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# *A GOAL PROGRAMMING APPROACH FOR A JOINT DESIGN OF MACROECONOMIC AND ENVIRONMENTAL POLICIES: A METHODOLOGICAL PROPOSAL AND AN APPLICATION TO THE SPANISH ECONOMY*

Francisco J. André (U. Pablo de Olavide)
M. Alejandro Cardenete (U. Pablo de Olavide)
Carlos Romero (U. Politécnica de Madrid)

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**Department of Economics**

# A GOAL PROGRAMMING APPROACH FOR A JOINT DESIGN OF MACROECONOMIC AND ENVIRONMENTAL POLICIES: A METHODOLOGICAL PROPOSAL AND AN APPLICATION TO THE SPANISH ECONOMY

**Running title: Goal Programming and Policy Making**


Francisco J. André [a]     M. Alejandro Cardenete [a]     Carlos Romero [b]

[a] Universidad Pablo de Olavide. Carretera de Utrera, km.1. 41008 Sevilla, Spain.

[b] Universidad Politécnica de Madrid-Research Group: Economics for a Sustainable Environment. ETS Ingenieros de Montes Ciudad Universitaria s/n. 28040 Madrid, Spain

**Corresponding Author:**

Francisco J. André. Department of Economics. Universidad Pablo de Olavide. Carretera de Utrera, km.1. 41008 Sevilla, Spain. Fax: 34 954 34 93 93. E-mail: andre@upo.es



## Abstract

Economic policy needs to pay more attention to environmental issues. This calls for the development of methodologies capable of incorporating environmental as well as macroeconomic goals in the design of public policies. In view of this, this paper proposes a methodology based upon Simonian satisficing logic implemented with the help of goal programming models to address the joint design of macroeconomic and environmental policies. The methodology is applied to the Spanish economy, where a joint policy is elicited, taking into account macroeconomic goals (economic growth, inflation, unemployment, public deficit) and environmental goals ($CO_2$, $NO_x$ and $SO_x$ emissions) within the context of a computable general equilibrium model.



**Keywords**: environmental policies, goal programming, macroeconomic policies, computable general equilibrium model, multiple criteria decision making, satisficing logic.

## 1. INTRODUCTION

The standard approach in economics for modelling the optimal design of economic policy is to assume that a social planner aims at maximizing some social welfare function, typically a representative consumer's utility function (see Ramsey (1927) for a pioneering work). This conventional approach is also often applied to model environmental policy, which is typically envisioned as the correction of externalities and other market failures in order to achieve maximum economic welfare (see, e.g., Pigou (1920) and Coase (1992) for pioneering works, Baumol and Oates (1988) for a classical comprehensive text or Xepapadeas (1997) for an up-to-date analysis).

A more pragmatic look at the design of economic and environmental policy in practice can lead to the conclusion that policy makers do not seek to maximize a single welfare function, but are typically concerned with a bundle of economic and environmental variables or indicators and try to design their policies to improve the performance of the economy as measured by these indicators. In other words, the government typically faces a decision-making problem with several policy goals, and these goals usually conflict with each other. In purely economic terms, an active anti-unemployment policy could foster inflation; increasing consumer demand could be harmful to the foreign sector, and so on. This is a particularly important point when the environment is added as a key concern. Economic objectives are typically opposed to environmental objectives, since economic activity requires the exploitation of natural resources and generates numerous wastes that have an impact on the environment (see, e.g. Meadows, 2004).

Multicriteria decision making (MCDM) paradigm was developed specifically to deal with situations in which there are multiple conflicting goals. Several particular techniques, such as multiobjective programming, compromise programming, goal programming and others, have been fruitfully applied to many problems in which it is unreasonable or impractical to assume the existence of any one criterion that rightly defines the preferences of the decision-maker (DM). See Ballestero and Romero (1998) for an introduction to multicriteria techniques and their applications to economic problems. This type of approach has been applied very extensively to the management of the environment and natural resources (see e.g., Romero and Rehman, 1987, Mendoza and Martins, 2006).

In a recent line of research, André and Cardenete (2005, 2006) and André, Cardenete and Romero (2007) proposed the use of MCDM techniques to design macroeconomic policies. We build on this line of research, extending it to include not only economic, but also environmental objectives. In this way we aim to provide a broader framework to plan jointly economic and environmental policies.

The key elements involved in applying this approach are as follows. First, a model or mathematical representation is needed of the economy under analysis, including both economic and environmental variables. Our basic methodological proposal is a joint representation of economic policy and environmental policy as a multicriteria problem. This idea could, in principle, be compatible with any economic model representing the decisions of and the interactions among economic agents under different policy scenarios. The specific model is not a key feature of the general methodological idea and should be selected by the researcher or the policy maker according to the goals of each analysis. As explained in section 2, we opted for a computable general equilibrium (CGE) model. Such models have been widely used for the empirical analysis of both economic and environmental problems (see, e.g., André *et* *al.*, 2005, O'Ryan *et al.*, 2005 or Böhringer and Löschel, 2006). The model is calibrated with 1995 data for the Spanish economy, since the most recent officially available social accounting matrix for Spain dates back to this year.

Second, the policy-making problem must be set up by defining the relevant policy objectives and policy instruments. To illustrate our methodological proposal, we select some common macroeconomic objectives for application —economic growth, inflation, unemployment and public deficit—, and some of the seemingly most important environmental objectives, like $CO_2$, $SO_X$ and $NO_X$ emissions. These elements are presented in section 3. Finally, policy-making problems must be tackled by means of some suitable multicriteria technique. In section 4 we claim that, in practice, Simonian satisficing logic, as opposed to maximizing logic, usually underlies policy-making problems (see Simon 1955, 1957). Thus, policy makers do not usually pursue the maximization of any policy objective, but they do try to come as close possible to some reasonable target levels. This idea is consistent with the multicriteria approach known as goal programming (GP). González-Pachón and Romero (2004) establish an axiomatic link between GP and the Simonian satisficing logic. In section 4 we formulate a GP model that can establish a satisficing economic and environmental policy design. The model is applied to the Spanish economy. This produces several suitable policies integrating economic and environmental aspects. The main methodological and applied conclusions derived from the model are discussed in section 5.

## 2. THE MODEL AND THE DATABASES

### 2.1. The basic model

We use a CGE model following the basic principles of the Walrasian equilibrium. See Kehoe *et al.* (2005) for an up-to-date review. The model is extended by including both the public and foreign sectors and explicitly accounting for polluting emissions. Taxes and the public sector activity are viewed as exogenous for consumers and firms, while they are considered as decision variables for the government. The activity level of the foreign sector is assumed to be fixed. The relative prices and the activity levels of the productive sectors are endogenous variables. Economic equilibrium 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 maximizes his or her utility. On the other hand, it is assumed that 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.

For reasons of space, we discuss only the key elements of the model. A more detailed description can be found in the appendix placed at the end of the paper.

The model comprises 9 productive sectors, after aggregation of Spain's 1995 social accounting matrix (SAM). The production technology is given by a *nested production function*. The domestic output of sector $j$, measured in euros and denoted by $Xd_j$, is obtained by combining outputs from the other sectors and the value added $VA_j$ using a Leontief technology. This value added is generated from primary inputs (labor, $L$, and capital, $K$), combined using a Cobb-Douglas technology. Overall output of sector $j$, $Q_j$, is obtained from a Cobb-Douglas combination of domestic output and imports $Xrow_j$, according to the Armington hypothesis (1969), in which domestic and imported products are taken as imperfect substitutes.

The government raises taxes to obtain public revenue, *R*, (the appendix specifies how every tax in the model is computed). Also it gives transfers to the private sector, *TPS*, and demands goods and services from each sector $j = 1,...,9$, $GD_j$. *PB* denotes the final balance (surplus or deficit) of the public budget:

$$PB = R - TPS\ cpi - \sum_{j=1}^{9} GD_j\ p_j, \tag{1}$$

*cpi* being the Consumer Price Index and $p_j$ a production price index before value added tax (VAT) referring to all goods produced by sector *j*. Tax revenue includes revenue raised from all taxes, including environmental taxes.

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

$$ROWD = \sum_{j=1}^{9} rowp\ IMP_j - TROW - \sum_{j=1}^{9} rowp\ EXP_j\ , \tag{2}$$

where $IMP_j$ denotes imports of sector *j*, $EXP_j$ exports of sector *j*, *TROW* transfers from abroad for the consumer and *rowp* is a weighted price index of imported goods and services.

Final demand comes from investment, exports and consumption demand from households and the public sector. In our model, there are 9 different goods –corresponding to productive sectors- and a representative consumer who demands present consumer goods and saves the remainder of her disposable income. Consumer disposable income (YD) equals labor and capital income, plus transfers, minus direct taxes:

$$YD = w\ L + r\ K + cpi\ TPS + TROW - DT\ (r\ K + cpi\ TPS + TROW)$$

$$- DT\,(w\,L - WC\,w\,L) - WC\,w\,L, \tag{3}$$

where $w$ and $r$ denote input (labor and capital) prices and $L$ and $K$ input quantities sold by the consumer, $DT$ is the income tax rate and $WC$ the tax rate corresponding to employee Social Security taxes The consumer's objective is to maximize her welfare, subject to her budget constraint. Welfare is obtained from consumer goods $CD_j$ (j = 1,…, 9) and savings $SD$, according to a Cobb-Douglas utility function:

$$\begin{aligned} &\text{maximize} \qquad U\ (CD_1,\ldots,CD_9, SD\ ) = \left(\prod_{j=1}^{9} CD_j^{\alpha_j}\right) SD^{\beta} \\ &\text{s.t.} \qquad \sum_{j=1}^{9} p_j CD_j + p_{inv}\ SD\ = YD \end{aligned} , \tag{4}$$

$p_{inv}$ being an investment price index.

Regarding investment and saving, this is a *savings-driven* model. The closure rule is defined in such a way that investment, $INV$, is exogenous, savings are determined from the consumer's decision, and both variables are related to the public and foreign sectors by the identity

$$\sum_{j=1}^{9} INV_j p_{inv} = SDpinv + PD + ROWD\,, \tag{5}$$

where $pinv$ is a price index of investment goods.

Labor and capital demands are computed under the assumption that firms aim to maximize profits and minimize the cost of their production. In the capital market we consider that supply is perfectly inelastic. In the labor market, it should be stressed particularly that there is unemployment (which provides some evidence of labor market imperfections or rigidities), and the unemployment rate should be explicitly included in the model. We take the following approach to labor supply, which shows a feedback between the real wage and the unemployment rate, related to the union power or other factors causing labor market friction (see Kehoe *et al.*, 1995):

$$\frac{w}{cpi} = \frac{1-u}{1-\bar{u}}, \tag{6}$$

where $u$ and $\bar{u}$ are the unemployment rates in the simulation and in the benchmark equilibrium, respectively, and $w/cpi$ is the real wage. This formulation is consistent with an institutional setting where the employers decide the amount of labor demanded and workers decide the real wage, taking into account the unemployment rate according to equation (6); i.e. if labor demand increases (decreases), the unemployment rate $u$ decreases (increases) and workers demand higher (lower) real wages. If, after the simulation, employment remains unchanged, the real wage is the same as in the benchmark equilibrium.

**2.2 Pollution and environmental taxes**

We focus on emissions obtained from production activities and we adopt a short-term approach. Therefore, 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 $j$ ($j = 1, \ldots, 9$). Then, we have the following equation, which assumes a linear relationship between production $Q_j$ (measured in constant euros) and emissions

$$E_j^m = \alpha_j^m \cdot Q_j, \tag{7}$$

where $\alpha_j^m$ measures the amount of emissions of pollutant $m$ per unit of output produced in sector $j$. The technical parameter $\alpha_j^m$ accounts for the differences in pollution intensities across sectors.

The government imposes an environmental tax of $t^m$ euros per emissions unit. As a consequence, each sector $j$ pays $T_j^m$ euros, because of its pollutant emissions $m$, where

$$T_j^m = t^m \cdot E_j^m . \quad (8)$$

Note that because the pollution intensity varies across sectors, the same tax on pollution implies a different economic burden with respect to output. Substituting (7) into (8), the tax to be paid by sector *j* can be written as

$$T_j^m = \beta_j^m \cdot Q_j , \quad (9)$$

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

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

$$E^m = \sum_{j=1}^{9} E_j^m \,. \qquad (10)$$

## 2.3. Databases and calibration

The main economic data used in the paper come from the aggregated 1995 social accounting matrix (SAM) for Spain. This is the most recent officially available SAM. It comprises 21 accounts, including 9 productive sectors, two inputs (labour and capital), a saving/investment account, a government account, direct taxes (income tax and payment and employees' Social Security tax) and indirect taxes (VAT, payroll tax, output tax and tariffs), a foreign sector and a representative consumer (see Cardenete and Sancho, 2006, for details).

The values for the technological coefficients, the tax rates and the utility function coefficients are calibrated to reproduce the 1995 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.

To calibrate the $\alpha_j^m$ coefficients, we also use sectorial data on the three considered pollutants from the Spanish Statistical Institute's satellite accounts on atmospheric emissions[1].

# 3. POLICY SETTING

## 3.1 Policy instruments

[1] Available at http://www.ine.es/inebase/cgi/um?M=%2Ft26%2Fp067&O=inebase&N=&L=0

We assume that the policy maker can use the following policy instruments: direct and indirect taxes, environmental taxes and public expenditure in each activity sector. To make the exercise more lifelike, the direct and indirect tax rates, as well as public expenditure by sectors will not be allowed to vary more than 3% with respect to the benchmark situation. As regards the environmental taxes, all the tax rates $t^m$ will be confined to 0 to 3 (from 0 to 3 monetary units per unit of pollutant). These values are chosen to represent a reasonable economic burden in terms of output.

### 3.2 Policy objectives

We assume that the government is concerned about two types of policy objectives: economic objectives and environmental objectives.

***Economic policy objectives***

1.- Real annual growth rate of GDP, computed as

$$f_1 = \frac{GDP_{1995} - GDP_{1994}}{GDP_{1994}} \cdot 100 \, . \tag{11}$$

**2.-** Inflation rate, computed as

$$f_2 = \frac{cpi_{1995} - cpi_{1994}}{cpi_{1994}} \cdot 100 \, , \tag{12}$$

where $cpi$ is the consumer price index.

3.- Unemployment rate, $f_3 = u$.

4.- Public budget (surplus/deficit) taken as a percentage of GDP:

$$f_4 = \frac{PB}{GDP}100\,, \qquad (13)$$

where $PB$ is the balance of the public budget ($PB > 0$ means surplus and $PB < 0$ means deficit).

***Environmental policy objectives***

5.- $CO_2$ emissions. For the sake of normalization, the indicator we take is the rate of change of $CO_2$ emissions with respect to the observed situation in 1995:

$$f_5 = \left[ \frac{E^{CO_2}}{E^{CO_2}_{bench}} - 1 \right] \cdot 100\,, \qquad (14)$$

where $E^{CO_2}$ represents emissions after applying the public policy and $E^{CO_2}_{bench}$ stands for the $CO_2$ emissions in the benchmark situation; i.e. the observed value in 1995.

6.- $NO_X$ emissions (rate of change with respect to benchmark situation):

$$f_6 = \left[ \frac{E^{NO_X}}{E^{NO_X}_{bench}} - 1 \right] \cdot 100\,, \qquad (15)$$

where $E^{NO_X}$ represents emissions after applying the public policy and $E^{NO_X}_{bench}$ stands for the $NO_X$ emissions in the benchmark situation; i.e. the observed value in 1995.

7.- $SO_X$ emissions (rate of change with respect to benchmark situation):

$$f_7 = \left[ \frac{E^{SO_X}}{E^{SO_X}_{bench}} - 1 \right] \cdot 100 \qquad (16)$$

where $E^{SO_X}$ represents emissions after applying the public policy and $E^{SO_X}_{bench}$ stands for the $SO_X$ emissions in the benchmark situation; i.e. the observed value in 1995.

## 4. A GOAL PROGRAMMING APPROACH: MODELS AND RESULTS

### 4.1 Determining the conflict among objectives

As is common in MCDM exercises, a useful first step is to determine the degree of conflict between the relevant criteria by computing the so-called payoff matrix. This is done by optimizing each objective separately and then computing the value of each objective at each of the optimal solutions. Table 1 lists the results of these calculations. The first row shows the values for each objective when economic growth is maximized. The second row shows the same values when inflation is minimized and so on. The elements of the main diagonal (in bold characters) display the best attainable value for each objective (the highest growth rate, the minimum inflation rate and so on), which, taken together, are called the ideal point. The worst element of each column (underlined) represents the so-called anti-ideal or nadir point.

Looking at Table 1, we find that there is a clear conflict between economic and environmental criteria, and especially between real growth and pollution reduction. An active pro-growth policy could get a real growth of 3.025%, but this would come at the cost of increasing $CO_2$ emissions (by 0.408 per cent), $SO_X$ emissions (by 0.3851 per cent) and $NO_X$ emissions (by 0.3833 per cent). 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 2.4 %. There is also some conflict among the economic criteria. For example, maximizing growth entails a higher level of inflation and a high public deficit. On the other hand, there appear to be no big conflicts among the environmental criteria, since the same policies seem to be consistent with the reduction of any of the selected pollutants.

After observing the pay-off matrix, it is quite clear that none of the solutions generated by the optimization of any one criterion is acceptable from both the economic and the environmental point of view. To get an acceptable policy design, it is absolutely necessary to look for best-compromise or satisficing policies between the seven single optimum policies shown in Table 1. This task is undertaken in the next section by formulating and solving several goal programming (GP) models.

### 4.2 Searching for a satisficing joint policy

For each of the seven policy objectives, we tentatively set a satisficing target level. In this way, the following goals are defined:

$$f_k + n_k - p_k = t_k \qquad k \in \{1,...,7\}, \tag{17}$$

where $n_k$ is the negative deviation variable measuring possible under-achievements and $p_k$ is the positive deviation variable measuring possible over-achievement for the $k$ th policy goal defined mathematically by $f_k$. The "more is better" postulate applies to the first and fourth policy goals, and therefore the unwanted deviation variable is the negative one (i.e. $n_k$), whereas the "less is better" postulate applies to the other goals, and therefore the unwanted deviation variable is the positive one (i.e. $p_k$).

Following GP logic, the unwanted deviation variables must be minimized in one way or in another. This leads to the following general achievement function:

$$Min\left(n_1, p_2, p_3, n_4, p_5, p_6, p_7\right). \tag{18}$$

Several types of achievement functions will be defined and preferentially interpreted. Before doing this, though, let us set sensible target values for the seven goals considered. These tentative figures, expressed in percentages, are

$$t_1 = 2, t_2 = 4, t_3 = 23, t_4 = -3.5, t_5 = 0, t_6 = 0, t_7 = 0.$$

The above vector of satisficing targets means that the policy maker would consider 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 % over the GDP, to be a reasonable achievement.

To find a policy that is consistent with these target levels we test several functional forms for the general achievement function given by (18). The first one is a weighted sum of the unwanted deviation variables, which leads to the following weighted GP (WGP) formulation (Ignizio, 1976):

$$Min\, W_1 n_1 + W_2 p_2 + W_3 p_3 + W_4 n_4 + W_5 p_5 + W_6 p_6 + W_7 p_7, \tag{19}$$

where $W_k$ is the weight or relative importance attached by the policy maker to the achievement of the $k$ th goal ($k = 1, \cdots, 7$). The minimization of (19) is subject to all the equations defined in the model, as well as the goals defined in (17). Suppose that the policy maker is equally concerned about the achievement of all the goals, making the weights $W_1 = W_2 = \ldots = W_7 = 1$. Based on this assumption and the above target values, we get the solution shown in Table 2.

Note that all the target values are defined in percentages. Hence, it is not necessary to undertake any type of normalization with the above goals. On the other hand, a well-known critical issue in goal programming (see Romero 1991) is the possibility of getting a Pareto inefficient solution. A solution is said to be inefficient if the value of some criteria can be improved without worsening the value of any other criterion. We find that the solution in Table 2 fully satisfies the specified target values and, in some cases, the obtained value is even better than the target value. This seems to indicate that the target values have been set at very soft levels. This is a typical situation in which inefficient solutions may arise and leads us to suspect that the solution shown in Table 2 may perhaps be inefficient (Tamiz and Jones, 1996).

To check the efficiency of the solution we run a test introduced by Masud and Hwang (1980). We proceed by maximizing the wanted deviation variables subject to the condition that the achievement of the seven policy goals derived from the WGP model cannot be degraded. Thus, the following optimization problem is formulated:

$$Max\ p_1 + n_2 + n_3 + p_4 + n_5 + n_6 + n_7, \tag{20}$$

subject to $f_1 \geq 2.63$, $f_2 \leq 4$, $f_3 \leq 23$, $f_4 \geq -3.3$, $f_5 \leq -0.46$, $f_6 \leq -0.55$, $f_7 \leq -0.48$ and all the equations in the model. The resulting solution is shown in Table 3.

Firstly, observe that the new solution Pareto dominates the previous one. This proves that the solution in Table 2 is inefficient. Also, by construction, we know that the solution in Table 3 is Pareto efficient. Secondly, note that, when moving from the first to the second solution, the results of all the economic objectives are unchanged, and the value of all the environmental objectives improve in the sense that the emissions of all the polluting substances decrease. This change can be interpreted as a rearrangement of economic activity to benefit the environment. Although efficiency is a typical economic concept, this example helps to illustrate the fact that, when the right criteria are considered, an increase in efficiency does not necessarily improve the economic results and may be beneficial to the environment.

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 target values

$$t_1 = 2.7, t_2 = 3, \; t_3 = 22.7. \; t_4 = -3.0, \; t_5 = -1, \; t_6 = -2, \; t_7 = -1. \tag{21}$$

When solving the problem with these targets, we get the solution that is shown in Table 4. Observe that, in this case, all the unwanted deviation variables have nonnegative values. This is a sufficient condition for the solution to be efficient. The argument is as follows: if solution $S$ is inefficient, it must be possible to improve the value of some objective without worsening any other objective. Suppose, for example, that the value of economic growth ( $f_1$ ) can be improved 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 a better value for the other unwanted deviation variables. But this would render a smaller objective function value in (20), meaning that $S$ cannot be the solution to problem (20).

Nevertheless, note that, although the solution in Table 4 is efficient, whereas the solution in Table 2 is not, the former does not Pareto dominate the latter, since some objectives reach a better value in the first solution and some objectives have a better value in the last one.

### 4.3 Balanced satisficing policies

So far, we have used the so-called WGP approach. WGP provides a solution that minimizes the weighted sum of unwanted deviations. Nevertheless, this approach does not prevent the solution from providing very unsatisfactory results for some of the above goals. For example, in the solution shown in Table 4, the target value for the $CO_2$ emissions is exactly reached. This can be seen as a very satisfactory outcome. But there is an 85% deviation from the target value for unemployment, which is likely to be unacceptable from an economic point of view.

In this section we focus on those cases in which the policy maker is interested in getting *balanced* solutions in the sense that none of the goals deviates too far from the targets, i.e. we look for policies that assure that in no case is criteria achievement much displaced from the target values. This can be expressed in mathematical terms by the minimization of the maximum (weighted) deviation, i.e.

$$Min\ Max\left\{W_1 n_1, W_2 p_2, W_3 p_3, W_4 n_4, W_5 p_5, W_6 p_6, W_7 p_7\right\}. \qquad (22)$$

Since this objective function is not smooth, its minimization could be computationally complicated. A better way to express this is by the following MINMAX GP formulation (Tamiz *et al.*, 1998):

$$\begin{aligned} &Min\ D \\ &s.t.: \quad W_1 n_1 \le D, \quad W_2 p_2 \le D, \quad W_3 p_3 \le D, \quad W_4 n_4 \le D, \\ &\qquad\quad W_5 p_5 \le D, \quad W_6 p_6 \le D, \quad W_7 p_7 \le D \end{aligned} \qquad (23)$$

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

By solving this problem for the target values defined in (21), we get the solution shown in Table 5. By comparison with the solution in Table 4, observe that the maximum unwanted deviation in Table 5 is 0.70. This corresponds to the second, the third and the sixth goals, whereas the maximum deviation in Table 4 is 0.85 corresponding to fourth goal.

### 4.4 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. They may have pre-emptive priorities in the sense that there is a hierarchy defined over the targets such that the achievement of goals at a higher priority level is incommensurably more important than the attainment of lower priority objectives.

Suppose, for example that the policy maker's targets can be ranked as follows: the first priority includes the environmental targets 5, 6, 7, the second priority level includes target 4 and the third includes targets 1, 2 and 3. The achievement function can be written as

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

Also, suppose that the aspiration levels are

$$t_1 = 2.7,\ t_2 = 4.5,\ t_3 = 22.7.\ t_4 = -3.0,\ t_5 = -1.5,\ t_6 = -1.5,\ t_7 = -1.5. \qquad (24)$$

This means that the government's highest priority is at least a 1.5 % decrease in $CO_2$ emissions, $SO_X$ emissions and $NO_X$ emissions with respect to the benchmark situation, while all the pollutants are considered as equally important (since they are grouped in the same priority level). The second priority is that the public deficit should be no more than 3 % over GDP. Finally, the government is equally concerned about the achievement of the targets for growth, inflation and unemployment.

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. Therefore, we need to first solve the following problem

$$Min\left(W_5 p_5 + W_6 p_6 + W_7 p_7\right), \tag{25}$$

subject to the goal definitions (for goals 5, 6 and 7 only) and all the equations in the model, assuming that $W_5 = W_6 = W_7 = 1$. The values achieved by the three goals are $f_5 = -1.18$, $f_6 = -1.56$, $f_7 = -1.06$, and the unwanted deviation variables in this exercise are equal to $p_5 = 0.32$, $p_6 = 0$, $p_7 = 0.44$, meaning that the target value for $SO_X$ emissions is exactly achieved (actually, emissions can be even further reduced), whereas the targets for $CO_2$ emissions and $NO_X$ emissions cannot be fully achieved.

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

$$\begin{array}{l} Min\ n_4 \\ s.t. \quad p_5 \leq 0.32,\ p_6 = 0,\ p_7 \leq 0.44, \end{array} \tag{26}$$

including the definition of goals 4, 5, 6 and 7, as well as all the equations in the model. The value for the public budget balance (in terms of GDP) is $f_4 = -3.14$, making the negative deviation variable $n_4 = 0.14$.

The third problem to be solved involves minimizing the weighted sum of the unwanted deviation variables corresponding to the goals placed in the third priority level. Thus, we have

$$\begin{aligned} &Min\ W_1 n_1 + W_2 p_2 + W_3 p_3 \\ &s.t. \quad p_5 \le 0.32,\ p_6 = 0,\ p_7 \le 0.44,\ n_4 \le 0.14 \end{aligned} . \tag{27}$$

For equal weights (i.e., $W_1 = W_2 = W_3 = 1$), model (27) reproduces the solution provided by model (26). This result is due to the fact that problem (26) has no alternative optimum solutions, and consequently the goals placed in the third priority level become redundant, i.e., in practice, they play no real role in the decision-making process (Amador and Romero, 1989).

The solution for the third priority level and for the whole lexicographic process is shown in Table 6.

## 5. CONCLUDING REMARKS

This paper proposes a methodology for designing joint macroeconomic and environmental policies. The methodology is based upon a Simonian satisficing philosophy and is implemented with the help of different goal programming models. The methodology seems sound from both a positive and a normative perspective.

From a positive perspective, the methodology is supported by conventional economic theory (as regards the CGE model) and 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.

From a normative perspective, the multi-criteria philosophy underlying the approach is consistent with the claim that policy makers should take the view that the environment is a key concern, and that environmental criteria are no less important than the economic ones. In this way, the proposed methodology provides policies that represent sound compromises among the economic and the environmental criteria.

Our results illustrate how, *a priori*, the government can set different target values for the key criteria and fine-tune its policy accordingly. It was demonstrated throughout the paper how GP models, which are very easy to formulate and to compute, can 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 the goals. On the other hand, *a posteriori*, by using GP models, it is possible to check if the target levels initially fixed by the government for each policy criterion are reasonable (i.e., feasible) and what is the trade-off of these targets in terms of the other criteria.

Concerning future research, the proposed approach can be extended in some directions. First, the weights attached to the achievement of each goal can be obtained using different preference elicitation techniques. Second, different GP formulations can be tested. Thus, an Extended GP formulation, which combines the WGP option (maximum aggregate performance) and the MINMAX GP option (maximum balance), is an interesting possibility, since this would specify the trade-off between aggregate achievement and maximum balance among the goals (see Romero, 2001). Finally, the economic model used for the application can be extended and improved in many ways depending on the aims of the analysis. For example, money supply and money demand can be given more attention, or the dynamics of the economy could be addressed in a more sophisticated model.

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## TABLES

Table 1: Payoff matrix

| | Growth | Inflation | Unempl. | PB/GDP | $CO_2$ | $SO_X$ | $NO_X$ |
|---|---|---|---|---|---|---|---|
| **Growth** | **3.025** | 3.824 | 22.460 | -3.857 | 0.408 | 0.3851 | 0.3833 |
| **Inflation** | 2.421 | **2.311** | 23.290 | -3.489 | -0.120 | -0.178 | -0.151 |
| **Unempl.** | 3.025 | 3.824 | **22.460** | -3.857 | 0.408 | 0.3851 | 0.3833 |
| **PB/GDP** | 2.412 | 5.601 | 23.290 | **-2.984** | -1.068 | -1.448 | -0.056 |
| **$CO_2$** | 2.470 | 5.810 | 23.200 | -3.353 | **-1.162** | -1.517 | -1.031 |
| **$SO_X$** | 2.438 | 5.056 | 23.240 | -3.111 | -1.180 | **-1.5648** | -1.059 |
| **$NO_X$** | 2.413 | 4.849 | 23.280 | -3.089 | -1.172 | -1.534 | **-1.063** |

All variables are measured in % with respect to benchmark situation. Bold figures denote ideal values and underlined figures anti-ideal values.

**TABLE 2.** Finding a satisfacing solution

| | **k** | **$f_k$** | **$n_k$** | **$p_k$** |
|---|---|---|---|---|
| Economic objectives | 1 | 2.63 | 0.00 | 0.63 |
| | 2 | 4.00 | 0.00 | 0.00 |
| | 3 | 23.00 | 0.00 | 0.00 |
| | 4 | -3.30 | 0.00 | 0.20 |
| Environmental objectives | 5 | -0.46 | 0.46 | 0.00 |
| | 6 | -0.55 | 0.55 | 0.00 |
| | 7 | -0.48 | 0.48 | 0.00 |

$f_k, n_k, p_k$ are measured in % with respect to benchmark situation.

| | **TABLE 3.** Testing for efficiency | | | |
|---|---|---|---|---|
| | **k** | **$f_k$** | **$n_k$** | **$p_k$** |
| Economic objectives | 1 | 2.63 | 0.00 | 0.63 |
| | 2 | 4.00 | 0.00 | 0.00 |
| | 3 | 23.00 | 0.00 | 0.00 |
| | 4 | -3.30 | 0.00 | 0.20 |
| Environmental objectives | 5 | -0.55 | 0.55 | 0.00 |
| | 6 | -0.73 | 0.73 | 0.00 |
| | 7 | -0.50 | 0.50 | 0.00 |

$f_k, n_k, p_k$ are measured in % with respect to benchmark situation.

**TABLE 4. A**n alternative efficient solution

| | k | $f_k$ | $n_k$ | $p_k$ |
|---|---|---|---|---|
| Economic objectives | 1 | 2.22 | 0.48 | 0.00 |
| | 2 | 4.00 | 0.00 | 0.55 |
| | 3 | 23.55 | 0.00 | 0.85 |
| | 4 | -3.03 | 0.03 | 0.00 |
| Environmental objectives | 5 | -1.00 | 0.00 | 0.00 |
| | 6 | -1.29 | 0.00 | 0.71 |
| | 7 | -0.93 | 0.00 | 0.07 |

$f_k, n_k, p_k$ are measured in % with respect to benchmark situation.

| | TABLE 5. A balanced solution | | | |
|---|---|---|---|---|
| | **k** | **$f_k$** | **$n_k$** | **$p_k$** |
| Economic objectives | 1 | 2.33 | 0.51 | 0.00 |
| | 2 | 3.70 | 0.00 | 0.70 |
| | 3 | 23.40 | 0.00 | 0.70 |
| | 4 | -3.04 | 0.04 | 0.00 |
| Environmental objectives | 5 | -1.00 | 0.00 | 0.00 |
| | 6 | -1.30 | 0.00 | 0.70 |
| | 7 | -0.91 | 0.00 | 0.09 |

$f_k, n_k, p_k$ are measured in % with respect to benchmark situation.

| | TABLE 6. Solution with a hierarchy for policy goals | | | |
|---|---|---|---|---|
| | **K** | $f_k$ | $n_k$ | $p_k$ |
| Economic objectives | 1 | 2.47 | 0.23 | 0.00 |
| | 2 | 5.21 | 0.00 | 0.71 |
| | 3 | 23.00 | 0.00 | 0.53 |
| | 4 | -3.14 | 0.14 | 0.00 |
| Environmental objectives | 5 | -1.18 | 0.00 | 0.32 |
| | 6 | -1.55 | 0.00 | 0.05 |
| | 7 | -1.06 | 0.00 | 0.44 |
| $f_k, n_k, p_k$ are measured in % with respect to benchmark situation. | | | | |

APPENDIX

***PRODUCTION***

Total production is given by the Cobb-Douglas technology

$$Q_j = \phi_j \left( Xd_j^{\sigma_j}, Xrow_j^{1-\sigma_j} \right), \tag{A1}$$

where $Q_j$ is the total output of sector $j$, $Xd_j$ stands for the domestic output of sector $j$, $Xrow_j$ stands for foreign output of sector $j$, $\phi_j$ is the scale parameter of sector $j$ and $\sigma_j$ (1-$\sigma_j$) is the elasticity of domestic (foreign) output.

Domestic production is calculated from the Leontief production function

$$Xd_j = \min\left\{ \frac{X_{1j}}{a_{1j}}, \ldots, \frac{X_{24j}}{a_{9j}}, \frac{VA_j}{v_j} \right\}, \tag{A2}$$

where $X_{ij}$ is the amount of commodity $i$ used to produce commodity $j$, $a_{ij}$ are the technical coefficients 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 $j$.

Value added in sector $j$ is obtained from labor and capital according to a Cobb-Douglas technology

$$VA_j = \mu_j L_j^{\gamma_j} K_j^{1-\gamma_j}, \tag{A3}$$

where $\mu_j$ is the scale parameter of sector $j$, $\gamma_j$ is the elasticity of labor, $L_j$ represents the amount of labor employed in sector $j$ and $K_j$ represents the amount of capital used in sector $j$.

***CONSUMERS***

The utility function is of the Cobb-Douglas type

$$U\ (CD_j, SD) = \left( \prod_{j=1}^{9} CD_j^{\alpha_j} \right) SD^{\beta}\ , \tag{A4}$$

where $CD_j$ stands for consumption of commodity $j$, $SD$ stands for consumer savings and $\alpha_j$ , $\beta$ measure the elasticity of consumer goods and savings.

***PUBLIC SECTOR***

***Indirect taxes***

Taxes on output, $R_P$, are calculated as

$$R_P = \sum_{j=1}^{9} \tau_j \left[ \sum_{i=1}^{9} a_{ij} p_i Xd_j + \left( \left( 1 + EC_j \right) wl_j + rk_j \right) VA_j \right], \tag{A5}$$

where $l_j$ and $k_j$ are the technical coefficients of capital and labor in sector $j$, $\tau_j$ is the tax rate on the output of sector $j$ and $EC_j$ is the Social Security tax rate paid by employees of sector $j$.

Social Security paid by employers, $R_{LF}$, is given by

$$R_{LF} = \sum_{j=1}^{9} EC_j wl_j VA_j\ . \tag{A6}$$

Tariffs, $R_{T,}$ equal

$$R_T = \sum_{j=1}^{9} t_j rowp\ a_{rwj} Q_j \,, \qquad \text{(A7)}$$

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

$R_m$ stands for the revenue obtained from the environmental tax on pollutant $m$, ($m \in \{CO_2, NO_X, SO_X\}$), and it is given by

$$\begin{aligned} R_m = & \sum_{j=1}^{9} \beta_j^m \left(1+\tau_j\right)\left[\sum_{i=1}^{9} a_{ij} p_i Xd_j + \left(\left(1+EC_j\right) wl_j + rk_j\right) VA_j\right] \\ & + \sum_{j=1}^{9} \beta_j^m \left(1+t_j\right) rowp\ a_{rwj} Q_j \end{aligned} , \qquad \text{(A.8)}$$

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

$$\begin{aligned} R_{VAT} = & \sum_{j=1}^{9} VAT_j \left(1+\tau_j\right)\left(1+\beta_j^{CO_2}+\beta_j^{NO_X}+\beta_j^{SO_X}\right)\left(\sum_{i=1}^{9} a_{ij} p_i Xd_j + \left(\left(1+EC_j\right) wl_j + rk_j\right) VA_j\right) \\ & + \sum_{j=1}^{9} VAT_j \left(1+t_j\right)\left(1+\beta_j^{CO_2}+\beta_j^{NO_X}+\beta_j^{SO_X}\right) rowp\ a_{rwj} Q_j \end{aligned} , \qquad \text{(A.9)}$$

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

***Direct taxes***

Social Security tax paid by employers, $R_{LC}$, is obtained from

$$R_{LC} = WC\,w\,L \,, \qquad \text{(A.10)}$$

where *WC* is the employers' Social Security tax rate.

Income tax, $R_I$, is computed from

$$R_I = DT\left(wL + rK + cpi\,TPS + TROW - WC\ L\ w\right) \tag{A.11}$$

where *DT* is the income tax rate, *TPS* stands for transfers from the public sector to the consumer (pensions, allowances, social benefits, unemployment benefits…) and *TROW* stands for transfers from the rest of the world to the consumer.