Tax Reform and Environmental Policy: Second Best Analysis Using a French Applied Dynamic General Equilibrium Model

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Abstract

This study draws upon the construction and use of a dynamic applied general equilibrium model, with perfect foresight, designed for clarifying the questions concerning taxation and the environment. The first section gives an overview of the model, focusing on an explicit introduction to the environmental dimension in the behaviour of the agents (the so-called non-separability assumption). Consumers choose between ‘green’ products and ‘non-green’ products under the influence of an environmental deterioration index, while the final and recyclable wastes intervene directly in the determination of the optimal firm’s plans. The second section will explain the hypothesis made for the calibration model based on French data and will describe the long term and dynamic impact that fiscal shocks (changes in VAT rates, modification of taxes placed on wastes) exhibit on the various macroeconomic and environmental variables. The double dividend issue is explored.

Keywords: environmental policy, fiscal policy, non-separability, double dividend, dynamic applied general equilibrium model, perfect foresight.

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Introduction

Should fiscal and environmental policies be made mutually reinforcing? Recent debates have stressed that the use of economic instruments, when compared to command-and-control measures, may provide gains of economic efficiency (OECD [1995]). Some countries—Finland, the Netherlands, Norway, and Sweden—have recently introduced a major tax reform with the aim of replacing or reducing distortionary taxes. Although the restructuring mainly concerns energy taxes, the basic idea is that a shift in tax structure away from, e.g., income taxation towards consumption taxation, including environmental taxes, may yield a ‘double dividend’, i.e., following BOVENBERG and DE MOOIJ [1997] ‘not only a cleaner environment but also a less distortionary tax system’ or, in terms of welfare effects ‘not only an increase in welfare from environmental amenities but also an increase in welfare from private commodities’.

Since a few years, intensive empirical and analytical literature has been devoted to the analysis of the so-called double dividend concept (see e.g. IPCC [1996] for a review of the empirical double dividend literature; GOLDER [1995], ASSOULINE-LEMALE [1998] for a survey of the theoretical double dividend literature).

Compared to the previous empirical literature on environmental tax reforms, this paper exhibits two originalities:

- first, we model explicitly the environmental feedbacks on households and producers behavior. Previous works (BALLARD-MEDEMA [1993] and BERGMAN [1995] for the producer, ESPINOSA-SMITH [1995], PIREDU [1996], MAYERES-PROOST [1997] for the consumer) have made significant steps towards this direction. However these works relies on a separability hypothesis i.e. the quality of the environment does not influence the trade-off between private goods and the quality of the environment. We here propose a dynamic applied general equilibrium model named PESTES\(^1\) where households behavior is not separable with the quality of the environment (see BEAUMAIS-SCHUERT [1994]). The productive sector is disaggregated into ‘green’ and ‘non-green’ industries. Green industry is modelled as a representative firm which produces its output without emitting final solid wastes and which uses recyclable wastes as inputs. Then, there are two producing sectors; all sectors are assumed to operate under constant returns to scale and cost optimization. The production technology is modelled as a nested tier structure of CES (constant elasticity of substitution) functions and each

\(^1\)PESTES stands for Politiques de l’Environnement SouTenables. PESTES is a simplified version of an applied general equilibrium model earlier developped by BEAUMAIS-SCHUBERT [1994]. Preliminary static results, using a version of PESTES calibrated on 1989 data have been presented at an International Symposium on ‘Models of sustainable development’ (Paris, march 1994) and are forthcoming in BEAUMAIS-RAGOT [1998].
of the markets is supposed to be in a perfect competitive equilibrium. An index of environmental quality directly affects the households welfare and their choice between green and non-green products; this latter specification may be viewed as a static non-separability (see de Mooij [1997] for analytical discussion about the separability assumption).

- second, PESTES is explicitly a dynamic model with perfect foresight. This feature allows us to explore both the effect of environmental quality on intertemporal path of, e.g., consumption (a kind of dynamic non-separability) and the effect of announced versus non-announced shocks.

Besides, because of market failures associated with environmental externalities, and because we allow for tax distortions and start from an initial equilibrium which is not necessarily optimal, our study is a second best world analysis.

Calibrating the model on french data, we find that an environmental reform may yield a double dividend, by enhancing the efficiency of the tax system and by ameliorating the availability of environmental amenities. However, when substitution between pollution and other inputs (into production) are easy, the dividend from private commodities appears to be small. Thereby, the dividend related to the non-separability assumptions accounts for a large part in the total welfare variations.

The rest of the paper is organized as follows: in the first section, we give an overview of the model. Then, in the second section we attempt to describe the principles of calibration and the results of several simulations implemented to study the non-separability hypothesis and the potential role of consumption taxes as a tool to promote a cleaner environment.

1 Description of the model

1.1 The consumer

1.1.1 Consumer behavior

The choices we made for the specification of consumer behavior have been guided by the concern of integrating the environmental dimension into the model. The majority of the applied general equilibrium models concerning the environment treats the phenomena of pollution through energy consumption (see Beaumais–Schubert [1996]). With the noteworthy exception of the works referred above, the environmental quality does not affect the collective or individual utilities, hence posing a problem of adequation of the model to the policies analyzed. Thus, we have considered a representative household, who maximizes its utility function under an intertemporal budget constraint. The total population in the economy is $N_t$ to the date $t$, increasing in the exogenous and constant rate $n$. That is to
say, $c_t$ being the total consumption per head at the period $t$, $l_t$ being the leisure demand and $E_t$ being an environmental deterioration index, the intertemporal utility function is written as:

$$U = \frac{1}{1 - \frac{1}{\gamma_0}} \sum_{t=1}^{\infty} \frac{1}{(1 + \delta')^t-1} E_t^a u(c_t, l_t)^{1 - \frac{1}{\gamma_0}}$$

$\gamma_0$ is the elasticity of intertemporal utility substitution, $\delta'$ is the preference rate for the present and $a$ is a positive ($\gamma_0$ is less than one) parameter indicating the weight of the environmental variable in the utility function. The household utility is thus affected by the variation in the quality of the environment measured by the index $E_t$.

The instantaneous utility function is written as:

$$u(c_t, l_t) = \left[ c_t^{1 - \frac{1}{\gamma_1}} + \beta l_t^{1 - \frac{1}{\gamma_1}} \right]^{\frac{1}{1 - \frac{1}{\gamma_1}}}$$

where $\gamma_1$ is the elasticity of substitution between consumption and leisure, and $\beta$ is the preference rate for leisure.

The debates around separability between the environment and consumption choices are not yet settled. However, as it is noted by de Mooij [1997] ‘for some types of externalities, such as congestion, we can hardly imagine that households will not respond to changes in the environment’. Furthermore, defensive expenditures, i.e. expenditures that are realized by households to protect themselves against negative externalities, are obviously influenced by the state of the environment.

So, we consider that the total consumption per head at each date, $c_t$, is itself composed of a consumption of non-green products $c_{d,t}$ and a consumption of green products $c_{g,t}$. The consumer’s choice between these two categories of products depends on their elasticity of substitution $\gamma_2$ and on a preference rate for green products $\alpha(E_t)$, dependent on the environmental index:

$$c_t = \left[ c_{d,t}^{1 - \frac{1}{\gamma_2}} + \alpha(E_t) c_{g,t}^{1 - \frac{1}{\gamma_2}} \right]^{\frac{1}{1 - \frac{1}{\gamma_2}}}$$

The equation for the preference rate of green products according to the environmental deterioration index is the following:

$$\alpha(E_t) = -\alpha_0 \log \left( \frac{E_m - E_t}{E_m} \right) + \alpha_1$$

$\alpha_0$ and $\alpha_1$ are non-negative parameters and $E_m$ is the maximum level of deterioration to the environment.

$^2d$ stands for dirty and $g$ for green.
The intertemporal household budget constraint is classically written:

\[
\sum_{t=1}^{\infty} \frac{(1 + n)^{t-1}p_t c_t}{\Pi_{s=1}^{t}(1 + r_s(1 - \tau_s^s))} = e p_1 + \sum_{t=1}^{\infty} \frac{(1 + n)^{t-1}(w_t(1 - \tau_t^w)(1 - \tau_t^{IR})(1 - l_t) + p_t r_t)}{\Pi_{s=1}^{t}(1 + r_s(1 - \tau_s^s))}
\]

where \(e p_1\) is the initial household asset, \(p_t\) and \(w_t\) is the price of the total consumption (all taxes included) and the gross wage rate, respectively, and, \(r_t\) is the interest rate to the date \(t\), \(\tau_t^w\) is the rate of employees social contributions, \(\tau_t^{IR}\) is the income tax rate, \(\tau_t^c\) being the tax rate on capital income and \(p_t r_t\) is the payment received by the household.

The utility maximization under the intertemporal budget constraint leads to the first order conditions which are written, if we note \(\omega_t = w_t(1 - \tau_t^w)(1 - \tau_t^{IR})(1 - l_t)\):

\[
\begin{align*}
    l_t &= c_t \left( \beta p_t \omega_t \right)^{\gamma_1} \\
    c_t &= c_{t+1} \left( \frac{E_t}{E_{t+1}} \right)^{a \gamma_0} \left( \frac{1 + \beta^{\gamma_1} \left( \frac{\omega_t}{p_t} \right)^{1-\gamma_1}}{1 + \beta^{\gamma_1} \left( \frac{\omega_{t+1}}{p_{t+1}} \right)^{1-\gamma_1}} \right)^{\gamma_0} \left( \frac{p_t}{p_{t+1}} \right)^{-\gamma_0} \left( \frac{1 + r_{t+1}(1 - \tau_t^c) - \gamma_0}{(1 + \delta')(1 + n)} \right)^{-\gamma_0}
\end{align*}
\]

In the steady state, this relation is then written:

\[
c = c(1 + e)^{a \gamma_0} \left( \frac{1 + r(1 - \tau^c)}{(1 + \delta')(1 + n)} \right)^{\gamma_0}
\]

where \(e\) is the long term growth rate for the environmental deterioration index. This last equation furnishes the ‘modified golden rule’ which regulates the economic growth:

\[
1 + r(1 - \tau^c) = (1 + e)^{-a}(1 + \delta')(1 + n)
\]

If \(e = 0\) (which will be the case, see section 1.6), the equation will take the habitual form

\[
1 + r(1 - \tau^c) = (1 + \delta')(1 + n)
\]

In the following, we drop the temporal index in order to relieve the notations.

Knowing the total consumption, the consumption of non-green products and green products are:

\[
c_d = c \left( \frac{p}{p_d} \right)^{\gamma_2}
\]

and

\[
c_g = c \left( \frac{\alpha(E)p}{p_g} \right)^{\gamma_2}
\]

where \(p_d\) and \(p_g\) are the included tax price of non-green and green products. The relation between the total consumption price and the previous prices is the following:

\[
p = \left( p_d^{1-\gamma_2} + \alpha(E)^{\gamma_2} p_g^{1-\gamma_2} \right)^{\frac{1}{1-\gamma_2}}
\]
Finally, each product in each category may come from the national territory or may be imported, according to the Armington [1969] specification. The VAT rates can then be applied to the elementary consumptions determined in this manner.

1.1.2 Waste stemming from consumption

In this version of the model, waste stemming from the household consumption can be of two types:

- recyclable wastes are, by definition, those which can be reintroduced into the production process as inputs to the green sector. This concerns reusable materials, after treatment, to produce new goods (paper, glass, aluminium...) as well as incinerated waste to produce energy;

- final waste. The solid parts of these need to be treated and eliminated. Their production means the deterioration of the environment, which may be adjusted by the evolution of technology for treatment.

So, we can write:

\[ dm_f = \epsilon^f_d c_d + \epsilon^f_g c_g \]

and

\[ dm_r = \epsilon^r_d c_d + \epsilon^r_g c_g \]

where \( dm_f \) and \( dm_r \) represent final wastes and recyclable wastes, and where \( \epsilon^f_{d,g} \) represent the coefficients of waste emissions.

1.2 The producer

In each non-green or green sector, we consider a representative firm which maximizes its profit under the hypothesis of perfect competition.

1.2.1 Non-green products

The functional form is a CET-CES:

\[
\left[ \alpha_1 Y_d^{1-\frac{1}{\rho_1}} + (1-\alpha_1) Y D_r^{1-\frac{1}{\rho_1}} \right]^{1-\frac{1}{\rho_1}} = \null
\]

\[ A_d \left[ \alpha_2 K_d^{1-\frac{1}{\rho_2}} + \alpha_3 L_d^{1-\frac{1}{\rho_2}} + \alpha_4 CI_d^{1-\frac{1}{\rho_2}} + (1-\alpha_2-\alpha_3-\alpha_4) D_f^{1-\frac{1}{\rho_2}} \right]^{1-\frac{1}{\rho_2}} \]

This functional form was chosen to give a particular role to wastes (see, e.g. Brock [1977] or Bovenberg-de Mooij [1997] for a discussion about environment as input or output). While the recyclable wastes are treated as a joint
Table 1: The Structure of Production

<table>
<thead>
<tr>
<th>Mnemonic</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Y_d$</td>
<td>Non-green product output</td>
</tr>
<tr>
<td>$Y_g$</td>
<td>Green product output</td>
</tr>
<tr>
<td>$YD_r$</td>
<td>Recyclable waste output</td>
</tr>
<tr>
<td>$D_r$</td>
<td>Recyclable wastes</td>
</tr>
<tr>
<td>$D_f$</td>
<td>final wastes</td>
</tr>
<tr>
<td>$K$</td>
<td>Capital</td>
</tr>
<tr>
<td>$L$</td>
<td>Labor</td>
</tr>
<tr>
<td>$CI_d$</td>
<td>Other input of the non-green sector</td>
</tr>
<tr>
<td>$CI_g$</td>
<td>Other input of the green sector</td>
</tr>
</tbody>
</table>

production (CET form: Constant Elasticity of Transformation), the final wastes appear as a production factor. In fact, although these products stem from the processes of production, just as the recyclable wastes are, they represent a cost to be assumed by the firms, since, in turn, they must assure the treatment of the wastes. The firm may choose between the different production factors in order to produce more or less final wastes. These wastes can then be considered as an input (demand for final wastes treatment) which has a cost (taxation, total cost for elimination) and which may be viewed as an intermediate environmental consumption.

So, $Z = \left[ \alpha_1 Y_d^{1-\frac{1}{\rho_1}} + (1 - \alpha_1)YD_r^{1-\frac{1}{\rho_1}} \right]^{-\frac{1}{\rho_1}}$, and $p_Z$ is the price of this production. The firm program is written as:

$$\text{Max } p_Z Z - p_K K_d - p_L L_d - p_{CI_d} CI_d - p_{D_f} D_f$$

under the CES. $p_L = (1 + \tau^w)w$ and $p_K = (r + \delta)p_i$ where $\tau^w$ stands for the rate of employers social contributions, $\delta$ is the depreciation rate of the capital stock, $p_i$ is the investment price, and $r$ is the endogenous interest rate.

The solution gives the optimal factor demand for the non-green sector as well as the factor price frontier derived under the hypothesis of zero profits. At an inferior level of the production structure, the intermediate consumption $CI_d$ is further disaggregated under the hypothesis that it is formed as a CES composite of green products and non-green products, each constituent then being allocated in the consumption of national and imported products, again according to the Armington specification.

One of the activities of the government will be to fix in an exogenous manner the price of final solid wastes so as to limit the demand for final wastes (i.e. environmental consumption) due to the firms. One alternative could consist in supposing that the government determine, in an exogenous manner, the capacities of elimination, with the price variations thus clearing the market.
1.2.2 Green products

In this sector, it has been considered that the production is obtained according to a clean process (i.e. without the production of final wastes). On the other hand, recyclable wastes in the non-green sector are considered here as inputs ($D_r$). Then, the top level of the production function is simply represented by a CES function.

The program for a representative firm is written as:

$$\text{Max } p_Y Y_g - p_K K_g - p_L L_g - p_{CI} C I_g - p_{D_r} D_r$$

under

$$Y_g = A_g \left[ \theta_1 K_g^{\frac{1}{\rho_5}} + \theta_2 L_g^{\frac{1}{\rho_5}} + \theta_3 C I_g^{\frac{1}{\rho_5}} + (1 - \theta_1 - \theta_2 - \theta_3) D_r^{\frac{1}{\rho_5}} \right]^{\frac{1}{1 - \frac{1}{\rho_5}}}$$

Just as in the non-green sector, the solution determines the optimal factor demands and factor prices frontier. The inferior levels of the tier structure of production are similar to those of the non-green industry.

1.3 Exportations

The specification is that explained by Wilcoxen [1988] according to Dixon et al. [1982]: for each good, the exportation quantity is determined by a demand equation (for the two categories of i products):

$$X_i = \xi_i \left[ \frac{p_{Y_i}}{p_{Y_e}} \right]^{\eta_i}$$

where $X_i$ represents the exportation of product $i$, $p_{Y_i}$ is the production price, $p_{Y_e}$ is the foreign price corresponding to national currency, $\xi_i$ is a positive constant, and $\eta_i$ is a negative elasticity.

1.4 The government

The government collects fiscal receipts (taxes, indirect taxes on intermediate inputs, on consumers expenditures, income taxes, taxes on capital revenue), operates households transfers, and consumes domestic or imported products.

In the calculable general equilibrium models applied to the environment, the economic activity of the government is specified according to one or the other of the two following solutions (Beaumais-Schubert [1996]):

- the first family of solutions, which is also the least commonly used (BURNIAUX et al. [1992], McKIBBIN-WILCOXEN [1992]), applies the notion of a public utility function. This representation of collective preference intervenes as a constraint during the optimal allocation of the government
expenditures. In practice, this choice appears simply as a means to obtain some allocation keys which are not trivial and whose reading is easy;

- the second family of solutions, accepted for the model (see also GOULDER [1992]), consists in retaining a matrix of expenditures generally corresponding to the benchmark year and then to apply it during the simulations.

The receipts are written simply according to the structure of the tax system described in the model. We assumed that the government budget is balanced at each period. Moreover, the totality of social contributions payed by employees and employers are paid back to households as allowances.

1.5 Investment

SCHUBERT-LETOURNEL [1991], in their model designed for the study of long term taxation, have chosen one of two domestic goods produced as a capital good. In practice, the applied solution for the general equilibrium sectorial models, while there are no adjustment costs on the capital, concern a similar method but of a more general scope: it is supposed (WILCOXEN [1988], BURNIAUX et al. [1992], GOULDER [1992]) that the total aggregated investment is a composite good produced according to a tier structure (see BEAUMAIS-SCHUBERT [1996]) close to that describing the productive sector.

In this model, the total investment $IT$, obtained as the sum of the investment in the non-green sector and green sector, is a non-green and green goods CES composite. This specification allows us to allocate the total investment in demands for non-green and green products ($IY_d$ and $IY_g$ respectively): 

$$IT = A_I \left[ \delta_1 IY_d^{\frac{1}{\rho_4}} + (1 - \delta_1) IY_g^{\frac{1}{\rho_4}} \right]^{\frac{\rho_4}{1-\rho_4}}$$

where $A_I$ is the scale parameter.

The optimal shares are then:

$$\begin{cases} 
IY_d = IT A_I^{\rho_4 - 1} \left( \frac{\delta_1 p_{IT}}{p_{IY_d}} \right)^{\rho_4} \\
IY_g = IT A_I^{\rho_4 - 1} \left( \frac{(1-\delta_1) p_{IT}}{p_{IY_g}} \right)^{\rho_4} 
\end{cases}$$

and the relationships between the corresponding prices are:

$$p_{IT} A_I = \left( \frac{\delta_1^{\rho_4} p_{IY_d}^{1-\rho_4} + (1 - \delta_1)^{\rho_4} p_{IY_g}^{1-\rho_4}} {p_{IY_d}} \right)^{\frac{1}{1-\rho_4}}$$

Equipment goods demand, as with final consumption and intermediate consumption, may come from the national territory or may be imported. The allocation is done according to the ARMINGTON specification.

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3Both are derived from the programs of the producers.
1.6 The definition of an environmental deterioration index

Once again, we will introduce the time index. Let \( d_t \) be the sum of final wastes emitted by the processes of consumption \( (dm_u) \) and production \( (du) \).

The evolution of the environmental deterioration index is defined in the following way:

\[
E_{t+1} = (1 - \chi_t)E_t + d_tN_t
\]

This index is an absolute level and not a magnitude per head: its evolution depends on the total accumulation of wastes being \( d_tN_t \). The \( \chi_t \) variable depends on time. This is a ‘clean-up’ rate which follows a temporal evolution determined by both the technical progress induced by the price variations and stemming from the organization of rules and norms.

Regarding the long term balanced growth path, the environmental deterioration index no longer varies \( (E_{t+1} = E_t) \), and the wastes per head emitted by the economy are constant \( (d) \). Then the rate of growth of \( \chi_t \) is the same as the population.

2 Taxation and the environment

2.1 The calibration of the model

The calibration of the model consists in valuing the model parameters and establishing its empiric foundations.

- The data base is an Input-Output table, for the 1990 year, stemming from French national accounts. Hypotheses concerning production, consumption, etc., of green products has been introduced so as to complete the initial matrix according to the needs\(^4\).

- The choices of elasticities have been realized following two principles:
  - a review of the economic literature provides an elasticity ‘basket’ whose validity is, \textit{a priori}, guaranteed. However, several problems of heterogeneity in the results presented problems, which in practice, led to a choice that appears to be the most relevant regarding the object of the study;

\(^4\)This information is available from the authors. Key assumptions were taken from public reports on clean technologies (shares in the total production, shares in the total investment etc.).
- moreover, we have differentiated the behaviors of agents for green products and non-green products. So the basic elasticities (those depending on the non-green macroeconomic variables) are adjusted before being applied to the functional forms, which in turn have the green products intervene.

- The other parameters are calculated so as to precisely reproduce the benchmark dataset. The scale factor \((A_d, A_g, A_I)\), the distribution coefficients are thus determined.

This stage presents numerous problems, essentially numerical, widely mentioned by Schubert–Letournel [1991]. It is not possible to provide an exhaustive list of chosen elasticities and parameters calculated by the model during calibration.

### Table 2: The imposed parameters

<table>
<thead>
<tr>
<th>Firms</th>
<th>Sector D</th>
<th>Sector G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elasticity of substitution of the CES</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>Elasticity of substitution of the CET</td>
<td>0.7</td>
<td>-</td>
</tr>
<tr>
<td>Annual capital depreciation rate</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>Elasticity of substitution in the investment of green and non-green products</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Households</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elasticity of intertemporal substitution</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>Elasticity of consumption-leisure substitution</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>Elasticity of substitution in the consumption of green and non-green products</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Imposition rate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VAT rate</td>
<td>13.09%</td>
<td>14.75%</td>
</tr>
<tr>
<td>Employer contribution rates</td>
<td>40%</td>
<td>40%</td>
</tr>
<tr>
<td>Employees contribution rates</td>
<td>30%</td>
<td>30%</td>
</tr>
<tr>
<td>Tax rates on capital revenues</td>
<td>35%</td>
<td></td>
</tr>
<tr>
<td>Annual population growth rate</td>
<td></td>
<td>1%</td>
</tr>
<tr>
<td>Annual real interest rate</td>
<td></td>
<td>5%</td>
</tr>
<tr>
<td>Exchange rate</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Clean-up rate</td>
<td></td>
<td>15%</td>
</tr>
</tbody>
</table>

However, several particularities of the model need to be underlined. The tax rates have been taken from Schubert–Letournel [1991], presenting a general
applied equilibrium model with overlapping generations, for the tax system study. Furthermore, in the present case, the golden rule is written as (with $e = 0$, see section 1.6):

$$1 + r(1 - \tau^e) = (1 + \delta')(1 + n)$$

$r$, $\tau^e$ and $n$ being imposed, thus allowing the calculation of the time preference rate $\delta'$ (see table 3). The VAT rates are from the Input-Output table. The apparent mean VAT rates VAT are applied to each product (green or non-green, domestic or imported). The balance of the government budget allows the endogenous calculation of the income tax rate ($\tau^{IR}$).

**Table 3: Value of principal parameters calculated by calibration**

<table>
<thead>
<tr>
<th>firms</th>
<th>sector D</th>
<th>sector G</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2.650</td>
<td>3.352</td>
</tr>
<tr>
<td>$\alpha_1$</td>
<td>0.999</td>
<td></td>
</tr>
<tr>
<td>$\alpha_2$</td>
<td>0.131</td>
<td></td>
</tr>
<tr>
<td>$\alpha_3$</td>
<td>0.407</td>
<td></td>
</tr>
<tr>
<td>$\alpha_4$</td>
<td>0.459</td>
<td></td>
</tr>
<tr>
<td>$\theta_1$</td>
<td></td>
<td>0.183</td>
</tr>
<tr>
<td>$\theta_2$</td>
<td></td>
<td>0.435</td>
</tr>
<tr>
<td>$\theta_3$</td>
<td></td>
<td>0.282</td>
</tr>
<tr>
<td>$A_I$</td>
<td>1.596</td>
<td></td>
</tr>
<tr>
<td>$\delta_1$</td>
<td></td>
<td>0.999</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Households</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$\delta'$</td>
<td>0.022</td>
<td></td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.336</td>
<td></td>
</tr>
<tr>
<td>$\alpha_0$</td>
<td>0.006</td>
<td></td>
</tr>
</tbody>
</table>

We have finally chosen to fix the exchange rate and to leave free the deficit (surplus) of the commercial balance.

However, the long term commercial balance and the external debt ($de$) are related:

$$(r - n)de = (x - m)$$

where $x$ and $m$ represent respectively exports and imports. **Walras’ law** is thus written as:

$$(r - n)ep + (r - n)de = (r - n)pi(k_s + k_v)$$

where $ep$ is the net macroeconomic saving and $pi$ the investment price.
2.2 Some fiscal scenarios

The realization of fiscal scenarios have a double objective: on one hand, to examine the responses of the model from well identified shocks, and on the other hand, to analyze the incentive properties of various measures *a priori* susceptible to benefit to the environment. We have simulated the long term consequences of:

- a rise in the VAT rate of non-green products;
- a fall in the VAT rate of green products;
- an increase of the tax on final wastes.

All the shocks are *ex ante* identically calibrated; the initial shocks represents exactly one percent of the total *ex ante* VAT receipts. All the scenarios are assumed to be revenue-neutral, *i.e.* the employers social contributions rate is adjusted so that the total amount of transfers from the government is unchanged compared to the baseline. Our purpose is not to derive some kind of optimal tax structure; neither do we intend to find some kind of pigovian tax which could internalize the external costs due to the pollution (see BOVENBERG-DE MOOIJ [1997] for analytical results in a framework of endogenous growth). Our purpose is to highlight the basic mechanisms of PESTES and especially the role of the non-separability assumptions. Before discussing the results reported in table 4, let us quote ATKINSON-STIGLITZ [1980] about fiscal reforms and partial welfare improvement:

> As it is well known from the literature on second best, this is the difficult area. Reforms that may appear to move on the correct direction can turn out on closer inspection to reduce welfare.

Then, in order to make our comments as clear as possible, it is necessary to refer back to the original mechanisms of the model:

- the trade-off between the consumption of green products and non-green products is affected by the evolution of pollution. *Ceteris Paribus*, a deterioration of the environment leads to a substitution away from green products towards non-green products. A decrease in pollutant emissions is accompanied by a symmetrical effect;

- the market for recyclable wastes is comprised of a noteworthy particularity: firms benefit gratuitously from the portion of recyclable wastes stemming from household consumption. This portion, calculated with the help of a constant coefficient, is insensitive to the variations in price of the recyclable wastes and follows the evolution of consumption;
• the elasticities of substitutions, in the non-green and green sectors, have been deliberately fixed to high values. This was done in order to allow an important flexibility which is justified by the long term feature of the model;

• the Euler equation (dynamics of consumption) stands that, *ceteris paribus*, when the household anticipates a deterioration of the quality of the environment, he diminishes his current consumption.

### 2.2.1 Long-term results

*Scenario A : a rise in the VAT rate on non-green products*

The rise in the VAT rate on non-green products (which represent more than 90% of the total consumption) provokes a rise in the price of consumption (+0.14%). Although this makes the consumption less attractive, the decrease in employers social contribution rate, which ensures *ex post* the revenue-neutrality of the measure leads to a net positive impact on total consumption (+0.4%).

Then, the change in the pollution index (+0.4%) is mainly due to the production of household’s final wastes associated with a higher consumption of products. As the environment is getting worse, the consumption of green goods ameliorates more than the consumption of non-green goods (+0.7% and +0.5% respectively); this evolution takes its roots in the specification of the household’s behavior. As it was mentioned before, the trade-off between green and non-green products is influenced by a parameter of preference for the environment (namely the function \( \alpha(E) \) in the green/non-green CES). Here the deterioration of the environment makes the green products more attractive than the non-green products. As a result of this structure of choice, the green production takes more benefits from the amelioration of the economic activity than the non-green production (+0.5% and +0.4% respectively). Finally, as we will see below (see section 2.2.2), this scenario does not provide a double dividend because the shift in the tax system from direct taxation towards indirect taxation generates net revenue effects which dominate widely the substitution effects.

*Scenario B : a decrease in the VAT rate on green products*

Paradoxically, the drop in the VAT rate on green products induces only a very light improvement of the environment (-0.5% on the pollution index). This result arises mainly because of two fundamental mechanisms. Firstly, the shift from indirect taxation (the decrease in non-green products VAT rate) towards direct taxation (the increase in employers social contributions rate) as a net effect on consumption which is obviously symmetric to the one we note for the
Table 4: Results of the scenarios

<table>
<thead>
<tr>
<th>in volume, differences of percentage in relation to the central account</th>
<th>Scenario A</th>
<th>Scenario B</th>
<th>Scenario C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pollution index</td>
<td>0.40</td>
<td>-0.46</td>
<td>-15.35</td>
</tr>
<tr>
<td>Households final wastes</td>
<td>0.40</td>
<td>-0.46</td>
<td>0.60</td>
</tr>
<tr>
<td>Firms final wastes</td>
<td>0.39</td>
<td>-0.45</td>
<td>-24.10</td>
</tr>
<tr>
<td>Firms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-green production</td>
<td>0.39</td>
<td>-0.45</td>
<td>0.55</td>
</tr>
<tr>
<td>Green production</td>
<td>0.49</td>
<td>-0.08</td>
<td>-2.65</td>
</tr>
<tr>
<td>Recyclable wastes production</td>
<td>0.16</td>
<td>-1.39</td>
<td>9.55</td>
</tr>
<tr>
<td>Non-green sector investment</td>
<td>0.39</td>
<td>-0.45</td>
<td>0.59</td>
</tr>
<tr>
<td>Green sector investment</td>
<td>0.53</td>
<td>0.07</td>
<td>-4.00</td>
</tr>
<tr>
<td>Intermediate cons. of non-green products</td>
<td>0.40</td>
<td>-0.45</td>
<td>0.59</td>
</tr>
<tr>
<td>Intermediate cons. of green products</td>
<td>0.51</td>
<td>0.01</td>
<td>-3.46</td>
</tr>
<tr>
<td>Households</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total consumption</td>
<td>0.39</td>
<td>-0.43</td>
<td>1.43</td>
</tr>
<tr>
<td>Consumption of non-green goods</td>
<td>0.40</td>
<td>-0.50</td>
<td>0.94</td>
</tr>
<tr>
<td>Consumption of green goods</td>
<td>0.68</td>
<td>0.41</td>
<td>-8.06</td>
</tr>
<tr>
<td>Leisure</td>
<td>-0.41</td>
<td>0.44</td>
<td>-0.49</td>
</tr>
<tr>
<td>Saving</td>
<td>1.41</td>
<td>-1.58</td>
<td>1.88</td>
</tr>
<tr>
<td>Transfers</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Prices</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consumption price</td>
<td>0.14</td>
<td>-0.14</td>
<td>-0.85</td>
</tr>
<tr>
<td>Non-green price</td>
<td>0.12</td>
<td>-0.00</td>
<td>0.10</td>
</tr>
<tr>
<td>Green price</td>
<td>0.03</td>
<td>-2.37</td>
<td>-1.31</td>
</tr>
<tr>
<td>Net wages</td>
<td>0.81</td>
<td>-0.87</td>
<td>0.73</td>
</tr>
<tr>
<td>Recyclable wastes price</td>
<td>0.33</td>
<td>1.35</td>
<td>-11.42</td>
</tr>
<tr>
<td>Government</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total VAT</td>
<td>1.36</td>
<td>-1.41</td>
<td>0.56</td>
</tr>
<tr>
<td>Board Tariffs</td>
<td>0.37</td>
<td>-0.47</td>
<td>0.47</td>
</tr>
<tr>
<td>Saving taxes</td>
<td>1.41</td>
<td>-1.58</td>
<td>1.88</td>
</tr>
<tr>
<td>Income taxes</td>
<td>1.21</td>
<td>-1.30</td>
<td>-1.22</td>
</tr>
<tr>
<td>Final wastes</td>
<td>0.39</td>
<td>-0.45</td>
<td>-24.10</td>
</tr>
<tr>
<td>Households recyclable wastes</td>
<td>0.40</td>
<td>-0.46</td>
<td>0.61</td>
</tr>
<tr>
<td>Foreign trade</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total exports (Volume)</td>
<td>0.00</td>
<td>-0.00</td>
<td>-0.05</td>
</tr>
<tr>
<td>Total imports (Volume)</td>
<td>0.40</td>
<td>-0.45</td>
<td>0.56</td>
</tr>
</tbody>
</table>

(1) Rise in the VAT rate on non-green products
(2) Drop in the VAT rate on green products
(3) Increase in the tax on final wastes
previous scenario. The decrease in price index (-0.14%) is not sufficient enough to compensate the impact of the increase in personal income taxation on the household’s revenue. Then consumption diminishes (-0.4%). Secondly, the slight improvement of the environment induces less preference for green products. This, in turn, reduces the substitution effect implied by the change in relative prices. However the substitution effect dominates the ‘preference effect’ so that consumption of non-green products exhibits a negative evolution (-0.5%), whereas the consumption of green products exhibits a positive evolution (+0.4%).

Scenario C: a rise in the tax on final wastes

This scenario presents the best results from the environmental outlook. The pollution index experiences a particularly favorable evolution (-15.3%). The incentive action is direct, since it reacts on the price of treating final wastes stemming from the production of the non-green sector. This is described according to a CES form, with a high elasticity of substitution, allowing important long term factorial substitutions. The ‘intermediate consumption’ of wastes, in response to the shock, strongly decreases (-24%). This decrease leads to the remarked results on the pollution index. Considering the specification for the consumer trade-off between green products and non-green products, the green consumption exhibits a significant drop (-8%), while the non-green consumption slightly increases (-2.8%). The production in the non-green sector ameliorates but is henceforth obtained according to a less polluting productive process. Finally, as we will show it in the next section, this policy scenario may be viewed as a ‘double dividend’ scenario: environmental quality and economic activity are simultaneously improved.

2.2.2 Dynamics

The dynamics in PESTES originate from three sources: the intertemporal allocation on consumption and leisure, the capital accumulation and the evolution of the environmental deterioration index. The representative household is assumed to base its decisions on rational expectations\(^5\) about the future states of the economy. Such a behavior implies that some dynamic equations are forward-looking and that the resolution of the model over a fifty years period requires a particular algorithm\(^6\). Terminal conditions for the dynamic model are taken from results given by the static version of the model, which is based on an analytical expression of the long-term steady state of the economy. In a model of balanced growth like PESTES the dynamic path between the initial (i.e. before the shock)

\(^5\) Since the resolution of the model is deterministic, rational expectations are equivalent to perfect foresight.

\(^6\) For the present version of PESTES we have used the Fair-Taylor algorithm as it is implemented in the SIMPC software (SIMPC [1992]).
and the final (i.e. after the shock) steady state does present a particular interest. Dynamic simulations allow for the calculation of exact welfare variations (see appendix A) and the comparison of the effects of announced and non-announced shocks. Exact welfare variations are induced by variation in private commodities consumption and by variations in environmental quality; the latter are captured through the non-separability hypothesis either through static non-separability or through dynamic non-separability. Then we can isolate three components for the total welfare variations:

- the first component or red dividend (referred as \( pw \) in table 5) is obtained under the assumptions that \( a = 0 \) and \( \alpha(E) \) is exogenous. This is the welfare effects of the policy without environmental feedbacks (direct or indirect) on household’s behavior;

- the second component or green dividend (referred as \( edw \) in table 5) stands for the sole effect of the direct influence of the environmental quality on the intertemporal utility and consumption path. This component is computed as the difference between the welfare effect for the scenario that is run under the assumption that \( a \) has a positive value and \( \alpha(E) \) is endogenous and the welfare effect for the scenario that is run under the assumption that \( a = 0 \) and \( \alpha(E) \) is endogenous;

- the second component or brown dividend (referred as \( eiw \) in table 5) corresponds to the sole effect of the indirect influence of the environmental quality on household’s behavior which acts through the trade-off between green and non-green products. This component is computed as the difference between the welfare effect for the scenario that is run under the assumption that \( a = 0 \) and \( \alpha(E) \) is endogenous and the welfare effect for the scenario that is run under the assumption that \( a = 0 \) and \( \alpha(E) \) is exogenous.

Then, the use of the dynamic model requires the intertemporal utility function to be totally calibrated. The value of the parameter \( a \) (the weight of the environmental index in the utility function) is taken from a previous work (see Beaumais [1995]). Since no sufficient information about household’s willingness to pay to reduce pollution was available, we have calculated \( a \) so that its value annulate the long-term total welfare variation provided by an arbitrary chosen policy scenario\(^7\). This value of \( a \) is used to compute the welfare variations associated with the scenarios A, B and C.

As this value of \( a \) is subject to caution, we also present results (total welfare variations) for which \( a \) is twice the initial calibrated value (denoted \( a' \)).

The five following points are worth emphasizing (see table 5 and 6\(^8\)):

\(^7\)This scenario was simulated using a more disaggregated model as a 10$ per barrel of oil equivalent measure.
\(^8\)Results are given as percentage differences from baseline welfare, see appendix A.
for scenario A and B, no significant differences appear between announced and non-announced shocks. This is because the initial shocks have only little effects both on macroeconomic and environmental variables;

for scenario C, there are significant differences between announced and non-announced shocks. Since the household is forward-looking, it anticipates the change in the consumption price which occurs after the shock. In scenario C, the change in the consumption price is a decrease; then the household postpones his consumption until the effect on price index fully arises. This mechanism is combined with the influence of the environmental quality in the consumption path (what we call dynamic non-separability). Since the quality of the environment ameliorates, and given the behavior involved by the Euler equation (see beginning of the section 2.2), the greater is \( a \), the less consumption depreciates when the shocks is non-announced (see figure 1)\(^9\). Finally, the price and the environmental influences lead to the differences represented on figure 1. Unambiguously, the price mechanism dominates, i.e. the consumption path is negatively affected when the shock is non-announced;

clearly, the quality of the environment influences the welfare variations; in scenario B and C the environmental welfare components (\( eiw \) and \( eiw' \)) are positive (the environmental quality ameliorates). On the contrary , in scenario A these components contribute negatively to the total welfare

\(^9\)Some help to read figure 1 : a-A means scenario C run with the calibrated value of \( a \), under the assumption of an announced shock; a-NA means scenario C run with the calibrated value of \( a \) under the assumption of an non-announced shock, etc....
variation (the environmental quality deteriorates);

- given our hypothesis on the parameters, $edw$ (the welfare variation due to the dynamic non-separability, see above section 2.2.2) dominates $eiw$ (the welfare variation due to the static non-separability). Obviously, the weight of the environment in the intertemporal utility function (the parameter $a$) plays a crucial role. For example, in scenario C (non-announced shock, see table 5), the total welfare variation is about 0.55%; the direct effect of the environmental quality accounts for 0.34% and the indirect effect for 0.18%; the welfare component from private commodities is about 0.03%. With $a'$ (twice the calibrated value of $a$) these effects are, respectively (see table 5), 0.90%, 0.63%, 0.18%, 0.03%;

- Finally, according to the exact welfare variation, scenario A and B appear to be positive. However, only scenario C yields a double dividend$^{10}$. As was pointed out in our comments on long run results, the rise in non-green products VAT rate and the rise in the tax on final wastes are not equivalent in term of environmental deterioration. The former measure improves welfare because it boosts total consumption; $pw = 0.06\%$, but the welfare impact of environmental quality is negative (-0.02%) because the environment deteriorates. The positive effect on consumption dominates the negative effect on the environment. The latter measure improves welfare because the shift away from direct fiscality towards green fiscality ameliorates both the consumption and the environment. The first dividend ($pw$) is relatively small (0.03% or 0.02%, see table 5) whereas the second dividend appears to be important. On one hand, substitution between pollution (wastes) and other inputs is rather easy. Then the erosion of the tax base implies that the tax on final wastes generates revenues which allow only to reduce slightly pre-existing distortionary taxes; this in turn enhances weakly the efficiency of the tax system. On the other hand, the environment ameliorates significantly. This makes more environmental amenities available, and permits the emergence of green and brown dividends.

$^{10}$Although we could speak about triple dividend (i.e. red, green and brown dividends), we will consider that the first dividend is the red dividend whereas the second dividend stands for the sum of the green and brown dividends.
Figure 1: Scenario C - Consumption

Figure 2: Scenario C - Pollution index
Conclusion

Changes in tax structure, that may *a priori* be thought favorable to the environment, may appear *a posteriori*, in light of numerical simulations, to be environmentally damaging. Revenue-neutral adjustments in VAT rates have negative or little positive effects on pollution. However, even when the household’s and producers behaviors react to the evolution of the environmental quality, as it is the case in our model, a measure which ameliorates the economic activity and deteriorates the environment (scenario A) can improve the welfare.

Perhaps surprisingly, it is a tax on intermediate consumption of final wastes (scenario C) that provides a ‘double dividend’; firms adapt their production processes to the new conditions and are thus able to produce while polluting less. Such a substitution effect could be reinforced by a technical change effect.

Previous analyses of the double dividend issue abstracted from the possibility of non-separability between the environment and the households behavior. We have shown that under assumptions of non-separability, the double dividend can still emerge.

In our model, the environment influences the welfare through two channels. The first channel is the environmental feedback on the intertemporal utility, and on the consumption path. The second channel is the trade-off between green and non-green products.

Clearly, given our data, the first channel is more important than the second. The weight of the environment acts both through the utility function and through the transitional consumption path. Moreover, the green dividend accounts for a great part in the total welfare variation. Furthermore, the brown dividend, which is a dividend that arises because of changes in private commodities allocation induced by the evolution of the environment, may not be ignored. When households respond to changes in the environment (less defensive expenditures, choice of new modes of transports) they can choose new patterns of consumption which in turn may raise their welfare.
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Appendix A

A measure of exact welfare variations.

As the instantaneous utility function is not quasi-linear, the compensating variation, the equivalent variation and the consumer’s surplus are approximation of the exact welfare variation. The first two measures are frequently used in applied general equilibrium models frequently, because they provided a monetary assessment of welfare changes. In our approach, this monetary assessment is of little interest, as compared to the exact calculation of intertemporal welfare variations.

Given a steady-state, the intertemporal utility is bounded and can be written as follows:

\[
U = \frac{1}{1 - \frac{1}{\gamma_0}} \sum_{t=1}^{\infty} \frac{1}{(1 + \delta')^{t-1}} SP^s - a u(c^s, l^o)_{1 - \delta' \gamma_0} = \frac{1 + \delta'}{\delta'} \frac{1}{1 - \frac{1}{\gamma_0}} SP^s - a u(c^s, l^o)_{1 - \delta' \gamma_0}
\]

where \(SP^s\), \(c^s\) and \(l^o\) are respectively steady state pollution stock, per capita consumption and leisure.

The initial steady state \((U_i)\) and the final steady state \((U_f)\) values of this utility can therefore be computed. Besides, given the period \((T)\) when the economy reaches its final steady state, subtracting the following expression from \(U_f\) (with obvious notations):

\[
\frac{1}{1 - \frac{1}{\gamma_0}} \sum_{t=1}^{T} \frac{1}{(1 + \delta')^{t-1}} SP_f^s - a u(c^s_f, l^o_f)_{1 - \delta' \gamma_0}
\]

and adding the following one:

\[
\frac{1}{1 - \frac{1}{\gamma_0}} \sum_{t=1}^{T} \frac{1}{(1 + \delta')^{t-1}} SP_t^s - a u(c_t, l_o)_{1 - \delta' \gamma_0}
\]

yields the intertemporal welfare \(U_v\) of the scenario, and the exact intertemporal welfare variation is given by:

\[
\left( \frac{U_v - U_i}{U_i} \right) \times 100
\]