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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

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Abstract The economic policy needs to pay increasingly more attention to the environmental issues, which requires the development of methodologies able to incorporate environmental, as well as macroeconomic, goals in the design of public policies. Starting from this observation, this article proposes a methodology based upon a Simonian satisficing logic made operational with the help of goal programming (GP) 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 consideration 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. The results show how the government can "fine-tune" its policy according to different criteria using GP models. The resulting policies aggregate the environmental and the economic goals in different ways: maximum aggregate performance, maximum balance and a lexicographic hierarchy of the goals.

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Introduction

The standard approach in economics to model the optimal design of economic policy is to assume that a social planner aims at maximizing some social welfare function, typically the utility function of a representative consumer (See Ramsey 1927 for a pioneering work). This conventional approach is also typically applied to the modeling of environmental policy, which is envisioned as the correction of externalities and other market failures in order to achieve the 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 an up-to-date analysis).

A more pragmatic look at the design of economic policy and environmental policy in practice can lead to the conclusion that policy makers do not seek to maximize a single welfare function, but they are typically concerned about a bundle of economic and environmental variables or indicators and they 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 problem with several policy goals and, moreover, these goals usually conflict with each other. In purely economic terms, an active anti-unemployment policy could foster inflation; giving positive incentives for consumption demand could be harmful for the foreign sector, and so on. This observation is particularly relevant when one includes the environment 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 impact the environment (see, for example, Meadows 2004).

The so-called Multicriteria Decision Making (MCDM henceforth) literature has been 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 not reasonable or operational to assume the existence of a single 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 for example, Romero and Rehman 1987; Mendoza and Martins 2006; Mavrotas and others 2006; Brody and others 2006; Liu 2007; Noble and Christmas 2008).

In a recent line of research, André and Cardenete (2008, 2009) and André and others (2008) have proposed the use of MCDM techniques for the design of macroeconomic policies. We build on this line of research, but we enlarge it by including, not only economic, but also environmental objectives. In this way we aim at providing a broader framework to envision jointly economic and environmental policies.

The key elements to apply this approach are the following: first, it is needed a model or mathematical representation of the economic 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 be, in principle, compatible with any economic model representing the decisions of economic agents and the interactions among them under different policy scenarios. The specific model is not a key feature of the general methodological idea and it should be selected by the researcher or the policy maker according to the goals of each analysis. As later explained, we resort to a Computable General Equilibrium (CGE) model. This kind of models has been extensively used for the empirical analysis of both economic and environmental problems (see, for example, André and others 2005; O'Ryan and others 2005 or Böhringer and Löschel 2006). The model is calibrated with data for the Spanish economy for the year 1995, since the most recent officially available Social Accounting Matrix for Spain corresponds to this year.

Second, the policy making problem must be set-up by defining the relevant policy objectives and the policy instruments. In order to illustrate our methodological proposal, in the application we select a bundle of key macroeconomic objectives: economic growth, inflation, unemployment and public deficit, and seemingly some of the most important environmental objectives, like the emissions of CO_2, SO_x and NO_x. These elements are presented in a later section. Finally, the policy making problems must be tackled by means of some suitable multicriteria technique. In the fourth section we claim that, in practice, policy making usually follows a Simonian satisficing logic rather than a maximizing logic (see Simon 1955, 1957). Thus, policy makers do not usually pursue the maximization of any policy objective, but they try to achieve as much as possible some reasonable aspiration levels. This idea is consistent with the multicriteria approach known as Goal Programming (GP). In González-Pachón and Romero (2004), an axiomatic link between GP and the Simonian satisficing logic is established. We also formulate a GP model that allows to establish a satisficing design of economic and environmental policies. The model is applied to the Spanish economy. In this way, several suitable policies integrating economic and environmental aspects are obtained. In the last section, the main methodological and applied conclusions derived from the model are discussed.

The Model and the Databases

The Basic Model

We use a CGE model following the basic principles of the Walrasian equilibrium. See Kehoe and others (2005) for an up-to-date review of this kind of models. Our model is enlarged by including both public and foreign sectors and explicitly accounting for polluting emissions. Taxes and the activity of the public sector are taken as exogenous by consumers and firms, while they are considered as decision variables by the government. The activity level of the foreign sector is assumed to be fixed, in the sense that the total amount of imports and exports is not sensitive to the policy changes implemented by the government. This assumption is consistent with a short run approach for 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 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.

In order to save some space, we just discuss some of the main elements of the model. Some additional details can be found in the appendix placed at the end of the article.

The model comprises 9 productive sectors, after aggregation of the 1995 Social Accounting Matrix (SAM) of Spain. The production technology is given by a *nested* *production function*. The domestic output of sector j ($j = 1,\ldots,9$), measured in euros and denoted by Xd_j, is obtained by combining, through a Leontief technology, outputs from the rest of sectors and the value added VA_j. In turn, this value added is generated from primary inputs (labor, L, and capital, K), combined by 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) as well as it gives transfers to the private sector, TPS, and demands goods and services from each sector $j = 1,\ldots,9, GD_j$. 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 hereafter) referring to all goods produced by sector j. Tax revenue includes that 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 scalar price index for the foreign sector calculated as a weighted average of all traded goods and services (including both imports and exports).

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

$$\begin{aligned} YD = {} & wL + rK + cpi\,TPS + TROW \\ & - DT(rK + cpi\,TPS + TROW) \\ & - DT(wL - WC\,wL) - WC\,wL \end{aligned} \tag{3}$$

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 the payment of the employees to Social Security. The consumer's objective is to maximize her welfare, subject to her budget constraint. Welfare is obtained from consumption goods CD_j ($j = 1,\ldots,9$) and savings SD, according to a Cobb-Douglas utility function:

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

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 $\sum_{j=1}^{9} \alpha_j + \beta = 1$.

Regarding investment and saving, this is a *saving 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 with the public and foreign sectors by the following identity:

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

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

$$\frac{w}{cpi} = \left(\frac{1-u}{1-\bar{u}}\right)^{\frac{1}{\beta}} \tag{6}$$

where u and $\bar{u}$ are the unemployment rates in the simulation (after some 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 labor demanded and workers (represented by trade unions) decide real wage taking into account the unemployment rate according to Eq. 6. If labor demand increases (decreases), the unemployment rate u decreases (increases); as a consequence, there are less (more) available workers, who enjoy now more (less) bargaining power and enables them to demand higher (lower) real wages. If, after the 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 the empirical exercises, we take an estimated value for Spain from the econometric literature: $\beta = 1.25$ (Andrés and others 1990).

Pollution and Environmental Taxes

We focus on emissions obtained from production activities and we adopt a short-term approach. The production technology is assumed to be fixed and so 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:

$$E_j^m = \alpha_j^m \cdot Q_j \qquad (7)$$

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-run setting, in which technology is given and substitution possibilities are limited.

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

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

Note that the different pollution intensity across sectors causes that 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

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

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. Henceforth, from the viewpoint of the industry, the impact of an environmental tax is similar to that of a unit tax on output, with the particularity of having a higher tax rate for more polluting industries. The tax will create a wedge between the price paid by consumers and the price received by firms. We can expect that equilibrium (consumer) price will increase and 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. So, we can expect that output will decrease more in those sectors. The final impact on total output, employment and prices will be the aggregation of all the sectoral effects.

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

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

Databases and Calibration

The main economic data used in the article come from the aggregated 1995 social accounting matrix (SAM) for Spain, which is the most recent officially available. It comprises 21 accounts, including 9 productive sectors (1 Agriculture, cattle, forestry and fishing, 2 Extractives, 3 Energy and Water, 4 Food, 5 Chemicals, 6 Machinery and transport, 7 Manufactures, 8 Construction, 9 Services), two inputs (labor and capital), a saving/investment account, a government account, direct taxes (income tax and Social Security employees contribution) and indirect taxes (VAT, payroll tax, output tax and tariffs), a foreign sector and a representative consumer (see Cardenete and Sancho 2006, 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 1995 SAM as an initial or benchmark equilibrium for the economy. In the simulations, the wage is taken as numeraire ($w = 1$) and the rest of prices vary as required to meet equilibrium conditions.

In order to calibrate the α_j^m coefficients, we also use data by sector of the three considered pollutants from the Satellite Accounts on atmospheric emissions of the Spanish Statistical Institute (INE).

Policy Setting

Policy Instruments

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. In order to approximate the exercise to the reality, we constrain the tax rates of direct and indirect taxes as well as public expenditure by sectors to vary less than 3% with respect to the benchmark situation. Concerning the environmental taxes, we constrain all the tax rates t^m between 0 and 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.

Policy Objectives

We assume that the government is concerned about two types of policy objectives: economic objectives and environmental objectives. For the sake of comparability, all of them are measured in percentage terms.

Economic Policy Objectives

1. Typically, one of the main concerns of macroeconomic policy makers is to stimulate production. Consistent with this fact, we include output growth as the first economic policy objective. We use the most usual indicator, which is the real annual growth rate of Gross Domestic Product (GDP), computed as

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

   in turn, GDP is calculated as the total value of all goods and services produced in the economy, measured at constant prices.
2. Another common concern or macroeconomic policy makers is inflation control. In order to model this issue, we also include inflation as an objective. The indicator we use to represent this objective is annual inflation rate, computed as

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

   where *cpi* is the Consumer Price Index calculated as a weighted average of the prices of all sectors, according to the participation of each one in the overall consumption of the economy. This is a usual way to approach the evolution of prices in the CGE tradition, i.e., in relative-prices models with a numerarie (see Kehoe and others 1995 for more details).
3. The third objective is unemployment control. This objective is measured by the unemployment rate, $f_3 = u$
4. The final economic objective is to avoid (or minimize) public deficit. As an indicator for this objective we use the Public Budget (surplus/deficit) taken as a percentage of GDP:

$$f_4 = \frac{PB}{GDP} 100 \tag{13}$$

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

Environmental Policy Objectives

We consider as environmental objectives reducing the emissions of three important pollutants: CO_2, NO_x and SO_x. For the sake of measurement, we take the rate of change of emissions with respect to the observed values in 1995. The rationale to use the observed values as a benchmark is to compare the results that can be achieved under different scenarios with the values that resulted from the policy that was applied in practice in Spain 1995.

5. CO_2 emissions (rate of change with respect to benchmark situation):

$$f_5 = \frac{E^{CO_2} - E^{CO_2}_{bench}}{E^{CO_2}_{bench}} \cdot 100 \tag{14}$$

   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):

$$f_6 = \frac{E^{NO_x} - E^{NO_x}_{bench}}{E^{NO_x}_{bench}} \cdot 100 \tag{15}$$

7. SO_x emissions (rate of change with respect to benchmark situation):

$$f_7 = \frac{E^{SO_x} - E^{SO_x}_{bench}}{E^{SO_x}_{bench}} \cdot 100 \tag{16}$$

A Goal Programming Approach: Models and Results

Determining the Conflict Among Objectives

As it is common in MCDM exercises, a useful first step consists in determining the degree of conflict between the relevant criteria by computing the so-called payoff matrix. This is made by optimizing each objective separately and then computing the value of each objective at each of the optimal (monocriterion) solutions. Table 1 displays the results from these calculations. The first row shows

Table 1 Payoff matrix

	Growth	Inflation	Unempl.	PB/GDP	CO_2	SO_x	NO_x
Growth	**2.98**	3.87	22.53	3.88	0.35	0.33	0.33
Inflation	2.46	**2.28**	23.24	3.47	−0.07	−0.13	−0.10
Unempl.	2.98	3.87	**22.53**	3.88	0.35	0.33	0.33
PB/GDP	2.19	3.62	23.59	**2.93**	−1.03	−1.38	−0.95
CO_2	2.49	5.83	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 the values of 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) and all together are called the ideal point. The worst element of each column (in underlined characters) represents the so-called anti-ideal or nadir point.

By inspecting Table 1 we 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) and, on the other hand, pollution reduction. An active pro-growth policy could get a real growth of almost 3% and unemployment rate of 22.53%, but this would come at the cost of increasing CO_2 emissions (in a 0.35%), SO_x emissions and NO_x emissions (both in a 0.33%). On the other hand, CO_2, SO_x and NO_x emissions could be reduced in 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 higher unemployment rate. On the other hand, no big conflicts seem to appear among the environmental criteria, since roughly the same policies seem to be consistent with the reduction of any of the selected pollutants.

Moreover, from the observation of the pay-off matrix it is straightforwardly deduced that no solution generated by the single optimization of any criterion seems acceptable from the economic as well as environmental point of view. Hence, to obtain 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 sub-sections by formulating and solving several goal programming (GP) models.

Searching for a Satisficing Joint Policy

For each of the seven policy objectives, we fix in a tentative way a satisficing target level t_k. In this way, the following goals are defined:

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

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. For policy goals first and fourth the postulate "more is better" applies, and therefore the unwanted deviation variable is the negative one (i.e., n_k) whereas, for the rest of the goals, the postulate "less is better" applies and therefore the unwanted deviation variable is the positive one (i.e., p_k). For logic reasons, the constraints $n_k \geq 0$, $p_k \geq 0$ and $n_k \, . \, p_k = 0$ are imposed for every goal.

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

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

Several types of achievement functions will be defined and preferentially interpreted, but before that we are going to fix sensible target values for the seven goals considered. These tentative figures, expressed in percentages, are the following:

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

The above vector of satisficing targets means that the policy maker would consider as a reasonable achievement to obtain 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. In order to find a policy which is consistent with these target levels we test several functional forms for the general achievement function given by (18). The first one consists in a weighted sum of the unwanted deviation variables, what lead 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 given by the policy maker to the achievement k-th goal ($k = 1, \ldots, 7$). The minimization of (19) is subject to all the equations defined in the model as well as the goals defined in (17). Assume that the policy maker is evenly concerned about the achievement of all the goals and, therefore, the weights are $W_1 = W_2 = \cdots = W_7 = 1$. By using this assumption and the target values introduced above, we obtain the solution displayed in Table 2.

Table 2 Finding a satisficing 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 %

It should be noted that all the target values are defined in percentages. Hence, it is not necessary to undertake any type of normalization with the goals previously defined. On the other hand, a well-known critical issue in goal programming (see Romero 1991) is the possibility to get Pareto inefficient solution. A solution is said to be inefficient if it is possible to improve the value of some criteria without worsening the value of any other criterion. In Table 2, we see that the solution found fully satisfies the target values previously specified 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 perhaps the solution displayed in Table 2 may be inefficient (Tamiz and Jones 1996).

In order to check the efficiency of the obtained solution we perform a test introduced by Masud and Hwang (1981). In this way, 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 with respect to the values displayed in Table 2. 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 $f_1 \geq 2.66$, $f_2 \leq 4$, $f_3 \leq 23$, $f_4 \geq -3.31$, $f_5 \leq -0.49$, $f_6 \leq -0.63$, $f_7 \leq -0.47$ and all the equations in the model. The resulting solution is displayed in Table 3.

Note that the solution in Table 3 is very similar to that in Table 2 except for the fact that unemployment is slightly lower. This means that the latter solution weakly dominates the first one. This ensures that the solution in Table 2 is inefficient although it is very close to being efficient. Moreover, by construction, we know that the solution in Table 3 is Pareto efficient. At this point, a reflection about the application of the efficiency concept can be useful. Efficiency is a typical economic concept and one may think that being more efficient always implies 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:

$$t_1 = 2.7, t_2 = 3, t_3 = 22.7.\ t_4 = -2.9, t_5 = -1, t_6 = -2, t_7 = -1 \tag{21}$$

When solving the problem with these targets (using again WGP and assuming equal weights for all the goals), we get the solution that is displayed in Table 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 the following: if a solution S is inefficient, 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 rest of 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 render a smaller value of the objective function in (19) so that solution S cannot be the solution to problem (19).

Nevertheless, note that, although the solution in Table 4 is efficient while 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.

Table 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 %

Table 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 %

Balanced Satisficing Policies

So far, we have used the so-called WGP approach, which provides a solution which minimizes the weighted sum of unwanted deviations. Nevertheless, this approach does not preclude the solution from providing very unsatisfactory results for some of the goals considered. For example, in the solution shown in Table 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 the unemployment departs from the target value in 0.90, which might be unacceptable from an economic point of view.

In this section we focus on those cases in which the policy maker is interested in obtaining *balanced* solutions, in the sense that none of the values departs too much from the targets; i.e., we look for 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.,

$$Min\ Max\{W_1n_1, W_2p_2, W_3p_3, W_4n_4, W_5p_5, W_6p_6, W_7p_7\} \tag{22}$$

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 (Tamiz and others 1998):

$$\begin{aligned} Min\quad & D \\ s.t.: \quad & W_1n_1 \le D, \quad W_2p_2 \le D, \quad W_3p_3 \le D, W_4n_4 \le D \\ & W_5p_5 \le D, \quad W_6p_6 \le D, \quad W_7p_7 \le D \end{aligned} \tag{23}$$

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

By solving this problem for the target values defined in (21), and again for the same vector of preferential weights (i.e., $W_1 = \cdots W_7 = 1$), we get the solution displayed in Table 5. By comparison with the solution in Table 4, we observe that the maximum unwanted deviation in Table 5 is 0.70 that corresponds to the second, the third and the sixth goals, whereas the maximum deviation in Table 4 is 0.9 corresponding to fourth goal.

Table 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 %

Establishing a Hierarchy for the Policy Goals

In some cases, although policy makers have multiple objectives, they are not evenly concerned by all of them, but they 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 goals in higher priority level are incommensurably more important than those in a lower priority level.

Assume, for example that the targets of the policy maker can be ranked in the following way: the first priority includes the environmental targets 5, 6, 7, the second priority level includes target 4 and the third one includes targets 1, 2 and 3. The achievement function can be written in the following way:

$$\begin{aligned} Lex\ Min\ & [(W_5p_5 + W_6p_6 + W_7p_7), (n_4), \\ & (W_1n_1 + W_2p_2 + W_3p_3)] \end{aligned}$$

Moreover, assume that the aspiration levels are the following:

$$\begin{aligned} & t_1 = 2.7, t_2 = 4.5, t_3 = 22.7.\ t_4 = -2.9, \\ & t_5 = -1.5, t_6 = -1.5, t_7 = -1.5 \end{aligned} \tag{24}$$

In words, this means that, for the government, the highest priority is that the CO_2 emissions, the SO_x emissions and the NO_x emissions decrease with respect to the benchmark situation at least 1.5%, while of 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 is not higher 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 the goals 5, 6 and 7, so we need to solve first the following problem

$$Min\ (W_5p_5 + W_6p_6 + W_7p_7) \tag{25}$$

subject to the goal definitions (only for goals 5, 6 and 7) and all the equations in the model, where we keep the assumption $W_5 = W_6 = W_7 = 1$. 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 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 the following:

$$\begin{aligned} &Min \quad W_4 n_4 \\ &s.t. \quad p_5 \leq 0.34,\ p_6 = 0,\ p_7 \leq 0.46, \end{aligned} \tag{26}$$

including the definition of goals 4, 5, 6 and 7 as well as all the equations in the model. The achieved value of 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 implies to minimize the weighted sum of the unwanted deviation variables corresponding to the goals placed in the third priority level. Thus, we have.

$$\begin{aligned} &Min \quad W_1 n_1 + W_2 p_2 + W_3 p_3 \\ &s.t. \quad p_5 \leq 0.35,\ p_6 = 0,\ p_7 \leq 0.46,\ n_4 \leq 0.13 \end{aligned} \tag{27}$$

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 not alternative optimum solutions, and consequently the goals placed in the third priority level become redundant; that is, in practice, they do not play an actual role in the decision-making process (Amador and Romero 1989).

The solution corresponding to the third priority level and to the whole lexicographic process is displayed in Table 6.

Table 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 %

Concluding Remarks

In this article a methodology for designing joint macroeconomic and environmental policies is proposed. The methodology is based upon a Simonian satisficing philosophy and is made operational with the help of different goal programming models. The methodology seems sound from a positive as well as 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 fix tentative targets for all the goals of economic and environmental nature 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 care about the environment as a key concern, and the environmental criteria are not less important than the economic ones. In this way, the proposed methodology allows to obtain 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 according to them. It was demonstrated along the article how through GP models, very easy to formulate and to compute, different policies can be obtained. These policies aggregate the environmental and the economic goals in different ways: maximum aggregate performance, maximum balance and a lexicographic hierarchy of the goals.

Concerning future research, the proposed models can be extended at least into two directions. First, through different techniques for the elicitation of preferences, the weights attached to the achievement of each goal can be obtained. Second, different GP formulations can be tested. Thus, it seems interesting to resort to an Extended GP formulation which combines the WGP option (maximum aggregate performance) and the MINMAX GP option (maximum balance), since in this way the trade-off between aggregate achievement and maximum balance among the goals can be made explicit (see Romero 2001).

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Appendix: Computable General Equilibrium Model

Production

Total production is given by the Cobb-Douglas technology

$$Q_j = \phi_j \cdot Xd_j^{\sigma_j} \cdot IMP_j^{1-\sigma_j} \qquad (28)$$

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

Domestic production obtains from the Leontief production function

$$Xd_j = \min\left\{\frac{X_{1j}}{a_{1j}}, \ldots, \frac{X_{9j}}{a_{9j}}, \frac{VA_j}{v_j}\right\} \qquad (29)$$

where X_{ij} is the amount of commodity i used to produce commodity j, a_{ij} is the ij-th (i-th row, j-th colum) element of the SAM, and it 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.

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

$$VA_j = \mu_j L_j^{\gamma_j} K_j^{1-\gamma_j} \qquad (30)$$

where μ_j is the scale parameter of sector j, γ_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

$$U(CD_1, \ldots CD_9, SD) = \left(\prod_{j=1}^{9} CD_j^{\alpha_j}\right) SD^{\beta} \qquad (31)$$

where CD_j stands for consumption of commodity j, SD stands for savings of the consumer and α_j, β measure the elasticity of consumption goods and savings.

Public Sector

Indirect Taxes

Taxes on output, R_P, are calculated as

$$R_P = \sum_{j=1}^{9} \tau_j \left[\sum_{i=1}^{9} a_{ij} p_i Xd_j + \left(\left(1 + EC_j\right) wl_j + rk_j\right) VA_j\right] \qquad (32)$$

where l_j and k_j are the technical coefficients of labor 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 of sector j.

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

$$R_{LF} = \sum_{j=1}^{9} EC_j wl_j VA_j \qquad (33)$$

Tariffs, R_T, equal

$$R_T = \sum_{j=1}^{9} tar_j rowp\, a_{rwj} Q_j \qquad (34)$$

where tar_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 and exported 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 the following equation:

$$R_m = \sum_{j=1}^{9} \beta_j^m \left(1 + \tau_j\right) \left[\sum_{i=1}^{9} a_{ij} p_i Xd_j + \left(\left(1 + EC_j\right) wl_j + rk_j\right) VA_j\right] + \sum_{j=1}^{9} \beta_j^m \left(1 + tar_j\right) rowp\, a_{rwj} Q_j \qquad (35)$$

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

$$R_{VAT} = \sum_{j=1}^{9} VAT_j \left(1 + \tau_j\right) \left(1 + \beta_j^{CO_2} + \beta_j^{NO_x} + \beta_j^{SO_x}\right) \times \left(\sum_{i=1}^{9} a_{ij} p_i Xd_j + \left(\left(1 + EC_j\right) wl_j + rk_j\right) VA_j\right) + \sum_{j=1}^{9} VAT_j \left(1 + tar_j\right) \left(1 + \beta_j^{CO_2} + \beta_j^{NO_x} + \beta_j^{SO_x}\right) \times rowp\; a_{rwj} Q_j \qquad (36)$$

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}, comes from

$$R_{LC} = WC\, w\, L \qquad (37)$$

where WC is Social Security tax rate for employers. Income Tax, R_I, is computed from

$$R_I = DT(wL + rK + cpi\,TPS + TROW - WC\,L\,w) \quad (38)$$

where *DT* is the income tax rate, *TPS* stands for transfers from 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.

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