get efficient solutions is to make all the constraints tougher by increasing the limit of the "more is better" constraints and reducing the limit of the "less is better" constraints until we get a solution where they are all binding. A sensible way to enact this adjustment procedure is to take into account the policy maker's preferences over all the objectives.

Table 6.3 Results obtained by applying the constraint method to the five objectives considered

	g_Q (%)	g_E (%)	u (%)	PD (€10^6)	FP (%)
Max g_Q	4.67	0.00	13.48	15,957	32.86
Min g_E	4.40	−1.03	13.86	15,957	32.90
Min u	4.46	0.00	13.48	15,878	32.96
Min PD	4.40	−0.54	13.88	14,578	32.74
Min FP	4.40	−0.47	13.88	15,054	32.74

Another approach to get efficient solutions is to use the so-called *weighting method* (see Sect. 3.5). Thus, by resorting to the strategy followed in Sect. 4.5 a weighted average of all the normalized objectives is maximized, as follows:

$$\omega_Q \frac{g_Q - g_{Q*}}{g_Q^* - g_{Q*}} + \omega_E \frac{g_{E*} - g_E}{g_{E*} - g_E^*} + \omega_u \frac{u_* - u}{u_* - u^*} + \omega_{PD} \frac{PD_* - PD}{PD_* - PD^*} + \omega_{FP} \frac{FP_* - FP}{FP_* - FP^*}, \tag{6.5}$$

where Y^* represents the ideal value and Y_* the anti-ideal value of objective Y ($Y = g_Q, g_E, u, PD, FP$), as shown in Table 6.3. Since the objectives are measured in different units, they cannot be aggregated if they are not normalized. This normalization can be done using the difference between the ideal and the anti-ideal values. By construction the individual ratios shown in equation (6.5) are bounded by zero (when the anti-ideal value is reached) and one (when the ideal is attained). The weighting coefficients ω_i are preference parameters measuring the importance the policy maker gives to each objective. As an example, assume that the policy maker considers that all the objectives are equally important and, therefore

$$\omega_Q = \omega_{\mathrm{E}} = \omega_u = \omega_{PD} = \omega_{FP}.$$

Maximizing function (6.5) given this symmetric weighting provides the following value for the objectives:

$$g_Q = 4.42 \quad g_E = -0.9 \quad u = 13.83 \qquad PD = 14552 \quad FP = 32.69.$$

Note that this solution Pareto-dominates the observed situation since it provides better values for all the objectives and it is efficient by construction. Using different combinations of the weighing parameters, it is possible to find different efficient policies corresponding to different decision-maker preferences. As an extreme case, if $\omega_i = 1$ for a single objective i and $\omega_\varphi = 00$ for the rest, we can represent a situation where the policy maker is concerned about objective i only and does not care about the others. The resulting problem is a single-criterion optimization problem like the ones solved to get the payoff matrix.

6.5 Conclusions

As we know, both economic and environmental objectives are relevant for the design of public polices. The concept of *efficient policies* allows us to simply represent the aim to get as good as possible results for environmental objectives while assuming the lowest possible loss in terms of economic objectives, and vice versa.

Adding environmental on top of economic objectives in policy design using a CGE model is a methodological innovation with respect to previous works. Another novelty of this application (this time a statistical one) is to use the recently developed 2000 SAM for Spain.

After calibrating our model for the Spanish economy and choosing the relevant objectives, we can build an approximation of the set of efficient policies. This way, we can estimate how much growth has to be sacrificed for each environmental goal in terms of reduced economic growth. It is also possible to determine in which direction the mixed policy should be reformulated in order to get efficient combinations of economic activity and environmental impact.

Our results show that a properly targeted policy (basically by reducing indirect taxes, while increasing direct taxes and shifting public expenditures to some specific sectors) would be able to get a growth rate of around 5%, providing we accept that pollutant emissions would be 0.6% higher than the benchmark value. On the other hand, an aggressive *green* policy could yield 2% fewer of emissions if policy makers were willing to accept a lower economic growth rate. This could be done by taxing emissions and raising other taxes, as well as retargeting public expenditure away from very polluting towards low polluting sectors, such as "other services".

By comparison with the efficient frontier, the observed policy in Spain 2000 could be reformulated to provide the same level of economic activity with 1% fewer emissions or, alternatively, to grow 0.4% more with the same CO_2 emissions.

We have also shown how this model can be enlarged to include more than two objectives. This enlargement complicates the computations, but, on the other hand, it is also more realistic.

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Chapter 7
Compromise Policies: An Integration of Economic and Environmental Criteria

Abstract The set of efficient policies could be too large to serve as a useful guide for real action. In this chapter we use compromise programming (CP) to reduce the number of eligible policies and get more precise policy recommendations than those derived from the efficient set itself. Apart from being efficient, so-called *compromise policies* have the property of minimizing the distance to the ideal point. We first perform a CP exercise which is a natural continuation of Chap. 6. We seek to offer policy recommendations that are as close as possible to the maximum growth rate and the minimum level of CO_2 emissions. We conclude that the compromise set basically consists of a single point, which turns out to be a very handy property for policy making in practice. We also present a review of some general interesting properties of the compromise set and interpret its usefulness for our case. Finally, we broaden the scope of our exercise by solving a policy-making problem with four (rather than two) criteria. We discuss that, although not all the interesting properties of the compromise set can be guaranteed, it is still a useful device for real policy making.

7.1 Introduction

In Chap. 6 we used multiobjective programming (MOP) to identify the set of efficient policies in terms of economic and environmental objectives. Since, as we know, efficiency is a minimum requirement for any decision to be rational (see, for example, Ballestero and Romero 1998, p. 7), eliminating inefficient alternatives can be seen as a required preliminary step to identify a set of eligible policies. However, as we already know (see Chap. 4), the set of efficient policies could be very large and, therefore, the efficient set itself might not be very useful as a guide for real action.

This chapter is a natural continuation of Chap. 6. Starting from the same policy setting and taking the set of efficient policies identified in Sect. 6.3 as given, we use compromise programming (CP), as was reviewed in Sect. 3.6, to determine the

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so-called compromise set. As illustrated in Sect. 4.4, CP is a more selective technique than MOP for reducing the number of eligible policies and getting more precise policy recommendations than those derived from the efficient set itself (see also André et al. 2008). Indeed, we refer to policies derived from the compromise set as *compromise policies*. Apart from being efficient by construction, these policies have the additional property that the distance to the ideal point is minimized. In our case, we seek to guarantee that the results of our policy recommendations are as close as possible to the highest feasible growth rate and the lowest attainable level of pollutant emissions.

In Sect. 7.2 we recall the basic elements of the policy design setting, which follow from Chap. 6. In Sect. 7.3 we obtain the compromise set of our two-criteria (growth vs. emissions) policy exercise. In this case, we conclude that the compromise set basically consists of a single point. In Sect. 7.4 we recall some interesting properties of the compromise set and interpret its usefulness for our case. In Sect. 7.5 we illustrate how CP can be used in a broader framework with more than two criteria. Section 7.6 illustrates how the observed policy can be evaluated with the help of the compromise set. Finally, Sect. 7.7 summarizes the main findings of this chapter.

7.2 Preliminaries

As in Chap. 6, we start with an application focused on real growth and CO_2 emissions as policy objectives. Concerning policy instruments, once again, we use fiscal policy together with an environmental tax on CO_2 emissions as the set of policy instruments. We also keep the constraints introduced in Chap. 6 on the policy instruments. Specifically, public expenditure by sectors and the average rate of all taxes (except the emissions charge) cannot vary more than 5% with respect to the real value observed in 2000, whereas total expenditure must remain equal to the observed real value. Finally, for the environmental tax rate, we keep a lower bound equal to 0 and an upper bound equal to €0.02 per unit of pollution (kton/year of CO_2 emissions).

For convenience, we reproduce here the payoff matrix of this MCDM problem (Table 7.1).

As we know, the elements of the main diagonal give the so-called ideal point, which, in this case, consists of a growth rate of 4.94% and 2.16% fewer emissions than in the benchmark situation. Since the ideal point is not feasible, it would be

Table 7.1 Payoff matrix growth-CO_2 emissions

	g_Q, Econ. Growth (%)	g_E, Emis. Growth (%)
Max g_Q	**4.94**	<u>0.40</u>
Min g_E	<u>3.45</u>	−**2.16**

Bold figures represent ideal values and underlined figures anti-ideal values for each objective

unrealistic to pretend that this is a government policy target. In CP, though, the ideal point is especially relevant as an anchor for identifying the most preferred policies. Note also that the minimum element of the first column of this payoff matrix (3.45%), as well as the maximum element of the second column of this matrix (0.40%) represent the anti-ideal values for the economic real growth and CO_2 emissions criteria, respectively. These figures are useful for normalizing purposes, as well as for determining the feasible ranges of the two policy objectives considered.

7.3 Obtaining the Compromise Set with Two Objectives

If we assume that the government is equally concerned about growth and CO_2 emissions deviating from their ideal values, then both deviations should be equally weighted when computing the distance to the ideal point. By minimizing the distance function L_p as shown in Sect. 3.6, different best compromise policies can be obtained. Table 7.2 shows the best compromise policies for metrics 1, 2 and ∞. Figure 7.1 illustrates these values together with the efficient policies identified in Chap. 6.

Table 7.2 Best compromise solutions for metrics 1, 2 and ∞ with two criteria

	Growth (%) g_Q	Emissions (%) g_E
Min L_1	4.45	−1.12
Min L_2	4.42	−1.17
Min L_∞	4.39	−1.22

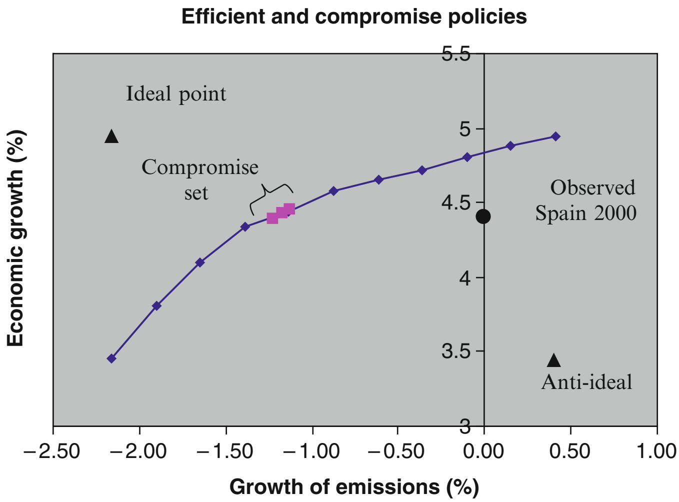

Fig. 7.1 Efficient frontier and compromise set

Noteworthy is the fact that the size of the compromise set for the analysed case is very small, especially compared with the size of the whole efficient set. However, this is not generally applicable but is an empirical fact depending upon the numerical characteristics of the analysed problem. In any case, when the size of the compromise set is as small as it is in our exercise, then the policy making task is rather easy. In short, for our particular case, the compromise set is a very operational tool for policy making in practice.

Rounded to one decimal place (which is usually the case in official macroeconomic data), the compromise set can be roughly seen as a single point with about 4.4 points of growth and about 1.2% fewer emissions than in the benchmark situation. Recall that, in those cases where the size of the compromise set is large, we can always resort to the method of the displaced ideal proposed by Zeleny (1974) in order to reduce its size (see Sect. 4.4). This step looks to be unnecessary in this case.

On the other hand, the compromise set has some desirable properties that are discussed in the following section.

7.4 Interpreting the Compromise Set

As we know from Chap. 3, apart from the general properties of CP, L_p solutions have some additional desirable properties in bi-criteria cases. First, metrics $p = 1$ and $p = \infty$ define a bounded subset on the Pareto efficient frontier, called compromise set, where the other best compromise solutions (policies) fall. This boundedness of the efficient set is very convenient for computational purposes.

As a second property, the L_1 solution represents the compromise that maximizes the aggregated achievement (or minimizes the aggregated disagreement) of the criteria considered (in this case, economic growth and CO_2 emissions), that is, L_1 can be viewed as the solution representing *maximum efficiency*. The L_∞ solution represents the compromise that maximizes the balance among the criteria considered in the sense that the maximum deviation from the ideal value is minimized. For the two-criteria case, and for $p = \infty$, the degree of achievement is always the same for both criteria, that is, L_∞ can be interpreted as the solution of maximum equity (Ballestero and Romero 1991, 1994).

Table 7.3 shows the (normalized) disagreement for each objective, as defined by

$$d_Q = \frac{g_Q^* - g_Q}{g_Q^* - g_{Q*}} \text{ and } d_E = \frac{g_E - g_E^*}{g_{E*} - g_E^*}.$$

Table 7.3 Disagreement for each objective in points of the compromise set

	d_Q	d_E	$L_\infty \equiv Max\{d_Q, d_E\}$	$L_1 \equiv d_Q + d_E$
Min L_1	0.33	0.40	0.40	0.73
Min L_2	0.34	0.39	0.39	0.73
Min L_∞	0.37	0.37	0.37	0.74

Table 7.3 also shows the maximum disagreement (i.e. the L_∞ distance) and the aggregated disagreement (i.e. the L_1 distance). Note that the L_1 compromise policy is better from an aggregated point of view since the aggregated disagreement (0.73) is minimized. Though slightly larger, rounded to two decimal places total disagreement is roughly the same in the L_2 solution. On the other hand, the L_∞ compromise policy guarantees the same degree of discrepancy or achievement ("perfect balance") for both objectives. This ensures that the maximum disagreement is 0.37, which is slightly smaller than the maximum discrepancy obtained by the L_1 solution (0.40). Nevertheless, the differences among the three solutions provided in Table 7.3 are remarkably small, and they can be seen as negligible from a policy-making perspective. Finally, it should be noted that, since the whole compromise set is bounded by the L_1 and the L_∞ solutions, the differences between these extreme points represent an upper bound for the differences between any two arbitrary L_p solutions.

Assume that the government preferences can be represented by a utility function (U) depending on the values of the policy objectives. Then, the third interesting property is that, under reasonable conditions, the compromise set can be considered as a good surrogate of the utility optimum. To justify this statement we resort to a theorem demonstrated by Ballestero and Romero (1991). This theorem provided a condition for the maximum of U to belong to the compromise set. In our case, the policy objectives are g_Q and g_E. Since g_E is a "less is better" objective, the government's utility function can be written as $u(g_Q, -g_E)$ in order to fit our problem to the setting described by Ballestero and Romero. The theorem implies that the utility maximum belongs to the compromise set if and only if the following condition holds:

$$MRS(g_Q, -g_E) = U_1/U_2 = 1 \text{ on the } L_\infty \text{ path } d_Q = d_E$$

where MRS represents the marginal rate of substitution between the two objectives (g_Q and $-g_E$), and U_1 and U_2 are the corresponding partial derivatives of U with respect to them (i.e. a way to measure *marginal utilities*). The above condition seems theoretically and empirically plausible since it simply implies a behaviour that is coherent with the diminishing *MRS* law. For more details about the economic soundness of the condition see Ballestero and Romero (1994). Moreover, Morón et al. (1996) proved the existence of a large family of utility functions satisfying the above condition. This strengthens the idea that the compromise set is a good surrogate of the utility optimum.

As a fourth desirable property of the compromise set, the interpretation given to the two bounds L_1 and L_∞ (maximum efficiency and maximum equity, respectively) leads to the idea of joining both solutions through a convex combination that represents a utility or social welfare function (Romero 2001). Thus, the utility function for our macroeconomic exercise can be written as follows:

$$Max\,U = -\left\{(1-\lambda)Max\left[\frac{g_Q^* - g_Q}{g_Q^* - g_{Q*}}, \frac{g_E - g_E^*}{g_{E*} - g_E^*}\right] + \lambda\left[\frac{g_Q^* - g_Q}{g_Q^* - g_{Q*}} + \frac{g_E - g_E^*}{g_{E*} - g_E^*}\right]\right\}.$$

For $\lambda = 1$, we have the L_1 solution and for $\lambda = 0$ the L_∞ solution. For intermediate values of the control parameter λ belonging to the open interval (0,1), compromise policies, if they exist, can be obtained. Interestingly, the λ parameter can be interpreted as measuring how important the aggregate deviation from the ideal point is as compared to the balancedness of the solution. In short, control parameter λ trades off efficiency against balance in policy objective achievement. Moreover, André and Romero (2008) showed that, in a two-criteria setting within a differentiability context, this procedure is equivalent to using standard compromise programming, and it is possible to find a one-to-one mathematical relationship between λ and p.

7.5 Constructing the Compromise Set with more than Two Policy Objectives

At the cost of some additional computational burden, compromise programming can also be used to address problems with more than two criteria. As an illustration, consider now that the government is concerned about four policy objectives: apart from increasing growth and reducing emissions, it is also interested in cutting down unemployment (u) and public deficit (PD). Table 7.4 is the new payoff matrix enlarged with four policy objectives.

In the new payoff matrix we conclude that maximizing growth and minimizing unemployment provide exactly the same solution, and, hence, there is no conflict between these objectives. On the other hand, minimizing emissions strongly conflicts with all the economic objectives since it delivers the worst outcome for all of them (minimum growth rate, maximum unemployment and maximum public deficit).

The new ideal point is a vector with four elements (printed in bold type along the main diagonal of Table 7.4), and the anti-ideal point is again defined by the worst value of each objective (underlined in the table). We can use these anchor values as a starting point to determine the best compromise policies for the government. Table 7.5 shows the results of these calculations, again under the assumption that the government attaches the same weight to the deviation of all the objectives considered against the ideal value.

In our exercise, the best compromise set with four objectives has in common with the two-objective case that it is remarkably small. Specifically, minimizing the

Table 7.4 Payoff matrix with four objectives

	g_Q (%)	g_E (%)	u (%)	PD (10^6 €)
Max g_Q	**4.94**	0.40	**13.09**	17,696.49
Min g_E	3.45	−**2.16**	15.28	24,536.94
Min u	**4.94**	0.40	**13.09**	17,696.49
Min PD	4.12	−0.99	14.19	**13,743.06**

Bold figures represent ideal values and underlined figures anti-ideal values for each objective

Table 7.5 Best compromise solutions for metrics 1, 2 and ∞ with four criteria

	g_Q (%)	g_E (%)	u (%)	PD (10^6 €)
Min L_1	4.46	−1.08	13.78	15,093.05
Min L_2	4.45	−1.08	13.78	15,094.54
Min L_∞	4.40	−1.24	13.86	17,636.88

Table 7.6 Disagreements in the compromise set

	d_Q	d_E	d_u	d_{PD}	L_1	L_∞
Min L_1	0.32	0.42	0.31	0.13	1.19	0.42
Min L_2	0.32	0.42	0.31	0.13	1.19	0.42
Min L_∞	0.36	0.36	0.35	0.36	1.43	0.36

L_1 and the L_2 distances provides essentially the same solution. The L_∞ solution is not the same, especially for public deficit, but it is still true that the compromise set is rather small and, therefore, it can be seen as a rather precise guide for policy design. Table 7.6 shows the normalized deviation or disagreements for all the objectives.

Once again, the L_1 compromise policy (which is essentially the same as the L_2 solution in this case) provides the minimum total disagreement (1.19). However, this comes at the cost of having a relatively large disagreement on one of the criteria (specifically, the deviation for emissions is 0.42), whereas the L_∞ compromise policy results in a larger aggregate deviation (1.43), whereas it guarantees that no disagreement exceeds 0.36. Therefore, in practice, moving from the L_1 solution to the L_∞ solution implies an improvement in emissions but a worse result for all the economic variables.

Table 7.7 shows the values of the policy instruments that should be implemented in order to achieve the results for the policy objectives in the compromise set. These can be understood as the policy recommendations derived from the CP model for the government. All the values, except the ecotax are expressed as the rate of change of the recommended value for each instrument with respect to the benchmark value. Since the emissions charge is zero in the benchmark situation, we cannot compute the rate of change of this tax, and we present the marginal (and average) rate instead.

From this table, we can obtain the following conclusions. A first general result is that the policy recommendations in all three solutions are very similar and, in most cases, they are exactly the same. This again suggests that the compromise set is very small and can, in practice, be seen basically as a single point. Specifically, the policy recommendations for the L_1 and the L_2 solutions are almost the same, whereas there are some additional (but still moderate) differences with respect to the L_∞ solution.

Concerning more specific conclusions, the model recommends reducing as much as possible public expenditure at all the points of the compromise set in sectors 13, 17, 19 and 24 and increasing it in sector 26 (while there is some discrepancy about sector 25). The model also recommends reducing most traditional taxes and setting the tax rate of the emissions charge at its highest admissible level. Some recommended

Table 7.7 Value of the policy instruments at different points of the compromise set. All instruments marked with (*) –all except the ecotax- are measured in rates of change with respect to the benchmark situation. The value of ecotax corresponds to the marginal (and average) rate of the emissions charge

Policy instruments		L_1	L_2	L_∞	Policy instruments		L_1	L_2	L_∞
Direct tax (*)		−3.3	−2.3	−0.5	Soc. Sec. Employees (*)		−0.1	−4.5	4.8
Indirect tax	Sect-1	−5.0	−5.0	−5.0	Social security	Sect-1	–4.9	–4.9	–4.9
(VAT) (*)	Sect-2	–5.0	–5.0	–5.0	employers (*)	Sect-2	–4.5	–4.5	–4.5
	Sect-3	5.0	5.0	5.0		Sect-3	4.9	4.9	4.9
	Sect-5	5.0	5.0	5.0		Sect-4	–5.0	–5.0	2.9
	Sect-6	–5.0	–5.0	5.0		Sect-5	–4.7	–4.7	–4.7
	Sect-7	5.0	5.0	5.0		Sect-6	–5.0	–5.0	–5.0
	Sect-8	–5.0	–5.0	4.8		Sect-7	5.0	5.0	5.0
	Sect-9	–4.6	–4.6	–4.6		Sect-8	–4.2	–4.2	–4.2
	Sect-10	–5.0	–5.0	–5.0		Sect-9	–5.0	–5.0	–5.0
	Sect-11	–5.0	–5.0	–5.0		Sect-10	–5.0	–5.0	–5.0
	Sect-12	–5.0	–5.0	–5.0		Sect-11	–5.0	–5.0	–5.0
	Sect-13	–5.0	–5.0	–5.0		Sect-12	–5.0	–5.0	–5.0
	Sect-14	–4.9	–4.9	–4.9		Sect-13	–5.0	–5.0	–5.0
	Sect-15	5.0	5.0	5.0		Sect-14	–5.0	–5.0	–5.0
	Sect-16	–5.0	–5.0	–5.0		Sect-15	–5.0	–5.0	–5.0
	Sect-17	–5.0	–5.0	–5.0		Sect-16	–5.0	–5.0	–5.0
	Sect-18	–5.0	–5.0	–5.0		Sect-17	–5.0	–5.0	–5.0
	Sect-19	–5.0	–5.0	–5.0		Sect-18	–5.0	–5.0	–5.0
	Sect-20	–4.9	–4.9	–4.9		Sect-19	–5.0	–5.0	–5.0
	Sect-21	–5.0	–5.0	–5.0		Sect-20	–5.0	–5.0	–5.0
	Sect-22	–5.0	–5.0	–5.0		Sect-21	–5.0	–5.0	–5.0
	Sect-23	–5.0	–5.0	–5.0		Sect-22	–5.0	–5.0	–5.0
	Sect-24	–4.9	–4.9	4.9		Sect-23	–5.0	–5.0	–5.0
	Sect-25	–5.0	–5.0	–5.0		Sect-24	–5.0	–5.0	2.6
	Sect-26	–5.0	–5.0	–5.0		Sect-25	–5.0	–5.0	–5.0
Public demand	Sect-13	–5.0	–5.0	–5.0		Sect-26	–5.0	–5.0	–5.0
(*)	Sect-17	–4.7	–4.7	–4.7					
	Sect-19	–4.1	–4.1	–4.1	Ecotax		0.02	0.02	0.02
	Sect-24	–5.0	–5.0	–5.0					
	Sect-25	5.0	–5.0	–5.0					
	Sect-26	0.4	0.5	0.5					

exceptional measures are to increase the value added tax (VAT) in sectors 3, 5, 7, 15, and to increase the payroll tax (social security contribution paid by employers) in sectors 3 and 7. Moreover, the L_∞ solution entails increasing VAT in sectors 6 and 24, as well as increasing the employee and employer social security contribution in sectors 4 and 24. Note also that the L_∞ solution implies a more modest reduction than the other points of the compromise set.

Summing up, the L_∞ solution, although generally similar to the others, has the distinguishing feature that it entails a (moderately) higher level of taxation. This is consistent with the earlier results. Remember that, as shown in Tables 7.5 and 7.6, the minimax solution entails a better result for emissions and a worse result for all economic variables. From an economic point of view, it is reasonable that increasing some taxes will damage economic activity to some extent and, as a consequence, will result in fewer emissions.

When we move from the two-criteria case to more complex problems, the compromise set is still a useful device with some interesting properties, although there is no guarantee that it will fulfil all the nice properties that hold in the two-criteria case. Notably, the fact that the compromise set is bounded by the solution for metrics $p = 1$ and $p = \infty$ is not necessarily true. Freimer and Yu (1976) give an example illustrating that the boundedness of the compromise set can fail, even considering a very simple feasible set for a three-criteria case. On the other hand, Blasco et al. (1999) proved that this property holds for problems with more than two criteria if the feasible set is a convex set in the positive cone, limited by a level hypersurface of a differentiable production-transformation. Although these conditions are likely to hold in many economic problems, we cannot be absolutely sure that this is the case in our application because of the complexity of the CGE model we are using, which involves both differentiable (Cobb-Douglas) and non-differentiable (Leontief) functions. Moreover, André and Romero (2008) showed that, in general, it is not possible to trace out the compromise set using a linear convex combination (by means of parameter λ) of the two bounds.

On the other hand, we can still assure that all the compromise solutions are efficient and we can interpret L_1 as the solution that minimizes aggregate deviation from the ideal point and the L_∞ solution as the compromise that maximizes the balance among the criteria considered.

7.6 Evaluating the Observed Policy

The real situation of the Spanish economy in 2000 is given by the following data: $g_Q = 4.4\%$, $g_E = 0{,}0\ \%$, $u = 14.0\%$, $PD = 15{,}957.01$.

One way to evaluate this situation is to measure the deviation of this situation from the ideal point (Table 7.8).

From these values we can conclude first that total deviation (1.83) is larger than at any of the reported points of the compromise set. This suggests that the observed situation is probably inefficient. Moreover, the stronger disagreement is on emissions, whereas the other deviations are more moderate. We can conclude that the observed policy was perhaps targeted better to the improvement of economic indicators than to controlling pollution. This is a reasonable conclusion since environmental protection is a relatively recent concern in Spain. Note that a similar conclusion also follows from the two-criteria case (see Fig. 7.1) since the observed growth rate is reasonably close to its ideal value, whereas emissions are notably displaced from this point.

Table 7.8 Deviations in the observed situation with respect to the ideal point

d_Q	d_E	d_u	d_{PD}	L_1	L_∞
0.36	0.84	0.42	0.21	0.84	1.83

7.7 Concluding Remarks

The contribution of this chapter is a procedure based on CP to identify a set of policies that, apart from being efficient in terms of economic and environmental policy objectives, have the property of being as close as possible to the ideal point. There are several arguments to support the usefulness of this approach for policy making.

The first argument is that, while preserving the basic economic property of efficiency, we can, thanks to this approach, reduce the number of eligible policies and, hence, obtain more precise policy recommendations than those derived from the efficient set. So, our results can be seen as an additional aid for policy makers to choose from the wide array of available policy options.

Second, the procedure used to identify the set of eligible policies (in this case, what we call compromise policies) is firmly supported by an axiomatic basis introduced by Zeleny (1973) and widely accepted in the literature. The idea is that the policy maker would probably prefer those policies that are closer to the ideal point.

Third, efficiency does not preclude the possibility that the values of one of more objectives are very displaced from their optimal values, whereas other objectives attain very satisfactory outcomes (i.e. very close to their optima). In many situations, *unbalanced* solutions are likely to be unattractive for policy makers. CP includes the explicit possibility of controlling this issue by penalizing very large deviations. By modulating the metric parameter p (or, alternatively, the control parameter λ), the policy maker can control the weight attached to the overall performance or efficiency of the solution (as determined by the aggregated deviation) against its symmetry or balancedness (as determined by the most displaced objective).

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Chapter 8
Joint Design of Economic and Environmental Policies: A Simonian Satisficing Approach

Abstract Multiobjective programming and compromise programming are underpinned by the traditional economic view of optimizing agents. In this chapter we explore an alternative view to human behaviour introduced by Simon, based on the idea that people do not aim to maximize any objective, but to *satisfice* some acceptable achievement levels. This view is consistent with another multicriteria approach known as goal programming (GP). We start from the idea that policy makers do not usually pursue the maximization of policy objectives, but they try to achieve some reasonable aspiration levels or targets. We enlarge the scope of the previous chapters by including emissions of CO_2, SO_X and NO_X, as well as four traditional macroeconomic objectives. After setting tentative target values for all the goals, we look for *satisficing policies* using different versions of GP. First, weighted GP minimizes a weighted sum of the unwanted deviation variables under the assumption that the policy makers have finite trade-offs between any two given objectives. Second, by using minimax GP, we look for *balanced policies* that aim to prevent any goal from being too displaced from its target value. Finally, by means of lexicographic GP, we address a situation in which the policy maker is assumed to have pre-emptive priorities over the targets.

8.1 Introduction

In the two previous chapters, we have illustrated the use of two MCDM techniques (multiobjective programming, MOP, and compromise programming, CP) for the design of economic and environmental policies. Both of these techniques are underpinned by the traditional economic vision of optimizing agents. In the particular case of policy design, we have presented a framework in which the government is interested in identifying the optimal values for its policy objectives (the maximum feasible growth, the minimum attainable emissions and so on) and in using these optimal values as a guide for decision making. CP (Chap. 7) is based on the

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axiom that any given policy is considered to be better the closer it is to the ideal point (and, therefore, to the optimal values of all the objectives).

The traditional vision of economic agents as optimizing individuals was challenged by Simon (1955, 1957). Simon suggested that people do not aim to maximize any objective, but to *satisfice*, as far as possible, some achievement levels considered to be acceptable. Note that the term satisficing does not appear in English dictionaries. In fact, "satisficing" is a Northumbrian term, chosen by Simon, to indicate the DM's desire to get "satisfying" and "sufficient" solutions to many real-world problems. In short, "satisficing" is a merger of the words "satisfying" and "sufficing". This idea is consistent with the multicriteria approach known as goal programming (GP). As it was commented in Sect. 3.7, the embryo of GP was introduced by Charnes et al. (1955) within the context of a "constrained regression" problem. However, the first formulation of GP as a decision-making approach for dealing with infeasibilities within a linear programming problem appears in a book by Charnes and Cooper (1961). GP has been extensively used to address economic and environmental problems (see, for example, Jones and Tamiz (2002), and Caballero et al. (2009) for two updated and extensive surveys of GP applications). Moreover, González-Pachón and Romero (2004) establish an axiomatic link between GP and the Simonian satisficing logic.

In this chapter, we start from the idea that, in practice, policy making can be viewed as following a Simonian satisficing logic rather than a maximizing logic. In other words, policy makers do not usually pursue the maximization of any policy objective, but they try to achieve some reasonable aspiration levels or targets. Indeed, it is common practice for the government to set annual target values for economic growth, inflation, public deficit, emission reductions and other policy objectives, and public policy typically aims to satisfy these aspiration values rather than trying to reach the optimal levels. In conformance with this view, we model policy making using GP in order to determine the policy combinations that are consistent with the government's "satisficing" aims.

This chapter is an adapted version of the article by André et al. (2009), which builds on the CGE-MCDM line of research for policy design presented in previous chapters, except that the government is assumed to follow a satisficing rather than a maximizing logic. The model presented in Chap. 5 was calibrated using Spain's 1995 social accounting matrix (SAM) (see Cardenete and Sancho (2006) for details).

In Sect. 8.2 we present the specific details of the policy setting, including the policy objectives and the policy instruments, as well as the payoff matrix of the problem. In Sects. 8.3–8.5 we show different versions of GP applied to the policy design problem depending on the government's preference structure. In Sect. 8.3 we illustrate the use of weighted goal programming, which is adequate for a situation where the government can set constant and finite trade-offs among the (unwanted) deviation of each objective with respect to its target. Section 8.4 shows how minimax goal programming can be used to address problems where the government is concerned about the balance among objectives in the sense that it does not want any objective to be too displaced with respect to its target. Finally, lexicographic goal programming is applied in Sect. 8.5 under the assumption that the government has an objectives hierarchy in the way of pre-emptive priorities. Section 8.6 presents some concluding remarks.

8.2 Policy Setting: Objectives and Instruments. The Payoff Matrix

Concerning the policy objectives, we enlarge the scope of the previous chapters on the side of environmental objectives by including more than one type of pollutant. Specifically, we consider emissions of CO_2, SO_X and NO_X. As for macroeconomic criteria, we use four traditional macroeconomic objectives: economic growth, inflation, unemployment and public deficit. Summing up, the objectives to be taken into account are:

f_1: Economic growth (as measured by the annual growth rate of GDP).
f_2: Inflation (as measured by the annual growth rate of CPI).
f_3: Unemployment (as measured by the unemployment rate).
f_4: Public balance (either surplus or deficit taken as a percentage of GDP).
f_5: CO_2 emissions (rate of change with respect to benchmark situation).
f_6: NO_X emissions (rate of change with respect to benchmark situation).
f_7: SO_X emissions (rate of change with respect to benchmark situation).

Concerning policy instruments, we keep essentially the same feasible set as in previous chapters: public expenditure by sectors as well as direct and indirect taxes. We also consider the possibility of setting an emissions charge on each pollutant. In order to approximate the exercise to the reality, we constrain the direct and indirect tax rates as well as public expenditure by sectors to a less than 3% variation with respect to the benchmark situation.

As usual, our first step is to determine the degree of conflict between the relevant criteria by computing the payoff matrix, which is presented in Table 8.1. From Table 8.1 we can see that there is a clear conflict between economic and environmental criteria, and especially between, on the one hand, real growth maximization and unemployment minimization (both of which provide exactly the same solution)

Table 8.1 Payoff matrix

	Growth	Inflation	Unempl.	PB/GDP	CO_2	SO_X	NO_X
Growth	**2.98**	3.87	22.53	<u>3.88</u>	<u>0.35</u>	<u>0.33</u>	<u>0.33</u>
Inflation	2.46	**2.28**	23.24	3.47	−0.07	−0.13	−0.10
Unempl.	2.98	3.87	**22.53**	<u>3.88</u>	<u>0.35</u>	<u>0.33</u>	<u>0.33</u>
PB/GDP	<u>2.19</u>	3.62	<u>23.59</u>	**2.93**	−1.03	−1.38	−0.95
CO_2	2.49	<u>5.83</u>	23.17	3.32	**−1.18**	−1.53	−1.03
SO_X	2.46	5.07	23.21	3.07	−1.17	**−1.58**	−1.06
NO_X	2.44	4.86	23.25	3.04	−1.16	−1.56	**−1.10**

All the variables are measured in %. Bold figures denote ideal values and underlined figures anti-ideal values for each objective and, on the other hand, pollution reduction. An active pro-growth policy could get a real growth of almost 3% and an unemployment rate of 22.53%, but this would come at the cost of increasing CO_2 emissions (by 0.35%), SO_X emissions and NO_X emissions (both by 0.33%). On the other hand, CO_2, SO_X and NO_X emissions could be reduced by more than 1% with respect to the benchmark situation, but this would imply getting a smaller growth rate, of about 2.45%.

There is also some conflict among the economic criteria: maximizing growth or minimizing unemployment entails a higher level of inflation and a high public deficit and, conversely, minimizing inflation or public deficit results in a lower growth rate and a higher unemployment rate. On the other hand, there do not appear to be any major conflicts among the environmental criteria, since roughly the same policies appear to be consistent with the reduction of any of the selected pollutants.

Looking at the payoff matrix it is clear that no solution generated by the single optimization of any criterion appears to be acceptable from the economic as well as the environmental point of view. Hence, it is absolutely necessary to look for best compromise or satisficing policies between the seven single optimum policies shown in Table 8.1 to obtain an acceptable policy design. This task is undertaken in the following sections by formulating and solving several goal programming (GP) models.

8.3 Searching for a Satisficing Joint Policy

For each of the seven policy objectives, we tentatively set a target level t_k. As explained in Chap. 3 (sect. 3.7), the following goals are defined:

$$f_k + n_k - p_k = t_k \quad k \in \{1, ..., 7\}, \tag{8.1}$$

where n_k and p_k are the negative and positive deviation variables measuring possible under- or over- achievements respectively for the kth policy goal. The "more is better" postulate applies for policy goals 1 (economic growth) and 4 (public budget), and therefore, the unwanted deviation variable is negative (i.e. n_1 and n_4), whereas the "less is better" postulate applies for the other goals, and therefore the unwanted deviation variable is positive (i.e., p_2, p_3, p_5, p_6 and p_7). We also impose the constraints $n_k \geq 0$, $p_k \geq 0$ and $n_k.p_k = 0$ for every goal to ensure that the deviation variables are non-negative and one of them is always zero.

Based on observed data of the Spanish economy, we fix the following target values for the seven goals considered:

$$t_1 = 2\%, \ t_2 = 4\%, \ t_3 = 23\%, \ t_4 = -3.5\%, \ t_5 = 0\%, \ t_6 = 0\%, \ t_7 = 0\%. \tag{8.2}$$

The above vector of satisficing targets means that the policy maker would consider obtaining the same emissions value as in the benchmark situation (neither decreasing nor increasing) together with a real growth rate of 2%, inflation rate of

4%, unemployment rate of 23% and a public deficit of 3.5% of the GDP as a reasonable achievement.

Following GP logic, the unwanted deviation variables must in one way or in another be minimized. In general terms this idea can be expressed by means of the following achievement function:

$$Min\ (n_1,\ p_2,\ p_3,\ n_4,\ p_5,\ p_6,\ p_7). \tag{8.3}$$

To find a policy that is consistent with the target levels specified above, we test several functional forms for the general achievement function (8.3). The first one is a weighted sum of the unwanted deviation variables. This leads to the following weighted GP (WGP) formulation (see model (3.16) in Chap. 3):

$$Min\ (W_1n_1 + W_2p_2 + W_3p_3 + W_4n_4 + W_5p_5 + W_6p_6 + W_7p_7), \tag{8.4}$$

where W_k is the weight or relative importance attached by the policy maker to the achievement of the kth goal ($k = 1, \ldots, 7$). The minimization of (8.4) is subject to all the equations defined in the model, as well as the definition of the goals and the target levels specified in (8.2). Assume that the policy maker is evenly concerned about the achievement of all the goals and, therefore, the weights are $W_1 = W_2 = \cdots = W_7 = 1$. Using this assumption and the target values introduced above, we obtain the solution shown in Table 8.2.

Note that all the target values are defined as percentages. Hence, it is not necessary to undertake any type of normalization with the previously defined goals. On the other hand, a well-known critical issue in goal programming (see Romero 1991) is the possibility of getting Pareto inefficient solutions. A solution is said to be inefficient if the value of some criteria can be improved without worsening the value of any other criterion. In Table 8.2, we see that the solution found fully satisfies the previously specified target values, and, in some cases, the actual value is even better than the target value. This suggests that the target values in (8.2) have been set at very soft levels. This is a typical situation where solutions will possibly be inefficient and leads us to suspect that perhaps the solution shown in Table 8.2 may be inefficient (Tamiz and Jones 1996).

To check the efficiency of the obtained solution we perform a test introduced by Masud and Hwang (1981). This test involves maximizing the wanted deviation

Table 8.2 Finding a satisfying solution

	K	f_k	n_k	p_k
Economic objectives	1	2.66	0.00	0.66
	2	4.00	0.00	0.00
	3	23.00	0.00	0.00
	4	−3.31	0.00	0.19
Environmental objectives	5	−0.49	0.49	0.00
	6	−0.63	0.63	0.00
	7	−0.47	0.47	0.00

By construction, f_k, n_k, p_k are measured in %

Table 8.3 Testing for efficiency

	K	f_k	n_k	p_k
Economic objectives	1	2.66	0.00	0.66
	2	4.00	0.00	0.00
	3	22.96	0.05	0.00
	4	−3.31	0.00	0.19
Environmental objectives	5	−0.49	0.49	0.00
	6	−0.63	0.63	0.00
	7	−0.47	0.47	0.00

By construction, f_k, n_k, p_k are measured in %

variables subject to the condition that the achievement of the seven policy goals derived from the WGP model cannot be degraded with respect to the values shown in Table 8.2. Thus, the following optimization problem is formulated:

$$Max\ (p_1 + n_2 + n_3 + p_4 + n_5 + n_6 + n_7), \tag{8.5}$$

subject to $f_1 \geq 2.66$, $f_2 \leq 4$, $f_3 \leq 23$, $f_4 \geq -3.31$, $f_5 \leq -0.49$, $f_6 \leq -0.63$, $f_7 \leq -0.47$ and all the equations in the model. The resulting solution is shown in Table 8.3.

Note that the solution in Table 8.3 is very similar to that in Table 8.2 except for the fact that unemployment is slightly lower. This means that the latter solution weakly dominates the first one. This indicates that the solution in Table 8.2 is inefficient, although it is very close to being efficient. Moreover, by construction, we know that the solution in Table 8.3 is Pareto efficient. At this point, it is worthwhile reflecting on the application of the efficiency concept. Efficiency is a common economic concept, and increased efficiency could be thought to always imply harming the environment. This example helps to illustrate the fact that, when the right criteria are considered, the concept of efficiency can be used to ensure that the economic activity is compatible with the achievement of environmental goals.

An alternative way to get efficient solutions is to set more demanding target values for the different criteria. Thus, let us assume that the policy maker sets the following target values:

$$t_1 = 2.7, \quad t_2 = 3, \quad t_3 = 22.7, \quad t_4 = -2.9, \quad t_5 = -1, \quad t_6 = -2, \quad t_7 = -1. \tag{8.6}$$

When solving the problem with these targets (again using WGP and assuming equal weights for all the goals), we get the solution that is shown in Table 8.4. Observe that, in this case, all the unwanted deviation variables have positive values. This is a sufficient condition for the solution to be efficient. The argument is as follows: by contradiction, assume that S is a solution to (8.4) and it is inefficient as long as all the unwanted deviation variables are strictly positive. By definition of inefficient solution, it must be possible to improve the value of some objective without worsening any other objective. Assume, for example, that it is possible to improve the value of economic growth (f_1) without worsening the value of the other objectives. This means that there is a feasible solution with a smaller value of n_1 and the same or better value of the other unwanted deviation variables. But this would

Table 8.4 An alternative efficient solution

	K	f_k	n_k	p_k
Economic objectives	1	2.18	0.52	0.00
	2	3.29	0.00	0.29
	3	23.60	0.00	0.90
	4	−2.94	0.00	0.06
Environmental objectives	5	−0.98	0.00	0.02
	6	−1.29	0.00	0.71
	7	−0.92	0.00	0.08

By construction, f_k, n_k, p_k are measured in %

render a smaller value of the objective function in (8.4) and, therefore, *S* cannot be an optimal solution to problem (8.4).

Note that, although the solution in Table 8.4 is efficient and the solution in Table 8.2 is not, the former does not Pareto dominate the latter, since the values of some objectives are better in the first solution and others are better in the last one. This illustrates a difference between the two efficiency tests we have introduced, since, if the original solution is inefficient, Masud and Hwang's procedure always renders by construction another solution that Pareto dominates the former.

8.4 Balanced Satisficing Policies

In Sect. 8.3 we have shown how the so-called WGP approach provides a solution that minimizes the weighted sum of unwanted deviations. Nevertheless, this approach does not preclude the solution from providing very unsatisfactory results for some of the considered goals. For example, in the solution shown in Table 8.4, the target value for the CO_2 emissions is almost exactly reached, which can be seen as a very satisfactory outcome, but the value for unemployment departs from the target value in by 0.90, which could be unacceptable from an economic point of view.

Policy makers are sometimes interested in obtaining *balanced* solutions in the sense that none of the values departs too much from the targets. In other words, the government might want to implement policies such that the achievement of none of the criteria is much displaced with respect to the target values. This can be expressed in mathematical terms by the minimization of the maximum (weighted) deviation, i.e.

$$Min\ Max\{W_1 n_1, W_2 p_2, W_3 p_3, W_4 n_4, W_5 p_5, W_6 p_6, W_7 p_7\}. \tag{8.7}$$

Since this objective function is not smooth, its minimization could be computationally complicated. A more convenient way to express this is by the following MINMAX GP formulation (see model (3.17) in Chap. 3):

$$\begin{aligned} & Min\ D \\ s.t.:\quad & W_1 n_1 \le D,\quad W_2 p_2 \le D,\quad W_3 p_3 \le D,\quad W_4 n_4 \le D, \\ & W_5 p_5 \le D,\quad W_6 p_6 \le D,\quad W_7 p_7 \le D \end{aligned} \tag{8.8}$$

Table 8.5 A balanced solution

	K	f_k	n_k	p_k
Economic objectives	1	2.33	0.37	0.00
	2	3.70	0.00	0.70
	3	23.40	0.00	0.70
	4	−2.97	0.00	0.03
Environmental objectives	5	−0.99	0.00	0.01
	6	−1.30	0.00	0.70
	7	−0.90	0.00	0.10

By construction, f_k, n_k, p_k are measured in %

plus all the previously defined equations and goals, D being the maximum deviation.

By solving this problem for the target values defined in (8.6), and again for the same vector of preferential weights (i.e. $W_1 = \cdots W_7 = 1$), we get the solution displayed in Table 8.5. By comparison with the solution in Table 8.4, we observe that the maximum unwanted deviation in Table 8.4 is 0.70. This corresponds to the second, the third and the sixth goals, whereas the maximum deviation in Table 8.4 is 0.9 corresponding to the fourth goal.

8.5 Establishing a Hierarchy for the Policy Goals

In some cases, although policy makers have multiple objectives, they are not evenly concerned about all of them, but have pre-emptive priorities in the sense that there is a hierarchy defined over the targets in such a way that the achievement of the higher priority goals is incommensurably more important than the lower priority goals.

Assume, for example, that the policy maker's targets can be ranked as follows: the top priority includes environmental targets 5, 6, 7, the second priority level includes target 4 and the third level includes targets 1, 2 and 3. The achievement function can be written as (see model (3.19) in Chap. 3):

$$Lex\ Min\ [(W_5 p_5 + W_6 p_6 + W_7 p_7), (n_4), (W_1 n_1 + W_2 p_2 + W_3 p_3)].$$

Moreover, assume that the aspiration levels are

$$t_1 = 2.7,\ \ t_2 = 4.5,\ \ t_3 = 22.7,\ \ t_4 = -2.9,\ \ t_5 = -1.5,\ \ t_6 = -1.5,\ \ t_7 = -1.5. \quad (8.9)$$

This means that the government's highest priority is that the CO_2 emissions, the SO_X emissions and the NO_X emissions decrease with respect to the benchmark situation by at least 1.5%, whereas all the pollutants are considered as equally important (since they are grouped at the same priority level). The second priority is that the public deficit should not be higher than 3% over GDP. Finally, the government is equally concerned about the achievement of the growth, inflation and unemployment targets.

This kind of lexicographic problem can be solved by resorting to a sequential approach. The idea is to solve a sequence of weighted goal programming problems corresponding to the different priority levels (Ignizio and Perlis 1979).

In our case, the first level groups goals 5, 6 and 7, so we first need to solve the following problem:

$$Min\ (W_5 p_5 + W_6 p_6 + W_7 p_7), \tag{8.10}$$

subject to the goal definitions (for goals 5, 6 and 7 only) and all the equations in the model, where the assumption is $W_5 = W_6 = W_7 = 1$. The values achieved by the three goals are $f_5 = -1.16$, $f_6 = -1.55$, $f_7 = -1.04$, and the unwanted deviation variables in this exercise are equal to $p_5 = 0.34$, $p_6 = 0$, $p_7 = 0.46$, meaning that the target value for SO_X emissions is exactly achieved (actually, emissions can be reduced even further), whereas the targets for CO_2 emissions and NO_X emissions cannot be fully achieved.

The second problem in the sequence is to minimize the unwanted deviation variable for the goals placed at the second priority level, which, in this case, includes just the fourth goal. The problem to be solved is

$$\begin{gathered} Min\ W_4 n_4 \\ s.t. \quad p_5 \leq 0.34,\ p_6 = 0,\ p_7 \leq 0.46, \end{gathered} \tag{8.11}$$

including the definition of goals 4, 5, 6 and 7, as well as all the equations in the model. The actual value for the public budget balance (in terms of GDP) is $f_4 = -3.03$ and, therefore, the negative deviation variable is $n_4 = 0.13$.

The third problem to be solved is to minimize the weighted sum of the unwanted deviation variables corresponding to the goals placed at the third priority level. Thus, we have

$$\begin{gathered} Min\ W_1 n_1 + W_2 p_2 + W_3 p_3 \\ s.t. \quad p_5 \leq 0.35,\ p_6 = 0,\ p_7 \leq 0.46,\ n_4 \leq 0.13. \end{gathered} \tag{8.12}$$

For equal weights (i.e. $W_1 = W_2 = W_3 = 1$), model (8.12) reproduces the solution provided by model (8.11). This result is due to the fact that problem (8.11) has no alternative optimum solutions, and consequently the goals placed at the third priority level become redundant, that is, in practice, they do not play an actual role in the decision-making process, which can be troublesome (Amador and Romero 1989).

The solution corresponding to the third priority level and to the whole lexicographic process is shown in Table 8.6.

Table 8.6 Solution with a hierarchy for policy goals

	K	f_k	n_k	p_k
Economic objectives	1	2.46	0.24	0.00
	2	4.96	0.00	0.46
	3	23.22	0.00	0.52
	4	−3.03	0.03	0.00
Environmental objectives	5	−1.16	0.00	0.34
	6	−1.55	0.05	0.00
	7	−1.04	0.00	0.46

By construction, f_k, n_k, p_k are measured in %

8.6 Concluding Remarks

In this chapter we have presented a different version of our methodological approach to the joint design of macroeconomic and environmental policies. Specifically, we have followed a Simonian satisficing philosophy operationalized with the help of different goal programming models. There are some key remarks to be made both from a positive and normative perspective.

From a positive viewpoint, recall that, on the one hand, this approach using our CGE model is strongly linked with conventional economic theory. On the other hand, though, it departs from the standard approach by resorting to a satisficing logic, where instead of maximizing a problematic welfare function, the policy maker sets tentative targets for all the economic and environmental goals involved in the decision-making process. We claim that this is a more realistic description of how policy makers act in many contexts.

From a normative perspective, the multicriteria philosophy underlying the approach is consistent with the claim that respect for the environment is a key concern for policy makers, and the environmental criteria are no less important than economic concerns. In this chapter, this principle is represented by the assumption that the government aims to satisfice certain levels of environmental impact together with usual economic targets, and public policy should be formulated according to this aim. In this way, the proposed methodology recommends policies that represent sound compromises among the economic and the environmental criteria.

Our results illustrate how the government can set different target values for the key criteria and fine tune its policy accordingly. Throughout the chapter we demonstrated how easily formulated and computed GP models output different policies. These policies aggregate the environmental and the economic goals in different ways: maximum aggregate performance, maximum balance and a lexicographic hierarchy of goals.

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Chapter 9
Proposal for an Alternative Multicriteria Policy Approach Based on Welfare Functions

Abstract In this chapter we offer an alternative view to the positive and prescriptive approach that we have taken throughout the rest of the book. Our main purpose is to show that MCDM is also compatible with a traditional normative approach to economic policy making. This traditional view requires identifying a set of members of society, each endowed with a utility function representing their preferences. Then, following multicriteria logic, we can construct an operational surrogate of the social welfare function that can be seen as an intermediate combination between two opposite poles. On the one hand, there is the Benthamite or utilitarian social welfare function, which aggregates the (weighted) utilities of all members of society. On the other hand, there is the Rawlsian social welfare function, which considers just the well-being of the worst-off member of society. We show how to construct a flexible social utility function that takes both issues (total weighted utility and minimum utility) into account. Finally, we suggest a more operational version by using a balancing factor between both extremes.

9.1 Introduction

The methodological approach presented throughout this book has a positive and prescriptive motivation. It is positive in the sense that it tries to offer a realistic vision of how policy makers approach their policy design problems in real life, since they typically pursue multiple objectives rather than the optimization of a single one. On the other hand, it is prescriptive in the sense that it attempts to help policy makers in the design, application and assessment of economic policies, within a realistic context of different types of multiple conflicting criteria.

However, it is common in the economics literature to approach policy-making problems from a normative viewpoint. Thus, the analysis of the different economic policies is based upon the characterization of a social welfare function that represents the preferences of society as a whole. This function is built making several normative assumptions. The defined social welfare function is optimized over the

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utility possibility frontier (i.e. the Pareto domain of feasible policies). This type of normative approach is to some extent an alternative to the positive/prescriptive perspective underlying the approaches presented in this book.

Nevertheless, both approaches can have a common link based on the MCDM philosophy. In this chapter, then, we are going to very tentatively present a first step in this direction. We will analyse how the basic ingredient in normative economic policy analysis, the "social welfare function", can be analytically determined and preferentially interpreted with the aid of the MCDM tools used in this book.

To achieve this purpose, we start in Sect. 9.2 by introducing some basic elements and notation. In Sect. 9.3 we recall two classical approaches of social welfare functions. First, the Benthamite or utilitarian social approach, which consists of aggregating the utilities of all the members of the society, perhaps with some weighting coefficients to represent the importance given to each individual or social group. On the other hand, the Rawlsian or maximin point of view considers just the well-being of that member of the society who is worse-off.

In Sect. 9.4 we argue that both of these polar approaches are too restrictive and we introduce an alternative specification for a social utility, which is consistent with compromise programming (CP) and based on a general p-metric distance function depending on the normalized deviation of each individual utility function with respect to its optimum. Although such an approach has some very interesting properties, it might be problematic from a computational point of view. Since one of the aims of this research is to provide tools that, apart from being theoretically sound, are also operational and useful in practice, we offer in Sect. 9.5 a closely related approach which is computationally more convenient. The idea is to specify a linear convex combination between total weighted utility and the minimum utility (representing the situation of the worse-off individual). By means of a control parameter it is possible to determine the importance given to both criteria, and therefore, how close the result is to the utilitarian or the Rawlsian solution. Section 9.6 offers some concluding remarks and a brief discussion. This chapter represents a revised and enlarged version of Romero (2001).

9.2 Basic Concepts and Notation

We start by defining the following common setting in the traditional normative analysis of economic policies:

$\mathbf{x} = (x_1, \ldots, x_j, \ldots, x_m)$ = vector of policy instruments.

$\mathbf{b} = (b_1, \ldots, b_k, \ldots, b_z)$ = vector of model parameters.

$\mathbf{u} = (u_1, \ldots, u_i, \ldots, u_n) = (h_1(\mathbf{x}, \mathbf{b}), \ldots, h_i(\mathbf{x}, \mathbf{b}), \ldots, h_n(\mathbf{x}, \mathbf{b})) = \mathbf{h}(\mathbf{x}, \mathbf{b})$ = policy outcome. Each component of **u** measures the utility or welfare of the corresponding individual or social group.

$T(u_1, \ldots, u_i, \ldots, u_n) = k$ = utility possibility frontier or feasible domain of Pareto efficient policies.

$W(\mathbf{u})$ = a Bergson–Samuelson social welfare function.

To obtain the optimal policy for the *i*th individual or social group, the following optimization problem is formulated:

$$\begin{aligned}&\text{Max } u_{\mathbf{i}}\\&\text{s.t.}\\&T(u_1, u_2, \ldots, u_n) = k\\&u_i = h_i(\mathbf{x}, \mathbf{b}).\end{aligned} \tag{9.1}$$

By solving (9.1), we get the optimum u_i^* for the *i*th individual or social group. By formulating and solving a similar model for the other n−1 individuals, the following ideal vector is obtained:

$$\mathbf{u}^* = \left(u_1^*, \ldots u_i^*, \ldots u_n^*\right). \tag{9.2}$$

Vector (9.2) represents a utopian solution, for which the utility or welfare of each individual is maximized. Obviously, this solution is infeasible and represents just a point of reference. The anti-ideal or worst value u_{i*} for the *i*th individual measures the worst value that may be achieved, whereas the other n−1 individual utility functions are maximized. Thus, the following vector of anti-ideal values can be obtained:

$$\underline{\mathbf{u}}_* = (u_1*, \ldots, u_i*, \ldots u_n*). \tag{9.3}$$

The difference between vectors (9.2) and (9.3) will provide the range or variation domain of the feasible utilities or levels of welfare for each of the n individuals or social groups forming the society.

9.3 Two Classical Approaches for Social Policy Making

To obtain a socially optimal policy x^*, the following optimization problem is formulated and solved:

$$\begin{aligned}&\text{Max } W(\mathbf{u})\\&\text{s.t.}\\&T(u_1, u_2, \ldots, u_n) = k\\&u_i = h_i(\mathbf{x}, \mathbf{b}) \quad i \in \{1, \ldots n\}.\end{aligned} \tag{9.4}$$

The main issue that needs to be addressed to apply this approach is to find a suitable expression for W(**u**), i.e., a function that aggregates the utilities of all the society while satisfying some desirable properties.

Normally the discussion related to the choice of W(**u**) moves between two opposite poles. The first pole represents the Benthamite or utilitarian social welfare function defined as the weighted aggregation of all individual utilities:

$$W(\mathbf{u}) = \sum_{i=1}^{n} \alpha_i \, u_i, \tag{9.5}$$

where α_i weights the importance or relative social power of the *i*th individual or social group.

The opposite pole represents the Rawlsian social welfare function, where

$$W(\mathbf{u}) = \underset{\forall i.}{\mathrm{Min}}[\alpha_i \, u_i] \tag{9.6}$$

Note that function (9.6) is not smooth, and its substitution into model (9.1) does not lead to a computable or solvable problem. However, it has been proved elsewhere that this optimization problem is equivalent to the following solvable mathematical programming problem (see, for example, Steuer 1989, Chaps. 14 and 15):

$$\begin{aligned} &\mathrm{Max}\ D \\ &\mathrm{s.t.} \\ &\alpha_i u_i - D \geqslant 0 \quad i \in \{1, \ldots n\} \\ &T(u_1, u_2, \ldots, u_n) = k \\ &u_i = h_i(\mathbf{x}, \mathbf{b}) \quad i \in \{1, \ldots n\}, \end{aligned} \tag{9.7}$$

where D is an auxiliary variable introduced to measure the minimum achievement (i.e. the achievement of the poorest or worst-off individual or social group).

9.4 An Alternative Proposal Based on Compromise Programming

Notice that function (9.5) and function (9.6) – or its computable version given by (9.7) – are generally too restrictive for the following reasons (Romero 2001):

(a) For a Benthamite function, the welfare of society is equal to the sum of the utilities of the different individuals or social groups. This concept involves the assumption that an increase in the welfare of a rich person by one unit has the same social value as an increase in the welfare of a poor person by one unit. Indeed, the linear dependence of W with respect to the individual utilities u_i implies that the marginal effect of u_i on W is constant. The use of this type of social welfare function allows for the maximization of the overall utility (what we can understand as a *maximum efficiency* solution), but can provide very unequal allocations of wealth. Moreover, the separability of the Benthamite social welfare function implies that the welfare level of an individual or social group is not affected by the welfare of any other individual or social group, which is also very questionable.

In technical terms, a Benthamite function implies that the mutual preferential independence condition holds (see Debreu 1960 or Keeney and Raiffa 1976).

(b) For a Rawlsian function, the welfare of society depends only on the utility of the poorest or worst-off individual or social group. In some sense, the use of this type of social welfare function allows for the optimization of the distributive aspects (what we can interpret as *maximum equity*), but can provide poor aggregate performance in terms of overall social welfare.

Given the restrictiveness of the social welfare functions given by (9.5) and (9.6)/(9.7), it is worthwhile searching for other functional forms for W(**u**). To do this, the following surrogate of model (9.4), corresponding to the minimization of a general p-metric distance function, is introduced (see Sect. 3.6):

$$\text{Max W}(\mathbf{u}). = -\sum_{i=1}^{n}\left[\alpha_i^p\left(\frac{u_i^* - u_i}{u_i^* - u_{i*}}\right)^p\right]^{1/p}, \tag{9.8}$$

where p is the metric that defines the family of distance functions, the other variables and parameters were defined previously. Note that, as shown in Chap. 3 of this book, model (9.8) corresponds to so-called compromise programming (see also Zeleny 1974), where decision objectives have been replaced by individual or group utilities and preferential weights have been replaced by parameters α_i measuring the importance or relative social power of each individual or social group.

From Sect. 3.6 we know that formulation (9.8) has some interesting economic and mathematical properties. Thus, Yu (1973) demonstrated that, for any finite p and any set of positive weights α_i, solutions provided by model (9.8) are always Pareto efficient, where Pareto efficiency has, in this framework, the most traditional meaning in terms of individual welfare (rather than in terms of the criteria or objectives space).

Apart from Pareto optimality, these solutions have other properties, such as feasibility, uniqueness, symmetry, etc. (see Yu 1985, pp 71–74 for a rigorous analysis of these properties). Moreover, recall that Freimer and Yu (1976) demonstrated that, for the two-criteria case (in our scenario, when there are two individuals or social groups), metrics $p = 1$ and $p = \infty$ define two bounds of the compromise set and the other best compromise solutions fall between these two bounds. For more than two criteria (individuals in our context), this property does not generally hold. However, it has been demonstrated (see Blasco et al. 1999) that under relatively general conditions (basically a convex feasible set limited by a differentiable hypersurface), common in welfare economics problems, the compromise set given by metrics $p = 1$ and $p = \infty$ is bounded. All these properties make the objective function introduced in the compromise programming model (9.8) a useful surrogate of the general Bergson–Samuelson social welfare function W(**u**).

This specification for the social welfare function can be seen as a generalization of both the utilitarian and the Rawlsian solutions. Clearly, the Benthamite social welfare function given by (9.5) is reproduced by making $p = 1$ in (9.8). In the same way, by taking the limit when p tends to infinity in (9.8), we reproduce the Rawlsian social welfare function given by (9.6) or (9.7). Hence, within our context, metric p has a preferential meaning. Thus, the interest of the majority is maximized (Bentham) for $p = 1$, whereas the interest of the minority is maximized (Rawls) for $p = \infty$. The preferential meaning of metric p was thoroughly studied by Yu (1973). Yu demonstrated that metric p plays the role of a "balancing factor" between "group utility" ($p = 1$) or average achievement for all the individuals or social groups involved (Bentham solution for all the individuals in our economic policy scenario) and the maximum discrepancy ($p = \infty$) or minimum individual regret (Rawlsian solution maximizing the welfare of the worst-off individual or social group).

9.5 A Computable Version

Given the above insufficiencies associated with the classical solutions and the more general character of the function introduced in (9.4), it is tempting to particularize model (9.8) for values of metric p belonging to the open interval (0,1). Thus, starting, for instance, with a value of $p = 1$ by increasing this value we are improving the solution from the point of view of the worst-off individual and degrading the solution from the point of view of the majority, and vice versa. By varying the value of metric p we can, to some extent, determine compromises between the interest of the majority and the interest of the minority or worst-off individual or social group. However, the implementation of this idea is very problematic for computational reasons. In fact, for values of metric p different to 1 and ∞, model (9.8) becomes a complex non-linear programming problem. For this reason, several authors (see for example, González-Pachón and Romero 2007; André and Romero 2008) have proposed a surrogate of problem (9.8) by forming a linear convex combination of the solutions provided by metrics $p = 1$ and $p = \infty$. Thus, the following formulation is obtained:

$$
\begin{aligned}
&\text{Max } (1-\lambda)\mathrm{D} + \lambda\left(\sum_{i=1}^{n} \alpha_i \frac{u_i}{u_i^* - u_{i*}}\right)\\
&\text{s.t}\\
&\alpha_\mathrm{i}\,\mathrm{u_i} - \mathrm{D} \geqslant 0 \quad i \in \{1, \ldots n\}\\
&\mathrm{T}(\mathrm{u_1}, \mathrm{u_2}, \ldots, \mathrm{u_n}) = \mathrm{k}\\
&\mathrm{u_i} = \mathrm{h_i}(\mathbf{x}, \mathbf{b}) \quad i \in \{1, \ldots n\},
\end{aligned}
\tag{9.9}
$$

where $\lambda \in [0, 1]$ plays the role of a control parameter. When $\lambda = 1$, model (9.9) collapses to the compromise programming problem with metric $p = 1$ that leads to the maximization of "group utility" or the Benthamite solution. For $\lambda = 0$, (9.9) gives the compromise solution for metric $p = \infty$ that leads to the best solution for the "worst-off" individual or Rawlsian point. Note the structural resemblance among this model and models (3.10) and (3.18) presented in Chap. 3.

For values of λ belonging to the open interval (0,1), intermediate or compromise solutions can be obtained. This task will always lead to mathematical programming problems with a linear objective function. This has a clear computational advantage over the general compromise programming model given by (9.8). Hence, control parameter λ can be interpreted as a trade-off or marginal rate of substitution between "group utility" (Benthamite solution) and the "utility of the worst-off individual" (Rawlsian solution). By varying the value of control parameter λ in model (9.9) many policy solutions trading off the interest of the majority against the minority can be obtained without an excessive computational burden. In short, through parametric variations of λ, model (9.9) can be a useful device for ranking or evaluating the examined economic policies.

Thus, for small values of λ, this model will favour policies improving distributive equity. On the other hand for large values of λ (1 is the maximum bound), the model will favour policies improving the aggregate utility or welfare of society. This appears to be more sensible than traditional approaches that basically reduce the discussion to a choice between two opposite poles: maximum efficiency (Benthamite social welfare function) and maximum equity (Rawlsian social welfare function). It is reasonable to conjecture that societies want balanced compromises between both of these judgement values, where the level of compromise is measured by the value attached to the control parameter λ.

Note that parameter λ in problem (9.9) plays a similar role to the metric parameter p in formulation (9.8). André and Romero (2008) studied the similarities between both approaches. Actually, for bi-criteria problems (with just two individuals or groups), specifications (9.8) and (9.9) can be seen as equivalent. Moreover, if function T is quasiconcave, it is possible to determine a one-to-one (i.e., a function) relationship between the values of λ and p. If, on the other hand, T is piecewise linear, it is still possible to find a correspondence linking λ and p by intervals.

In short, model (9.9) can be considered a sound theoretical and operational framework for dealing with social welfare functions from the perspective of the empirical assessment and design of economic policies, for the following reasons:

1. Model (9.9) is very general. In fact, most social welfare functions proposed in the theoretical and applied literature can be considered particular cases of (9.9) (see surveys by Bullock et al. 1999 and Bullock and Salhofer 2003).
2. Given the underlying linearity of the objective function of (9.9), it is relatively easy to compute.
3. In practice, control parameter λ acts as a "balancing factor" between the interest of the "majority" and the interest of the "worst-off" individual or social group. Thus, control parameter λ can simply trade off efficiency (Bentham) against equity (Rawls).
4. All the policy solutions derived from model (9.9) have a straightforward meaning in social preference terms.

We recognize that the link presented in this chapter between the normative and the positive/prescriptive approaches for dealing with the design and assessment of economic policies is very tentative and can be considered as just a first step in this important direction. However, this endeavour seems promising, and the MCDM philosophy also looks to be a fertile vehicle for addressing this crucial issue.

9.6 Conclusions and Discussion

In this chapter we have shown that even if we take a normative (rather than positive or prescriptive) viewpoint, MCDM is still a useful and fruitful toolbox. As an alternative to the pragmatic approach developed so far, we have introduced an approach policy making in a more normative fashion resorting to the construction of a social welfare function.

Indeed, we have proposed two alternative formulations to serve as surrogates for the social utility function. The first one is fully consistent with compromise programming and, therefore, it enjoys all the desirable properties of this technique that have been proved in the literature. The second formulation is a more operational version which has the advantage of being computationally more convenient. Both of them include the classical Benthamite and Rawlsian functions as particular cases. In both specifications there is a parameter which allows us to control the weight given to efficiency and equity.

This MCDM proposal for policy making is introduced tentatively and, of course, also has its limitations (most of them shared by other approaches within this normative framework). First, by moving from our positive description of real policy making based on economic and environmental indicators, we are sacrificing some degree of realism. Second, we are assuming that individual utility functions exist, which is not a trivial issue. A third tricky question to answer is how to determine the weight of different individuals or groups. And finally, by combining all the individual utilities in a single function, we are ignoring the complications associated to the interpersonal comparison of utilities.

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Chapter 10
Conclusions and Further Research

Abstract This is the concluding chapter. We have introduced an approach to handle the design of public economic and environmental polices based on multicriteria decision making in connection with a computable general equilibrium model. This approach endeavours to be both operational and consistent with economic theory. In doing so, we have also tried to build a bridge between operational research methods and economic analysis. We have introduced the notions of *efficient policy*, *compromise policy* and *satisficing policy*, which correspond to different MCDM approaches. Efficient policies guarantee that policy makers do not miss any costless opportunity of improvement. Compromise policies aim to provide policy results that are as close as possible to the optimum values. Satisficing policies fit frameworks in which policy makers are concerned not about optimality but about attaining some target levels for their objectives. We also offer some discussion and guidelines for future research. Coming works could relax some simplifying assumptions that we have introduced to keep our model manageable. Among others, it would be possible to build a dynamic rather than static model, relaxing the small country hypothesis, performing a more accurate analysis of the job market, or explicitly accounting for technical change and pollution abatement activities.

10.1 Conclusion

This book has introduced an approach to handle the design of public policies based on multicriteria decision making in connection with a structural economic model. The starting point of this research is the observation that the conventional (single-criterion) approach does not appear to match the observed practice in real policy design, insofar as policy makers do not usually have a single, well-defined objective function that they try to optimize when they take their decisions. Rather policy making is a complex decision-making problem characterized by the existence of multiple conflicting objectives and interests.

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In response to this observation, we have presented a line of research recently developed by the authors where economic polices are addressed as a MCDM problem. But this book is not merely confined to economic policies, and we have broadened the scope of our approach to consider both economic and environmental dimensions. As a matter of fact, we claim that including environmental concerns is particularly relevant nowadays, and these concerns make the MCDM perspective a particularly suitable approach. Therefore, our study stresses the joint determination of economic and environmental policies.

We have shown how MCDM techniques can be very helpful, on the one hand, for understanding how economic and environmental policy decisions are made in practice and, on the other hand, to support policy makers in the decision-making process. The MCDM methods benefit from the selection of a sound economic model to represent the main economic mechanisms (and, therefore, how the values of policy objectives follow from the implemented policies, as well as economic agents' decisions). For that purpose, we built a CGE model incorporating some environmental elements together with conventional economic mechanisms. The model includes analytical specifications of technology by activity sectors, preferences, consumer and producer behaviour, and market interactions to reach equilibrium. It also incorporates a description of public sector activity through a taxonomy of taxes and public expenditure. Using this model, we can represent and measure the effects of public policies on the most significant economic and environmental variables that are, at the same time, consistent with standard economic theory and empirically applicable.

Our methodological approach involves combining a CGE model, which is based on standard economic theory, with MCDM techniques, which are typical of the disciplines of operational research/management science (OR/MS). As a matter of fact, the decision-making problems that we formulate here can be seen as operational models rather than theoretical economic models. By making this combination, this research aspires to rebuild old bridges between operations research methods and economic analysis. It is well known that these disciplines have been strongly connected in the past but perhaps there has not been enough sustained exploitation of their complementarities. There are several hypotheses explaining this fact, one being that both fields are well developed. But, in any case, building bridges between OR/MS methods and economic analysis can enrich both disciplinary fields from a theoretical as well as an applied perspective.

In our view, policy design is a field where the interactions between these two fields (economics and OR/MS) can be particularly fruitful. On the one hand, a purely theoretical economic vision could be unrealistic and difficult to apply in practice. So, resorting to a more operational view can help to cross the bridge from theory to practice. On the other hand, using a purely operational view without paying enough attention to the economic underpinnings could fail to capture many relevant elements and interactions that economic analysis has studied very thoroughly.

Apart from constructing a structural model (in this case, a CGE model), our methodological proposal requires some additional elements, such a suitable database to calibrate the model and make it fully applicable and consistent with reality, identifying the relevant policy instruments and policy objectives and choosing the best MCDM technique to address each specific problem. Throughout this book we have presented several applications using Spanish data. Note, though, that these applications were not the main purpose of the book. On the contrary, our main contribution is the methodological approach itself. In short, the Spanish case studies presented are just to illustrate how the proposed theoretical approach works. Thus, we have attempted to provide policy makers with a toolbox that should be applied and adapted to meet any specific policy needs.

In our analysis, we have introduced the notions of *efficient policy*, *compromise policy* and *satisficing policy*. These concepts correspond to different MCDM approaches and, hence, to different philosophies about how to deal with decision-making problems with multiple criteria. The concept of efficient policy, which is naturally linked to multiobjective programming, serves to guarantee that policy makers do not miss any costless opportunity of improvement, i.e. that there no other alternative policies that provide better results for some objectives without any cost in terms of other objectives. Compromise programming outputs a subset of the efficient set called the compromise set. By implementing compromise policies, the policy makers can know for sure that their outcomes for the policy objectives, apart from being efficient, will be as close as possible to the optimum values. Finally, in cases where policy makers are concerned not about optimality but about attaining set target levels for their objectives, they can resort to goal programming in order to get so-called Simonian satisficing policies.

10.2 Discussion and Guidelines for Future Research

At this point, it could be useful to underline some of the problems and limitations of our analysis. Some of these limitations are deliberate and obey the omnipresent trade-off between realism and simplicity. To keep our model manageable and understandable, we have opted to include some simplifying assumptions. The relaxation of those simplifications points to plausible lines of future developments.

First, we have included some simplifications in terms of how different market interactions have been modelled. These include the small country hypothesis and overlooking the international relationships both at the economic and the environmental levels. Also, we have decided to keep a simple heuristic approach for labour supply. Elaborating a more detailed analysis of this element could be relevant for those analysis aiming to focus on the effects of policies on the labour market.

One of the most notable simplifications is that we have confined ourselves to a static short-term approach. Although there is nothing to prevent us from upgrading the model to a dynamic version, this extension would be too complicated for this first stage. A richer (although more complex) dynamic framework that could be developed in future extensions would allow us to address an array of interesting additional issues. First, purely economic issues, such as investment and capital accumulation. Second, technological issues such as R&D and technical progress. And, finally, environmental issues such as long term sustainability.

Specifically regarding the environmental issues (and consistent with the short-term approach), we have kept the assumption that pollution intensity is constant. This assumption implicitly neglects the possibility that firms engage in abatement activities or investments in clean technology. On the other hand, we have assumed a unidirectional effect of the economy on the environment (more activity implies more pollution). In a longer term analysis, it might be relevant to consider the opposite effect, i.e. the impact of environmental quality on the economy, an issue that is attracting increasing attention, particularly since the Stern review was published (see Stern 2007). Some analysis on this direction can be found in Nordhaus and Yang (1996) or Böhringer et al. (2006). For a recent survey see Tol (2009).

Nevertheless, some additional qualifications for the adoption of these assumptions can also be worthwhile. One first reason that we have already reported to include them is to simplify the analysis. But there is still one further argument if the primary aim of the study is positive. Indeed, one of the main goals of this research has been to offer a realistic description of how real policy making is made in practice. It is arguable to what extent the government follows sophisticated analyses in order to design its policies or it just follows some simple rules and, arguably, sometimes a strictly short-term approach. It may even be the case that our CGE model is still far more complex than the tools that some governments use in practice. So, those analysts interested in broaden this research should assess to what extent it is relevant to make the model more complex and in which directions to do so. If the objective is to offer policy prescriptions or to obtain realistic simulations, it will be probably worth to construct a richer and more complex model. But if one wants to represent, from a descriptive, positive point of view, how policy is made in practice, using a extremely sophisticated model could reduce rather than increase the degree of realism.

In any case, note that these shortcomings are not inherent to our methodological approach, and they obey deliberate simplifying assumptions. But our proposal is also subject to some intrinsic complications that are worth noting. Probably, the most important is the complexity of making a sound implementation. Even after making a number of simplifications, any researcher or analyst who takes up our proposal should have a good knowledge of at least the following elements: macroeconomic and environmental policy making, multicriteria decision analysis, general equilibrium modelling and computer programming. In turn, it is well-known that CGE modelling itself requires combining a good deal of ingredients, as J. Whalley remarked:

> ...when involved in modelling activity in the applied general equilibrium area, one has to be familiar with general equilibrium theory, to be able to program (or at least communicate with programmers), to be familiar with data and be able to manipulate and convert it into a model admissible form, to be conversant with literature estimates of key parameters

(including elasticities), to have a clear sense of policy issues and institutional structure, and to be able to interpret results.[1]

In return for the rich disaggregated information provided by a CGE model, we have to elaborate and deal with rather large multi-equation models. For example, the computer version of our model contains about 1,260 equations and 1,440 variables.

Another intrinsic difficulty of applying this procedure has to do with the large amount of data required to calibrate the model (essentially, the social accounting matrices). The technical difficulties associated with the construction of such databases means that researchers typically have to work with data that are several years' old. This tends to undermine the validity of numerical results, which should, in any case, always be viewed with caution.

Throughout most of the book, we have taken a positive view and tried to model policy making more realistically than is usually done in the mainstream economics literature. On top of this approach, we have also introduced a tentative approximation for policy design based on a more classical normative viewpoint (see Chap. 9). MCDM techniques can be readily adapted for this task if we take the welfare or utility of individuals or social groups as the decision objectives to be optimized or rather compromised. The compromise objective function that we construct on these grounds can be naturally interpreted as a social welfare function that represents social preferences along the lines of classical social choice theory. Our approach has the advantage of providing an explicit measure of the trade-off between fairness (in the sense of equilibrium or balancedness among individual welfare) and overall efficiency (in the sense of aggregated welfare). This proposal is introduced tentatively and, of course, also has its limitations. Apart from sacrificing some degree of realism compared with our initial proposal, a number of tricky issues need to be addressed, such as how to measure individual preferences, how to determine the weight of different individuals or groups or the interpersonal comparison of utilities.

Summing up, we must confess that our approach is not perfect and is clearly subject to limitations. Nevertheless, we modestly hope to have contributed a useful proposal for going about policy making in a different and more open-minded fashion and to have provided some inspiration for researchers interested in addressing policy making in a well-founded and realistic way.

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