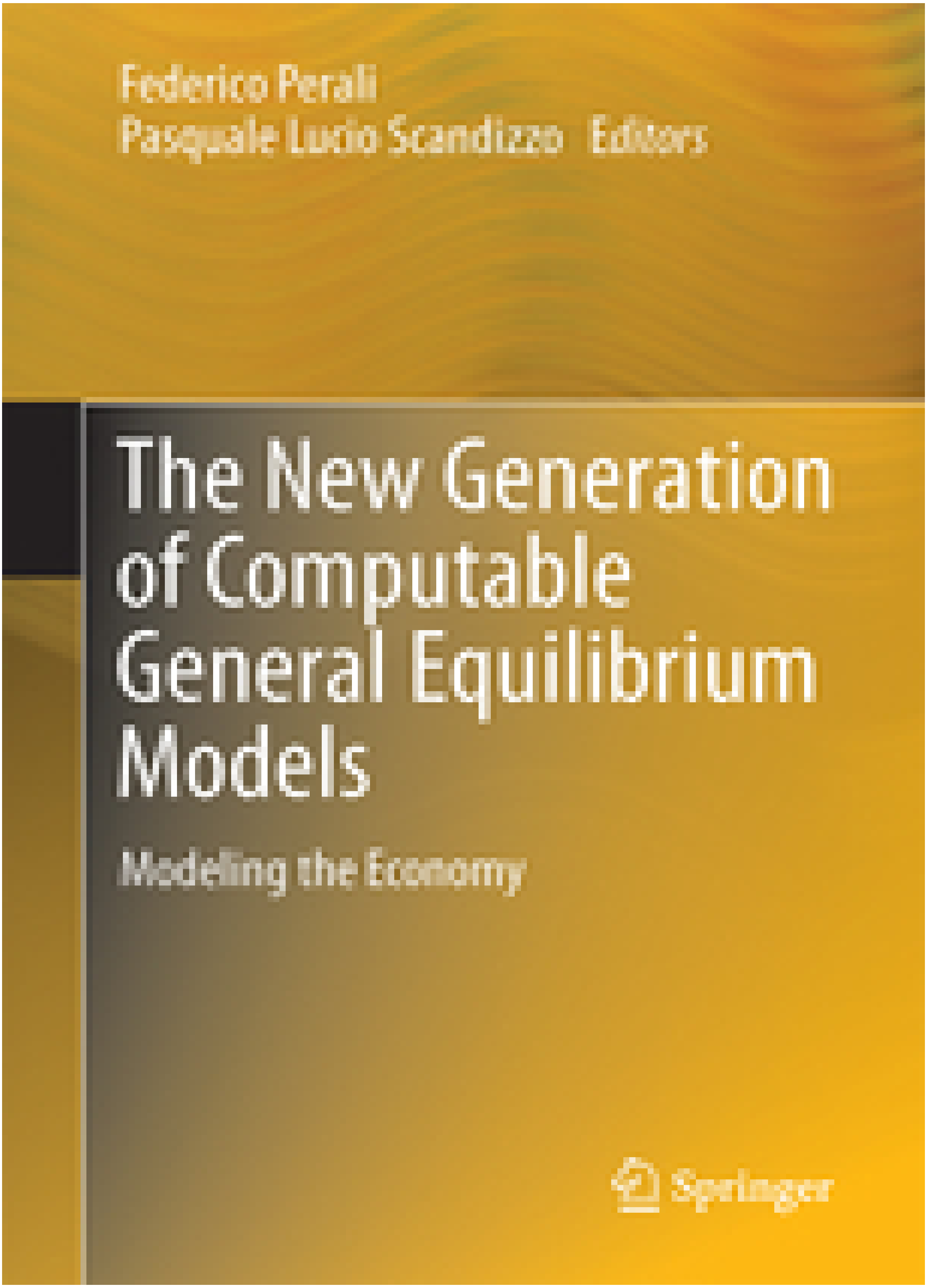

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Green and Blue Dividends and Environmental Tax Reform: Dynamic CGE Model

Francesca Severini, Rosita Pretaroli and Claudio Socci

Abstract The challenge of climate change needs to be tackled with environmental policies carefully designed to achieve environmental benefits and avoid negative economic effects. The introduction of an environmental tax in the economic system can generate a double benefit represented by the attainment of the environmental target (first or green dividend) and other additional benefits (second/third or blue dividends) represented by gains in welfare, employment, consumption etc. In this perspective, the general equilibrium analysis is able to quantify the environmental and welfare direct and indirect effects that an environmental policy generates within the economic system. Since international environmental agreements set clear target deadlines on the reduction of GHG emissions, in this paper a dynamic CGE model based on a bi-regional SAM framework for Italy is developed.

Keywords Environmental tax reform · SAM · Dynamic CGE model · Double dividend

JEL Classification H23 · D58 · D57

1 Introduction

In recent years, the European Union has promoted initiatives on environmental protection as required by the Kyoto Protocol[1] and the member states are committed to introduce environmental policies for the reduction of greenhouse gas emissions

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[1] In 2000, the European Commission launched the European Climate Change Program (ECCP) to identify and develop all the elements necessary to match the Kyoto Protocol. The goal of EU environmental policy for the year 2020 includes the cut of 20% in CO_2 emissions, the increase in renewable energy use of 20% and the increase in energy efficiency by 20% with respect to 1990 levels.

F. Severini (✉) · R. Pretaroli · C. Socci
Department of Economics and Law, University of Macerata, via Crescimbeni 14, 62100 Macerata, Italy
e-mail: francesca.severini@unimc.it

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(GHG). However, the need of structurally reducing the pressure of the human activities on environment cannot be kept apart from the need of stimulating economic growth as suggested by the European Commission (EC 1993). Therefore, the trade-off between environmental and economic targets that often emerges should be taken into consideration when selecting the most appropriate environmental policy instruments to deal with this complex target.

Among the variety of economic measures, more than a few Central Governments adopted taxes on emissions and emission permits trading that are widely known as market-based policy instruments dealing with externalities of pollution (Baumol and Oates 1988; Morris 1999). The environmental taxation, in particular, is considered a powerful tool of pollution control (Parry 2004; Farmer and Steininger 1999) because it discourages the pollutant behaviour and provides public revenue that can be recycled both at state and federal level to enhance environmental and non-environmental benefits (Pearce 1991). As for the potential positive impact of environmental taxation, we can refer to the concept of double or triple dividend (Bovenberg and De Mooij 1994), widely debated in the economic literature. In particular, it is possible to identify as benefits from the environmental taxation the reduction in GHG emissions (first or green dividend) and the positive non-environmental benefit related to economic welfare improvement (second or blue dividend). This latter can be assessed when the tax revenue, collected by Central or Local governments, is used to cut existing distortive taxes (Parry 1995). In the literature, many empirical studies debate around the existence of the double dividend in its weak and strong version, starting from the survey of Goulder (1995b). In general, there is evidence that the weak double dividend hypothesis holds, while the strong version seems to fails, that is to say, the environmental tax revenue can be used to reduce other existing tax distortions but does not easily allow achieving also an income or, more generally, a welfare benefit. For the literature that neglects the presence of a second dividend we can see Goulder (1995a), Bovenberg and Goulder (1996), Bovenberg and Goulder (1997) and Böhringer et al. (1997).

However, when considering the complexity and peculiarities of each economic system, there are many empirical studies that demonstrate the possibility to reach a strong double dividend as a result of an accurate environmental tax revenue recycling scheme. Nonetheless, there is even evidence of a third benefit that might arise with the second dividend effect for certain countries (Schneider 1997; Bovenberg and De Mooij 1998; Manresa and Sancho 2005; Takeda 2007; Glomm et al. 2008; Bor and Huang 2010). These second and third benefits can be represented by better performances of economic variables such as employment, production, consumption, inflation or income (Gimenez and Rodriguez 2010).

As for the Italian economy, the analysis carried out by Pench (2002), Bulckaen and Stampini (2002) and Roson (2002) tries to detect the double dividend effect by introducing different environmental tax reforms in a general equilibrium framework. In particular, they simulate the introduction of a "carbon tax" (Pench 2002) and analyse the impact of the environmental policy in a dynamic framework (Roson 2002). The results of their simulations do not confirm the possibility to get any further advantages apart from the environmental benefit, however the opportunity of getting a double dividend for the Italian economy is still an open question since the introduction of an environmental taxation to realize both environmental and budget objectives is still present in the policy debate. Indeed, it is worth pointing out that the possibility to get a double dividend through an environmental policy strictly depends on the structure of the existing tax system, on the production technology and above all on the structure of tax reform. Following Bovenberg and Goulder (2002), the presence of double dividend depends on a set of different conditions: the structure of primary factors' taxation; the elasticity in primary factors supply; the international immobility of capital; the value of elasticity of substitution between energy and labour (if higher than elasticity of substitution between energy and capital) and the sensibility of real wages to unemployment falls (as a consequence of the reduction of taxes on labour).

From this point of view, in a country characterised by economic differences at regional and social level, the double dividend could differ between regions or it could not occur for all regions where environmental fiscal reform is implemented (Takeda 2007). In this respect, empirical studies on environmental tax reforms and double dividend are typically focused on countries rather than regions and either accept or refuse the hypothesis of double dividend merely observing the effects of the policy on the macroeconomic variables' changes at national level. When the analysis of the environmental tax reform is performed at regional rather than national level, it is possible to figure out the economic and social differences among regions within the same country and let the regional peculiarities in technologies and habits emerge also in terms of ability in generating ecological dividends.

Such regional analysis can be carried out through a set of instrument able to quantify the direct and indirect effects of the environmental policy in a multisectoral and multiregional framework. Computable general equilibrium models (CGE) are widely considered in the literature as suitable instruments of analysis (Radulescu and Stimmelmayr 2010) to quantify the impacts of an exogenous shock on macroeconomic variables along the income circular flow (Ciaschini and Socci 2007a, b; Yeldan 1997). Moreover, since the European Commission sets to the member states clear deadlines (year 2020) to achieve the CO_2 emissions targets, the analysis should be carried out in a long term perspective, moving from the static to a dynamic approach.

In this perspective, this study develops a bi-regional multisectoral dynamic CGE model to verify the compatibility between the environmental taxation and the economic targets in terms of double/triple dividend. In particular we analyse the impact of an environmental fiscal policy for the Italian economy through a dynamic CGE model. Three main aspects inspire the use of a dynamic CGE model: first, static CGE is based upon a single set of equilibrium conditions and leaves aside relationships over time.[2] Second, the vector of prices that solve the static equilibrium does not hold over time and refers to an uncertain time horizon. Finally, even if the assumptions on elasticity of supply and demand can be interpreted as relatively long run adjustments,

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[2] As an example, producers and consumers, which maximize their utility choosing the optimal allocation of consumes and savings become myopic in the between period decisions (savings and investment).

static models do not account for more than a few factors such as capital accumulation, population growth and technological change (Lau et al. 2002). Therefore, we suggest a disaggregate and regional perspective for the study of environmental policies that can offer a further contribution in the existing debate on double dividend.

In addition, since the introduction of an environmental tax is becoming a prerogative of European countries, we focus on Government taxations from two sides: the side of production and generation of income (that is affected by the introduction of a new environmental tax) and the side of the secondary income distribution (that is affected by different tax revenue recycling schemes). Actually, once the environmental tax rate and tax base are determined, the government action should focus on the best possible use of tax revenues in order to reduce existing distortions in taxation.

The environmental tax reform proposed is characterized by the introduction of a regional environmental tax, which affects the production process according to the level of CO_2 emissions by each commodity. In particular, this tax is designed with a different '*polluter pays*' principle that follows instead, the idea that "who pollutes more should pay more", so that the activities that have a level of emission over a certain limit, pay a tax that is reshaped by and has a progressive structure. The main purpose of this reform is to assess if there is the possibility to obtain, through an environmental tax, a positive effect both on environment and on disposable income.[3] Thus, the corresponding tax revenue is used to cut income taxes and the regional tax on activities' value added. The reduction of income tax has the aims to mitigate the green tax effects on households real disposal income: the price of goods in fact, may be affected by tax shift and the private final consumption may dampen as a consequence of the higher price. On the other side the reduction of the regional tax on activities' value added is applied to face directly the tax shift correlated to the green tax on commodities.

The analysis is carried out on the bi-regional Social Accounting Matrix (SAM) for the Italian economy that allows to quantify both the economic and the environmental effects generated by the environmental fiscal reform in the long run. Furthermore, the aim to identify the convenient green tax reform requires the integration of the SAM with the environmental data set concerning CO_2 emissions by commodity. In this respect, the European Commission suggests the use of the National Accounting Matrix with the integration of the Environmental Accounts (NAMEA) as the basic tool for the integration between environmental and economic flows.[4] This detailed database represents the benchmark for the CGE model that is calibrated on it, and allows to discuss the results of the policy proposed in terms of changes in prices, total output, final demand and total emissions. Moreover, the analysis is integrated with considerations about the changes of the burden index over time. Indeed this

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[3] The model assumes that all markets clear, therefore we do not considers any rigidity on wage formation and unintentional unemployment.

[4] The NAMEA integrates the major economic aggregates—total output, value added and final demand—with the GHG emissions data in physical terms according to the input output disaggregation (EC 1994). This approach avoids the difficulties connected to a correct valuation of environmental costs.

indicator is classically considered as a measure of government efficiency in the income distribution act and we assume its performance as a welfare measure.

The next section points out the main features of the dynamic model and describes the tax burden indicator. Section three gives a description of the database and introduces the environmental policy targets for the Italian economy. Than in the fourth section, we suggest a suitable environmental tax reform consistent with the reduction of CO_2 emissions and propose two tax revenue recycling alternatives. The fifth section provides a description of the simulation results emerging from the application for the Italian case, in terms of CO_2 emissions by activities, total output, price trend, gross investment, final consumption and tax burden over time.

2 Dynamic CGE Model Relationships

BiReg17 (Bi-Regional 2017), is a bi-regional and multisectoral dynamic CGE model where the evolution path is a sequence of single period static equilibria linked each other by the capital accumulation condition (Lau et al. 2002). It is a recursive dynamic model that can be illustrated in two phases: the first refers to the description of the single period equilibrium conditions; the second introduces the dynamic rule.

The model considers an open economy with two regions, m commodities, c components of value added, h Institutional Sectors including Households, Firms, Government[5] and Rest of the World. In every time period the demand equals the supply in all commodities and primary factors markets (market clearing conditions) and extra profits are not allowed (no profit conditions) (Pretaroli and Severini 2009).

Bireg17 can be described as an integrated representation of the bi-regional income circular flow (Ciaschini et al. 2012) where the entire process of generation, primary and secondary distribution of income is represented by a system of behavioural equations and income constrains for agents, which are price taker and maximise their utility function. Following the scheme provided by Table 1, the total output ($\mathbf{X_t}$) resulting from the sum of domestic and imported output ($\mathbf{M_t}$)[6] is equal to intermediate demand ($\mathbf{B_t}$), final consumption expenditures ($\mathbf{C_t}$), final consumption expenditure incurred by Government ($\mathbf{CG_t}$), gross fixed capital formation ($\mathbf{I_t}$) and exports ($\mathbf{E_t}$). Likewise, primary factors' endowments correspond to primary factors' demanded by production process ($\mathbf{Y}$) and their markets are perfectly competitive. We do not consider any rigidity on wage formation and thus we assume that there is no unintentional unemployment.[7] Domestic production is formalized as a nested constant return to scale technology. Assuming the Leontief production function,

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[5] The Government is represented as a Central Government, that has a national dimension, and as Local Government that is represented together with the other institutional sectors. The assumptions on Institutional Sectors hold also for Central and Local Government.

[6] Following Armington's hypothesis (Armington 1969), imported and domestically produced commodities are not perfect substitutes. This solves the problem that the same kind of good is found to be both exported and imported.

[7] Labor supply (endowment) is exogenous.

domestic output is the combination of intermediate goods (**B**), depending on total output and prices, and value added that is affected by total production and primary factors compensations (**Y**). Then assuming a CES technology, the value added is generated by combining capital and labour that are perfectly mobile across activities.[8]

Following the logic of the Ramsey model, the Institutional Sectors maximise the present value of their intertemporal utility function, which depends on final consumption expenditure ($\mathbf{C_t}$ and $\mathbf{CG_t}$), and gross saving ($\mathbf{S_t}$ and $\mathbf{SG_t}$) subject to the lifetime budget constraint. The budget constrain for Households is verified when the total disposable income (**Rd**) is equal to the sum over time of final consumption expenditures (**C**) and savings (**S**). The primary factor compensations ($\mathbf{R_t}$) plus net transfers from Institutional Sectors ($\mathbf{Tr_t}$), minus income taxes ($\mathbf{Ta_t}$), determine consumers total endowments in every time period. As to Government, public saving (or deficit) ($\mathbf{SG_t}$) is calculate as total tax revenue ($\mathbf{Ta_t}$) minus the sum of final consumption expenditures by Government ($\mathbf{CG_t}$) and transfers to other Institutional Sectors ($\mathbf{Tr_t}$). This description represents the public budget constrain.[9] We distinguish direct income taxes and a set of indirect taxes (tax on products, value-added tax and payroll taxes).

The single period equilibrium regarding the condition on gross capital formation requests that total gross fixed capital formation ($\mathbf{I_t}$) becomes equal to gross savings by Institutional Sectors ($\mathbf{S_t}$ and $\mathbf{SG_t}$). The dynamic component in the model is given by the inter-temporal capital accumulation condition. According to the market clearing condition for capital, any change in gross fixed capital formation must affect the capital yearly growth given a constant rate of capital depreciation (δ).[10]

Then, in the dynamic model, the optimization problem for all the consumers becomes:

$$\max \sum_{t=0}^{\infty} \left(\frac{1}{1+\rho} \right)^{t} u \left[C_t \left(y_{d_t}, p_t \right) \right] \tag{1}$$

s.t.

$$C_t = f\left(K_t, L_t, M_t, Ta_t\right) - I_t - E_t \tag{2}$$

$$K_{t+1} = (1-\delta)K_t + I_t \tag{3}$$

Every institutional sector maximizes intertemporal utility which depends on consumption, under the constraints represented by two conditions:

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[8] The elasticity of substitution between labor and capital derives from econometric estimates for Italy (Van der Werf 2007).

[9] The marginal cost of public funds are set equal to zero.

[10] According to the literature on dynamic CGE we employ the term '*depreciation*' in place of the term '*consumption of fixed capital*' used by the SNA. The term 'consumption of fixed capital' refers to the decline, during the course of the accounting period, in the current value of the stock of xed assets owned and used by a producer as a result of physical deterioration, normal obsolescence or normal accidental damage. It is used in the SNA to distinguish it from 'depreciation' as typically measured in business accounts (United Nations 2008).

Table 1 CGE model following SAM framework (our source)

		South-Islands			North-Centre			Central government	Formation of capital	Rest of word
		Commodities	Primary factors	Institutional sectors	Commodities	Primary factors	Institutional sectors			
S-I	*Comm.*	$\mathbf{B}^{ss}(x, p)$		$\mathbf{C}^{ss}(rd, p)$ $\mathbf{GL}^{ss}(rd, p)$	$\mathbf{B}^{sn}(x, p)$		$\mathbf{C}^{sn}(rd, p)$ $\mathbf{GL}^{sn}(rd, p)$	$\mathbf{G}^{sg}(rd, p)$	$\mathbf{I}^{s}(p)$	$\mathbf{E}^{sw}(e, p)$
	Fact.	$\mathbf{Y}^{ss}(x, pi, pk)$			$\mathbf{Y}^{sn}(x, pi, pk)$					
	Ins.Sec.	$\mathbf{T}^{ss}(x)$	$\mathbf{R}^{ss}(y)$	$\mathbf{T}^{ss}(r, t)$ $\mathbf{T}_r^{ss}(r, t)$		$\mathbf{R}^{sn}(y)$	$\mathbf{T}^{sn}(r, t)$ $\mathbf{T}_r^{sn}(r, t)$	$\mathbf{T}_r^{sg}(r, t)$		$\mathbf{t}^{sw}(r)$
N-C	*Comm.*	$\mathbf{B}^{ns}(x, p)$		$\mathbf{C}^{ns}(rd, p)$ $\mathbf{GL}^{ns}(rd, p)$	$\mathbf{B}^{nn}(x, p)$		$\mathbf{C}^{nn}(rd, p)$ $\mathbf{GL}^{nn}(rd, p)$	$\mathbf{G}^{ng}(rd, p)$	$\mathbf{I}^{n}(p)$	$\mathbf{E}^{nw}(e, p)$
	Fact.	$\mathbf{Y}^{ns}(x, pi, pk)$			$\mathbf{Y}^{nn}(x, pi, pk)$					
	Ins.Sec.		$\mathbf{R}^{ns}(y)$	$\mathbf{T}^{ns}(r, t)$ $\mathbf{T}_r^{ns}(r, t)$	$\mathbf{T}^{nn}(x)$	$\mathbf{R}^{nn}(y)$	$\mathbf{T}^{nn}(r, t)$ $\mathbf{T}_r^{nn}(r, t)$	$\mathbf{T}_r^{ng}(r, t)$		$\mathbf{t}^{nw}(r)$
C.G.		$\mathbf{T}^{gs}(x)$	$\mathbf{R}^{gs}(y)$	$\mathbf{T}^{gs}(r, t)$ $\mathbf{T}_r^{gs}(r, t)$	$\mathbf{T}^{gn}(x)$	$\mathbf{R}^{gn}(y)$	$\mathbf{T}^{gn}(r, t)$ $\mathbf{T}_r^{gn}(r, t)$			
F.K.				$\mathbf{S}^{s}(rd)$			$\mathbf{S}^{n}(rd)$	$\mathbf{S}^{g}(rd)$		(+/−)a
RW		$\mathbf{M}^{ws}(x, e)$	$\mathbf{t}^{ws}(y)$	$\mathbf{T}_r^{ws}(r)$	$\mathbf{M}^{wn}(x, e)$	$\mathbf{t}^{wn}(y)$	$\mathbf{T}_r^{wn}(r)$			

(i) total output produced by each commodity $\mathbf{X_t}$ is equal to the sum of intermediate consumption, households consumption expenditures ($\mathbf{C_t}$), government current expenditures ($\mathbf{CG_t}$), gross fixed capital formation $\mathbf{I_t}$ and exports $\mathbf{E_t}$ (market clearing conditions);

(ii) the capital stock in period $t + 1$ is equal to the capital stock in period $t(\mathbf{K_t})$,[11] less depreciation ($\boldsymbol{\delta}\mathbf{K_t}$) plus gross fixed capital formation in period t($\mathbf{I_t}$)[12]. The rate of capital depreciation is exogenous. It depends on the value of steady state interest rate r and growth rate g.[13]

In order to solve the model for a finite number of periods, we approximate the infinite horizon with endogenous capital accumulation condition according to Lau et al. (2002). Thus in order to obtain the terminal period equilibrium we set the terminal gross capital formation growth rate equal to the growth rate of aggregate output (see the Appendix 1).

In BiReg17 two regions are modelled, therefore all equilibrium condition and budget constraint hold for both regions. As for the economic flows between regions, they are not considered as exports or imports, but are modelled as intermediate consumption of commodities associated to the other region (in the production block) and as income transfers between institutional sectors belonging to the other region (in the primary and secondary income distribution). Imports and Exports are determined at national level and include the economic flows of each region only with the rest of the world.

Because there are two regions and a set of Institutional sectors, the model produces a disaggregate set of information on prices, total output by commodity and incomes. However, a welfare measure that allows seeing the overall effects of a policy is represented by the tax burden index that is considered as a measure of government efficiency in income redistribution. Moreover, the computation of this index allows to understand whether there are efficiency gains or only redistribution effects when a policy is implemented. The tax burden index is calculated as the ratio between the sum of all taxes (direct taxes, indirect taxes—tax on products, value-added tax and payroll taxes) and the Gross Domestic Product (GDP). It is set equal to 100pt in the baseline equilibrium and it is recursively calculated each year in order to show its evolution over time.

3 Environmental Accounts in a Social Accounting Scheme

The parameters of BiReg17 are calibrated on the bi-regional SAM for the Italian economy. It describes the production system features and the income circular flow in terms of intra-regional and inter-regional flows (Pretaroli and Severini 2009).

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[11] The capital stock in period t is calibrated on the SAM data following Paltsev (2004).

[12] For the specification of the dynamic model see the appendix Appendix 1.

[13] In our model, we assume r = 4% (nominal interest rate) and g = 0.6% (real growth rate). According to the rule for investment on a steady state $I_t = (d + g)K_t$ we calibrate the value of the depreciation rate δ on the SAM data.

A SAM scheme of the bi-regional flows is showed in Fig. 1. The flows are split in two macro regions, the North-Centre region and the South-Islands region (Pretaroli and Severini 2008) and the rows and columns of the SAM are headed to 16 commodities—[1. Products of agriculture, 2. Energy products, 3. Metal and non metal ore, 4. Non-metallic mineral products, 5. Chemical products, 6. Mechanics, 7. Transport equipment, 8. Food products and beverages, 9. Textile, 10. Other manufacturing products, 11. Construction work, 12. Trade, 13. Transport, 14. Financial services and Insurance, 15. Private services, 16. Government services]; 2 primary factors—[Labor and Capital]; 5 Institutional Sectors—[I. Households, II. Firms, III. Regional Government, IV. Central Government, V. Rest of the World]. The disaggregation of Institutional Sectors follows the exigency of testing the impacts of policy reforms on public and private balances. For this purpose, different typologies of tax and expenditures are considered. In particular, we distinguish social contributions, regional value added tax, a set of indirect taxes on commodities and income taxes. The average tax rates are calibrated on the SAM data and are fixed at their benchmark level in all scenarios.

Since the paper aims to assess the economic and environmental impacts of a fiscal reform at regional level, the SAM database is integrated with environmental indicators provided by the National Accounting Matrix including Environmental Accounts (NAMEA) developed by ISTAT (2008). We focused on CO_2 emissions by commodity[14] and associated these physical flows to the commodities classification in the SAM. This phase allows to construct a data scheme in which the economic flows related to the 16 commodities in each region (North-Centre and South-Islands) are associated to a specific level of CO_2 emissions. The different polluting power associated to each commodity depends on the technology employed in the production process and is measured by the CO_2 emission coefficient.[15]

4 Fiscal Policy Through an Environmental Tax Reform

According to the Kyoto Protocol, the Italian economy had to reduce the CO_2 emissions by 16.9% with respect to the 1990's level within 2020.[16] From 1990, when the total CO_2 emissions were 360 Mlt, Italy should be reducing the emissions of CO_2 on average by 2.045 Mlt each year, in order to achieve the Kyoto target represented

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[14] We do not consider the CO_2 emissions resulting from final consumption expenditure. The impact on CO_2 emissions is not included in utility function of the Government in order to obtain Environmental Domestic Product.

[15] The emission coefficient by commodity is the ratio between the of CO_2 emission tons by commodity and the total output.

[16] The Kyoto protocol established the reduction of 20% of Italian GHG. CO_2 emissions represent the 85% of total GHG, thus the Kyoto target for Italian CO_2 can be considered as 16.9%.

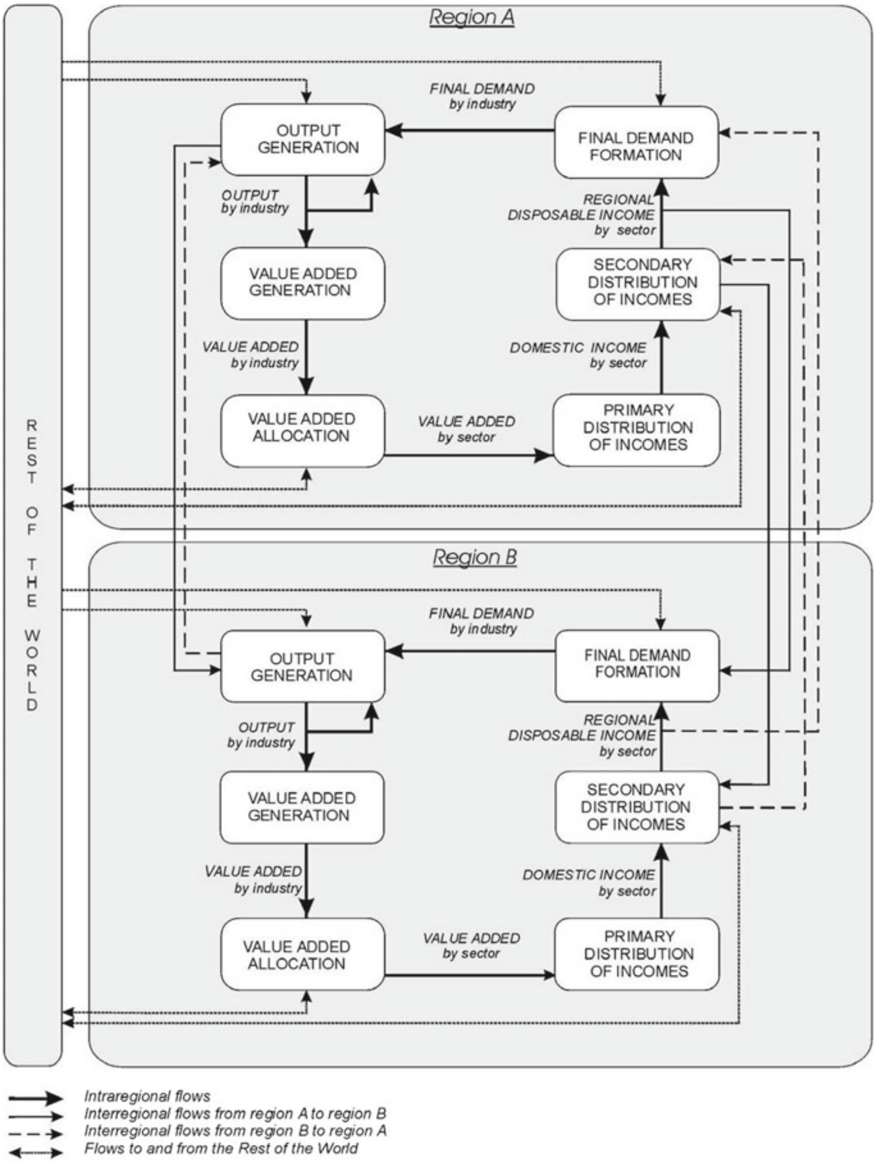

Fig. 1 Bi-regional SAM framework (our source)

by 300 Mlt in 2020 (ISTAT 2008).[17] Actually, the annual level of CO_2 emissions is exceeding the hypothetical annual level compatible with the 2020 target and this difference can be easily interpreted as the annual Italian potential debit of CO_2 emissions (Ciaschini et al. 2012, 2014). This trend should reverse or, at least, terminate to approach the 2020 target. For this purpose, we can consider the introduction of an environmental tax that takes into account the above-mentioned polluting license and the polluting power of each commodity represented by the emission coefficient. The average level of emission allowed by commodity can be calculated as the ratio between the total level of CO_2 for Italy in each year and the number of commodities considered in the benchmark.[18] The "no-tax area" therefore, reflects the average level of CO_2 emissions that fulfils the Kyoto Protocol target and the commodities charged by the taxation are those with a level of CO_2 emissions exceeding this level.

In Table 2, we calculate the distance in tons between the actual and the admitted level of emissions in the base year by commodity. Those showing a negative value do not pay any environmental tax since they pollute under the permitted level, on the contrary those with a positive value are burdened by the taxation following the principle "who pollutes more should pay more". This means that they pay a higher marginal tax rate and should have an incentive to reduce their emissions to avoid the taxation, allowing the achievement of the so called green environmental dividend.[19]

Technically, we consider the introduction of a carbon tax on output differentiated by commodity according to CO_2 emissions coefficients. The exemption area is calculated as the ratio between the total level of CO_2 allowed for Italy in the base year and the number of commodities in the benchmark. Thus, the environmental tax is designed with a progressive structure, with 5 classes of taxation and a fixed price per ton of CO_2 emission established in each class. When total emissions by commodity exceeds the cut-off point, the commodity is taxed according to the subsequent class of taxation for the emissions in excess. The structure of the tax for the base year can be described as follow:

from 0 to 10.871.958 t (no-tax area);
from 10.871.958 t to 15.000.000 t (9 euro per CO_2 t);
from 15.000.001 t to 30.000.000 t (16 euro per CO_2 t);
from 30.000.001 t to 50.000.000 t (22 euro per CO_2 t);
over 50.000.001 t (32 euro per CO_2 t).

According to the database, the commodities burdened by the tax in North-Centre region are: 'Energy products', 'Non metallic mineral products', 'Chemical products', 'Mechanics', 'Trade' and 'Transport'. In South-Islands region, the tax is calculated on 'Energy products', 'Non metallic mineral products' and 'Transport'.

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[17] We do not consider the emissions deriving from final consumption process. Therefore, the levels and the target of emissions considered do not include direct emissions caused by households and firms.

[18] There are 32 commodities (16 for North-Centre and 16 for South-Islands regions).

[19] Because we do not know the costs of the environmental damage, we consider the amount of CO_2 emissions as a proxy of the environmental damage and consider its reduction as a positive effect (dividend).

Table 2 Distance from admitted level of CO_2 emissions by commodity tons in base year (our elaboration)

	South-Island	North-Centre
1. Products of agriculture	−8193883	−6481826
2. Energy products	41741701	79085967
3. Metal and non metal ore	−11658202	−10710630
4. Non metallic mineral product	569054	21842393
5. Chemical products	−6322697	22121753
6. Mechanics	−8674561	14339882
7. Transport equipment	−11164576	−9053772
8. Food products and beverages	−9641433	−4622612
9. Textile	−10621875	−1373467
10. Other manufacturing products	−10647291	−1972093
11. Construction work	−10820342	−9343867
12. Trade	−6188216	2824093
13. Transport	−1284255	16843725
14. Financial services and insurance	−11600401	−11099251
15. Private services	−10092737	−7181543
16. Government services	−7543571	−4155521

The environmental tax revenue can be attributed alternatively to the Central or Local Government and used to cut existing local or central taxes. Depending on the choice, we can identify two hypothetical scenarios: in s1 the tax revenue is allocated to the Regional Government and recycled to reduce the regional tax on value added by activity; in s2 the tax revenue is allocated to the Central Government and recycled to reduce Households income tax.

The reasons that led us to model these two scenarios refers to the opportunity of reducing the indirect effects of the environmental tax on commodity prices and stimulating income generation. Indeed, the tax directly affects the most polluting goods and indirectly leads to higher final prices even for the other commodities, since all the production processes are integrated. For this purpose, by reducing the income tax we attempt to compensate Households for the loss purchasing power. Similarly the reduction of regional tax on value added by activities should reduce the costs of production and compensate for the environmental tax burden on final prices formation. The effectiveness of the policies in this sense is analysed also in terms of tax burden in order to measure the action of the Government in the redistribution of income.

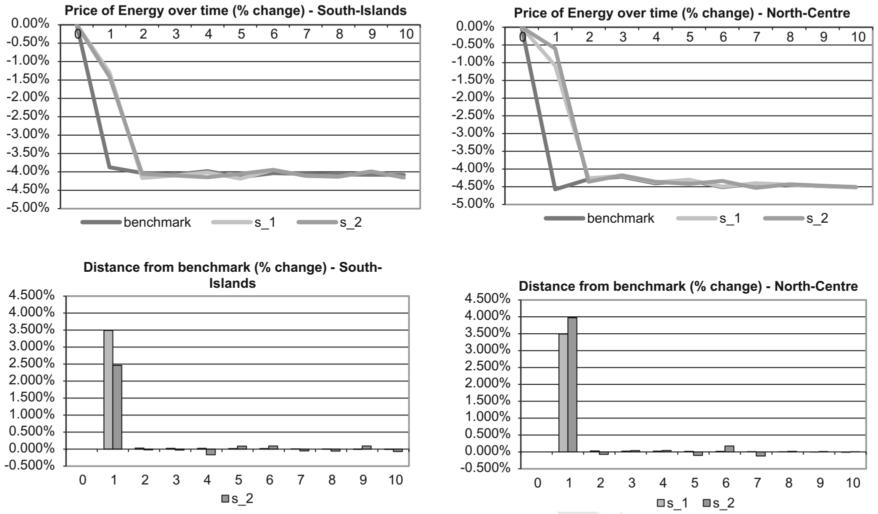

Fig. 2 Effects on energy price—% change

5 Looking for Dividends

5.1 Economic Impact of the Environmental Tax Reform

The simulations compare the baseline equilibrium (or benchmark equilibrium) without any environmental taxation, with the new equilibrium resulting from the environmental policy reform. The distance in every period (year) between the baseline trend and the path after the simulation represents the impact of the policy, that is measured on the main environmental and welfare variables in the long run.

The results of the simulations are discussed starting from the effects on total output, prices, CO_2 emissions, final demand and tax burden index.

In both scenarios, the environmental tax is modeled as a new tax on total output. In particular, the burden is on the commodities whose CO_2 emissions exceed the allowed level (the no-taxed level). Among the other, the Energy commodity is the most pollutant in both regions, thus pays a higher tax (class 4). As a result of the environmental fiscal reform, total output of Energy decreases and the price increases with respect to the benchmark path (Figs. 2 and 3). The impact on prices and outputs is greater in the North-Centre region, where the production of Energy generates a higher level of CO_2 emissions and the tax burden is higher. This effect is more evident when the tax revenue is recycled through a reduction of households' income tax (scenario s2). In the first scenario (s1) in fact, the cut in the regional tax on value added mitigates the pressure of the policy on final prices and reduces the impact on total production.

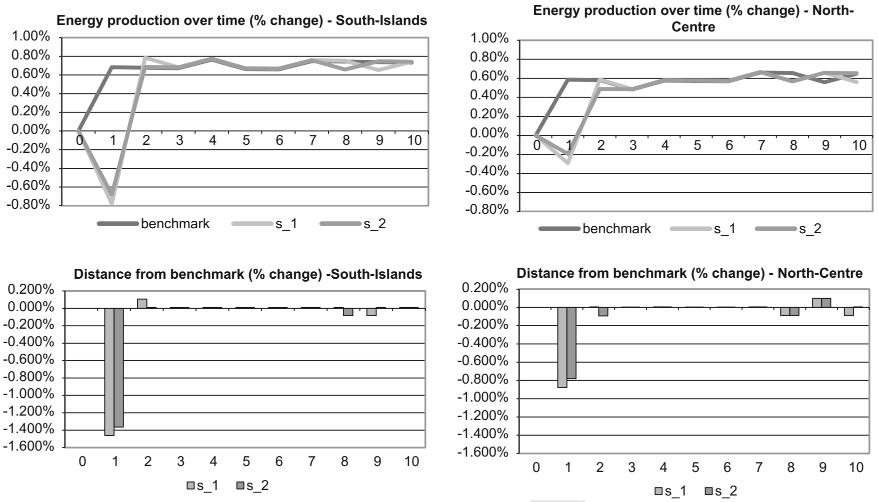

Fig. 3 Effects on energy output—% change

Similarly, total output of all the other goods decreases and prices increase with respect to the benchmark. Nevertheless, the impact of the environmental reform on commodity outputs and final prices is relevant only in the short run. In the long run, changes adjust back to the benchmark trend.

Looking at the general level of CO_2 emissions, in both scenarios the policy allows achieving the expected environmental target as results from the reduction in CO_2 emissions showed in Fig. 4. The decrease in CO_2 emissions is greater in the North-Centre area but, as already observed for the commodities total output, the distance from the benchmark path almost disappears after few periods. It is possible to say that in all scenarios the environmental (green) dividend can be pursued although for a short time and with regional differences. The results allow us to identify the relevance of the second recycling scheme (scenario s2), which provides the reduction of households income tax, in terms of environmental performance in both regions.

The research for further benefits associated to the recycling scheme of the tax revenue, requires the collection of results in terms of income generation and distribution. In particular, to identify a welfare blue dividend, we consider the evolution of final demand formation and distinguish the impact of the reform on gross capital formation and final consumption expenditure. Since the inter-temporal utility depends on the single period utility and the single period utility depends on final consumption expenditures by all institutional sectors, observing the change in final consumption expenditures we derive information on consumers' utility or welfare.

In the South-Islands region we observe a reduction in final consumption in both scenarios for the first year (see Fig. 5) than it gradually follows the benchmark path. In the North-Center region, final consumption in the short run increases with respect to the benchmark in the first scenario (s1) when the environmental tax is recycled

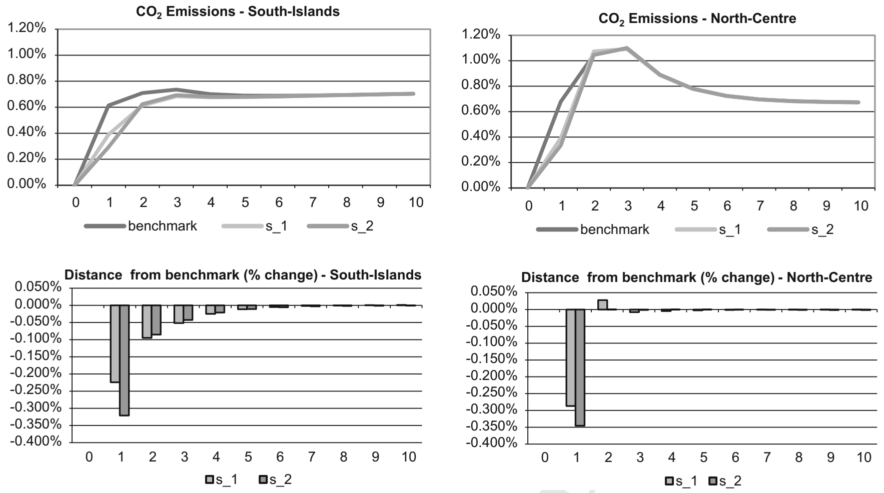

Fig. 4 Effects on total CO_2 emissions—% change

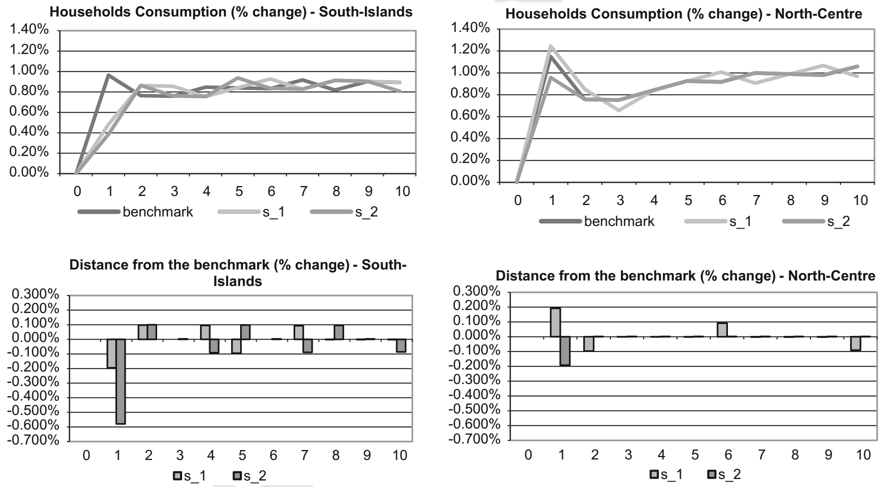

Fig. 5 Effects on households' consumption—% change

by reducing the regional tax on activities. As already observed for the South-Islands region, this rise in final demand disappears in the long run.

Similarly, in South-Islands region it is possible to observe a reduction in gross capital formation with respect to the benchmark path in the short run, regardless to the recycling assumptions. Conversely, in the North-Centre region, this policy does not affect the gross capital formation that almost replicates the same benchmark trend over the time in both scenarios as shown in Fig. 6 ~~(Fig. 7)~~. AQ2

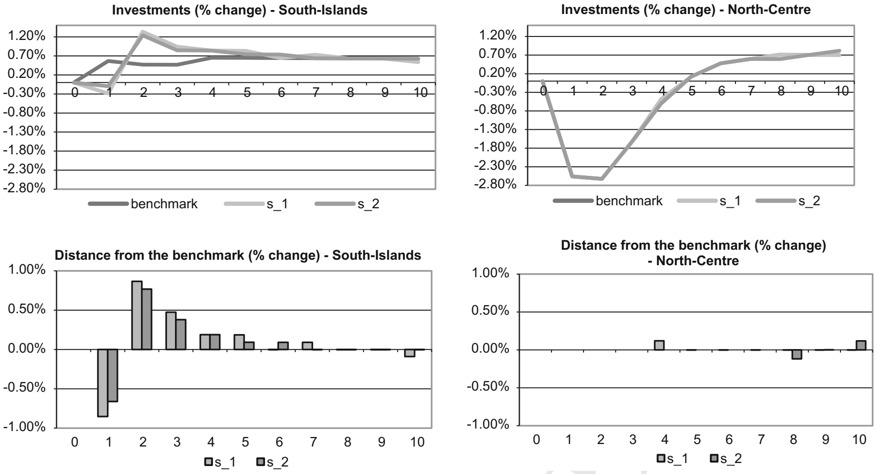

Fig. 6 Effects on gross investment—% change

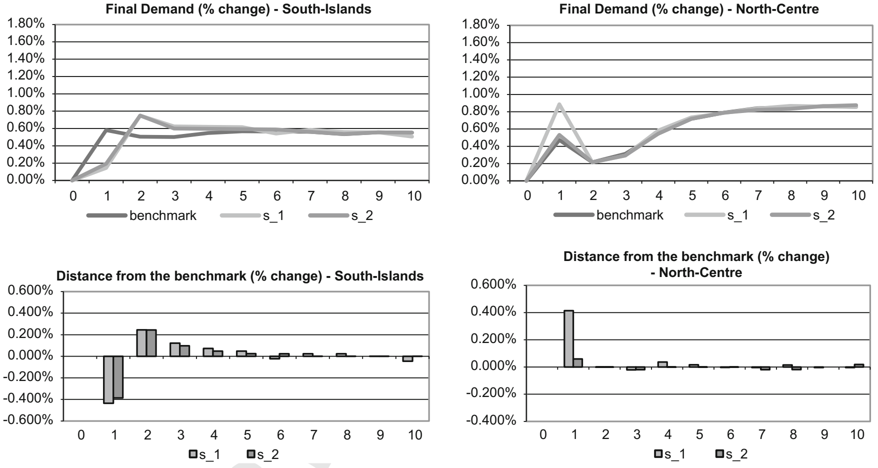

Fig. 7 Effects on final demand—% change

The combination of the effects on consumption and gross capital determines the performance of the policy reform in terms of final demand. In general, the introduction of the environmental tax in the economic system generates positive effects on final demand only in the North-Centre region in the first scenario. This result might lead to conclude that recycling the tax revenue through a reduction of income taxes is a less efficient measure than cutting taxes on regional value added in terms of final demand and investment. This result is confirmed also by the performance of the tax burden index. As a measure of government efficiency in income redistribution, this index shows whether the environmental policy generates efficiency gains or only

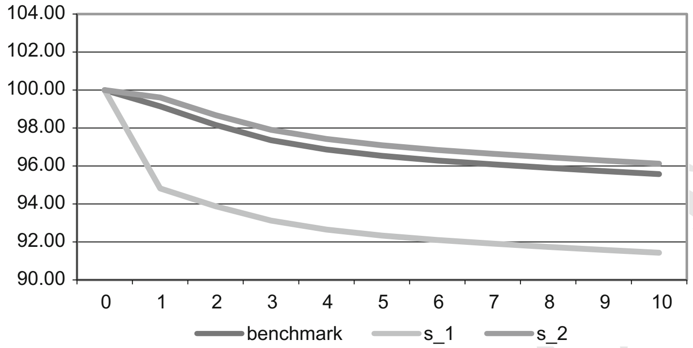

Fig. 8 Tax burden index

redistribution effects. The value of the index in the benchmark is fixed to 100 pts in the base year and it is recursively calculated in the following years. As showed in Fig. 8, when the tax revenue is recycled according to the first scenario (reducing the regional tax on value added by activities) the tax burden is lower than the benchmark and the second scenario, allowing a gain in welfare. As a result of the previous disaggregate analysis we can assert that probably this overall effect is mostly driven by the effectiveness of the policy more in the North-Centre region than in the South-Islands region.

5.2 Sensitivity Analysis of the CGE Model Results

In the economic literature on CGE modeling, the consistency of the results are commonly argued to be strictly dependent on the assumption on exogenous parameters, such as elasticity of substitution in production and utility function (Grassini 2009). Therefore, in order to strengthen the validity of the outcomes already described, we integrate the study with the sensitivity analysis for the elasticity of substitution between primary factors (labor and capital) in the value added aggregate. To be more specific, in the nested production function, when combining labor and capital to generate the value added aggregate, we assumed a CES technology with elasticity of substitution equal to 0.5218 (Van der Werf 2007). The sensitivity analysis is carried out assuming two alternative parameters for the elasticity: sigma1 = 0.6262 (the original parameter increased by 20%) and sigma1 = 0.4174 (the original parameter decreased by 20%).

Then the simulations are run again considering these new parameters. The results of the sensitivity analysis are showed in Tables 3 and 4 in the Appendix 2 and confirm the robustness of the analysis. We compare the outcomes of the new simulations with the results of the simulations s1 and s2 as regard to the changes in Energy commodity output and price, the change in the CO_2 emissions (Table 3), the change in final consumption, gross investment and final demand (Table 4). As showed the results are persistent since only small differences are detected in final consumption, gross investment and final demand change but only in the fifth decimal.

6 Conclusions

The effectiveness of an environmental policy measure can be tested using the multisectoral approach that allows determining its direct and indirect (desired and undesired) impacts in a general equilibrium analysis. In particular, the use of the SAM integrated with environmental data on CO_2 emissions allows to calibrate a dynamic CGE model in which the environmental aspects are modelled as dependent to agents behavior over the time.

The environmental tax proposed for the Italian economy is modelled to reduce the pollution power of each activity following the principle "those who pollute more, should pay more" in order to assess the existence of a regional second dividend that integrates the first national dividend related to an improvement of environment through the reduction of CO_2 emissions.

The first step of this analysis consists in the definition of the tax structure. In particular, disaggregated data on CO_2 emissions permits the classification of commodities according to their polluting capacity. They allow to identify the production processes that exceed the level of emissions compatible with International Targets. Then, an environmental tax on output with a progressive structure was introduced to restore the correct level of CO_2 whether the admitted level of emissions is not respected. The most interesting aspect of the policy scenarios is related to the destination of the tax revenue to reduce existing tax burden and provide a better income distribution. Indeed, we focus on the Government action that affects the behavior of economic agents from two sides: the side of production and generation of income (that is affected by the introduction of a new environmental tax) and the side of the secondary income distribution (that is affected by different tax revenue recycling schemes). In particular, two alternative recycling scheme are developed: the first refers to the reduction of income tax, the second concerns the reduction of regional tax on value added generated by activities.

The second step concerns the assessment of the environmental and the social-economic benefits (the first or green and the second or blue dividend). The results show the importance of using a detailed database inthe general equilibrium analysis to detect the impacts of the environmental fiscal reform within the economic system. We ascertain the existence of a green dividend in the economy as a whole, regardless to the recycling scheme, given by the reduction in CO_2 emissions. This effect is particularly strong in the short run and endures in the long run, with a lower trend.

As to the blue dividend, we considered the evolution over the time of the final demand in order to obtain information on the intertemporal utility change, which depends on the consumption over time. The results show that the final demand in the North-Centre region increases in particular when the tax revenue is recycled through

Table 3 Sensitivity analysis results for energy price, energy output and CO_2 emissions

Years	Benchmark		s_1						s_2					
			sigma = 0.5218		sigma = 0.6262		sigma = 0.4174		sigma = 0.5218		sigma = 0.6262		sigma = 0.4174	
	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre
	Energy production													
0	1.026	1.025	1.027	1.025	1.027	1.025	1.027	1.025	1.027	1.025	1.027	1.025	1.027	1.025
1	1.033	1.031	1.019	1.022	1.019	1.022	1.019	1.022	1.02	1.023	1.02	1.023	1.02	1.023
2	1.04	1.037	1.027	1.028	1.027	1.028	1.027	1.028	1.027	1.028	1.027	1.028	1.027	1.028
3	1.047	1.042	1.034	1.033	1.034	1.033	1.034	1.033	1.034	1.033	1.034	1.033	1.034	1.033
4	1.055	1.048	1.042	1.039	1.042	1.039	1.042	1.039	1.042	1.039	1.042	1.039	1.042	1.039
5	1.062	1.054	1.049	1.045	1.049	1.045	1.049	1.045	1.049	1.045	1.049	1.045	1.049	1.045
6	1.069	1.06	1.056	1.051	1.056	1.051	1.056	1.051	1.056	1.051	1.056	1.051	1.056	1.051
7	1.077	1.067	1.064	1.058	1.064	1.058	1.064	1.058	1.064	1.058	1.064	1.058	1.064	1.058
8	1.085	1.074	1.072	1.064	1.072	1.064	1.072	1.064	1.071	1.064	1.071	1.064	1.071	1.064
9	1.093	1.08	1.079	1.071	1.079	1.071	1.079	1.071	1.079	1.071	1.079	1.071	1.079	1.071
10	1.101	1.087	1.087	1.077	1.087	1.077	1.087	1.077	1.087	1.078	1.087	1.078	1.087	1.078

(continued)

Table 3 (continued)

Years	Benchmark		s_1						s_2					
			sigma = 0.5218		sigma = 0.6262		sigma = 0.4174		sigma = 0.5218		sigma = 0.6262		sigma = 0.4174	
	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre
	Price of energy													
0	0.852	0.831	0.851	0.831	0.851	0.831	0.851	0.831	0.851	0.831	0.851	0.831	0.851	0.831
1	0.819	0.793	0.840	0.822	0.840	0.822	0.840	0.822	0.839	0.826	0.839	0.826	0.839	0.826
2	0.786	0.759	0.805	0.787	0.805	0.787	0.805	0.787	0.805	0.790	0.805	0.790	0.805	0.790
3	0.754	0.727	0.772	0.754	0.772	0.754	0.772	0.754	0.772	0.757	0.772	0.757	0.772	0.757
4	0.724	0.695	0.741	0.721	0.741	0.721	0.741	0.721	0.740	0.724	0.740	0.724	0.740	0.724
5	0.694	0.665	0.710	0.690	0.710	0.690	0.710	0.690	0.710	0.692	0.710	0.692	0.710	0.692
6	0.666	0.635	0.682	0.659	0.682	0.659	0.682	0.659	0.682	0.662	0.682	0.662	0.682	0.662
7	0.639	0.607	0.654	0.630	0.654	0.630	0.654	0.630	0.654	0.632	0.654	0.632	0.654	0.632
8	0.613	0.580	0.627	0.602	0.627	0.602	0.627	0.602	0.627	0.604	0.627	0.604	0.627	0.604
9	0.588	0.554	0.602	0.575	0.602	0.575	0.602	0.575	0.602	0.577	0.602	0.577	0.602	0.577
10	0.564	0.529	0.577	0.549	0.577	0.549	0.577	0.549	0.577	0.551	0.577	0.551	0.577	0.551

(continued)

Table 3 (continued)

Years	Benchmark		s_1						s_2					
			sigma = 0.5218		sigma = 0.6262		sigma = 0.4174		sigma = 0.5218		sigma = 0.6262		sigma = 0.4174	
	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre
	CO_2 emissions													
0	107939100	287328500	107691300	287319700	107691400	287319600	107691400	287319700	107740800	287321400	107740800	287321400	107740800	287321400
1	108601900	289279600	108111200	288446800	108111300	288446700	108111300	288446800	108056600	288279800	108056600	288279700	108056600	288279800
2	109371800	292306700	108775000	291545500	108775200	291545800	108775100	291545700	108730600	291296800	108730700	291297100	108730700	291296900
3	110176200	295521800	109518700	294729400	109518800	294729100	109518800	294729200	109483900	294497400	109484000	294497200	109484000	294497300
4	110948200	298151900	110259100	297339200	110259200	297338800	110259200	297339000	110228000	297117200	110228100	297116900	110228000	297117000
5	111713200	300477400	111006800	299650900	111006900	299650600	111006900	299650800	110976300	299433100	110976400	299432800	110976300	299433000
6	112482100	302653400	111765400	301816700	111765500	301816400	111765400	301816500	111734000	301599100	111734100	301598900	111734000	301599000
7	113259200	304761500	112535700	303916500	112535800	303916200	112535700	303916300	112502700	303696700	112502800	303696600	112502700	303696600
8	114046300	306843800	113317600	305991000	113317700	305990800	113317600	305990900	113282500	305767700	113282600	305767600	113282600	305767700
9	114843900	308920800	114110900	308060500	114111000	308060400	114110900	308060500	114073500	307832900	114073600	307832900	114073500	307832900
10	115652200	311002000	114915300	310134200	114915400	310134000	114915400	310134100	114875400	309902000	114875500	309901900	114875400	309901900

Table 4 Sensitivity analysis results for final consumption, gross investment and final demand

Years	Benchmark		s_1						s_2					
			sigma = 0.5218		sigma = 0.6262		sigma = 0.4174		sigma = 0.5218		sigma = 0.6262		sigma = 0.4174	
	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre
	Final consumption													
0	1.037	1.044	1.038	1.044	1.038	1.044	1.038	1.044	1.038	1.044	1.038	1.044	1.038	1.044
1	1.047	1.056	1.043	1.057	1.043	1.057	1.043	1.057	1.042	1.054	1.042	1.054	1.042	1.054
2	1.055	1.064	1.052	1.066	1.052	1.065	1.052	1.065	1.051	1.062	1.051	1.062	1.051	1.062
3	1.063	1.072	1.061	1.073	1.061	1.073	1.061	1.073	1.059	1.07	1.059	1.07	1.059	1.07
4	1.072	1.081	1.069	1.082	1.069	1.082	1.069	1.082	1.067	1.079	1.067	1.079	1.067	1.079
5	1.081	1.091	1.078	1.092	1.078	1.092	1.078	1.092	1.077	1.089	1.077	1.089	1.077	1.089
6	1.09	1.101	1.088	1.103	1.088	1.103	1.088	1.103	1.086	1.099	1.086	1.099	1.086	1.099
7	1.1	1.112	1.097	1.113	1.097	1.113	1.097	1.113	1.095	1.11	1.095	1.11	1.095	1.11
8	1.109	1.123	1.107	1.124	1.107	1.124	1.107	1.124	1.105	1.121	1.105	1.121	1.105	1.121
9	1.119	1.134	1.117	1.136	1.117	1.136	1.117	1.136	1.115	1.132	1.115	1.132	1.115	1.132
10	1.129	1.146	1.127	1.147	1.127	1.147	1.127	1.147	1.124	1.144	1.124	1.144	1.124	1.144

(continued)

Table 4 (continued)

Years	Benchmark		s_1						s_2					
			sigma = 0.5218		sigma = 0.6262		sigma = 0.4174		sigma = 0.5218		sigma = 0.6262		sigma = 0.4174	
	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre
	Gross investment													
0	1.059	0.899	1.051	0.899	1.051	0.899	1.051	0.899	1.052	0.899	1.052	0.899	1.052	0.899
1	1.065	0.876	1.048	0.876	1.048	0.876	1.048	0.876	1.051	0.876	1.051	0.876	1.051	0.876
2	1.070	0.853	1.062	0.853	1.062	0.853	1.062	0.853	1.064	0.853	1.064	0.853	1.064	0.853
3	1.075	0.839	1.072	0.839	1.072	0.839	1.072	0.839	1.073	0.839	1.073	0.839	1.073	0.839
4	1.082	0.834	1.081	0.835	1.081	0.835	1.081	0.835	1.082	0.834	1.082	0.834	1.082	0.834
5	1.089	0.835	1.090	0.836	1.090	0.836	1.090	0.836	1.090	0.835	1.090	0.835	1.090	0.835
6	1.096	0.839	1.097	0.840	1.097	0.840	1.097	0.840	1.098	0.839	1.098	0.839	1.098	0.839
7	1.103	0.844	1.105	0.845	1.105	0.845	1.105	0.845	1.105	0.844	1.105	0.844	1.105	0.844
8	1.110	0.850	1.112	0.851	1.112	0.851	1.112	0.851	1.112	0.849	1.112	0.849	1.112	0.849
9	1.117	0.856	1.119	0.857	1.119	0.857	1.119	0.857	1.119	0.855	1.119	0.855	1.119	0.855
10	1.124	0.862	1.125	0.863	1.125	0.863	1.125	0.863	1.126	0.862	1.126	0.862	1.126	0.862

(continued)

Table 4 (continued)

Years	Benchmark		s_1						s_2					
			sigma = 0.5218		sigma = 0.6262		sigma = 0.4174		sigma = 0.5218		sigma = 0.6262		sigma = 0.4174	
	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre	South Islands	North Centre
	Final demand													
0	1.0335	1.0048	1.0323	1.0048	1.0323	1.0048	1.0323	1.0048	1.0325	1.0048	1.0325	1.0048	1.0325	1.0048
1	1.0400	1.0070	1.0338	1.0103	1.0338	1.0103	1.0338	1.0103	1.0348	1.0070	1.0348	1.0070	1.0348	1.0070
2	1.0453	1.0068	1.0415	1.0103	1.0415	1.0100	1.0415	1.0100	1.0423	1.0068	1.0423	1.0068	1.0423	1.0068
3	1.0500	1.0078	1.0483	1.0110	1.0483	1.0110	1.0483	1.0110	1.0485	1.0078	1.0485	1.0078	1.0485	1.0078
4	1.0560	1.0123	1.0545	1.0153	1.0545	1.0153	1.0545	1.0153	1.0548	1.0118	1.0548	1.0118	1.0548	1.0118
5	1.0620	1.0180	1.0610	1.0215	1.0610	1.0215	1.0610	1.0215	1.0613	1.0180	1.0613	1.0180	1.0613	1.0180
6	1.0680	1.0250	1.0668	1.0288	1.0668	1.0288	1.0668	1.0288	1.0675	1.0250	1.0675	1.0250	1.0675	1.0250
7	1.0738	1.0325	1.0730	1.0360	1.0730	1.0360	1.0730	1.0360	1.0730	1.0320	1.0730	1.0320	1.0730	1.0320
8	1.0798	1.0403	1.0788	1.0438	1.0788	1.0438	1.0788	1.0438	1.0793	1.0395	1.0793	1.0395	1.0793	1.0395
9	1.0860	1.0475	1.0850	1.0518	1.0850	1.0518	1.0850	1.0518	1.0850	1.0473	1.0850	1.0473	1.0850	1.0473
10	1.0918	1.0555	1.0905	1.0595	1.0905	1.0595	1.0905	1.0595	1.0910	1.0555	1.0910	1.0555	1.0910	1.0555

the cut of the regional tax on value added by activities. This result is consistent with several studies on double dividend (e.g. Takeda 2007), according to which the combination of environmental taxation and the reduction in capital taxes improves welfare. Thus if we concentrate on the benefits connected with environmental policy, the introduction of a tax on CO_2 emissions by commodity, with a progressive structure and a convenient distribution of the tax revenue, i.e. reduction of income taxes and regional value added taxes, allows for the attainment of both the green and the blue dividends at regional level.

This phenomenon can be considered as an actual second dividend since it is confirmed by the performance of the tax burden index over time. We considered the tax burden on the economic system and derived a measure of the effectiveness of government action within the economic system. This allows the achievement of a second blue dividend in the first scenario both at national and regional level.

The consideration that the result depends at a greater extent on the distinct peculiarities of technology and behavioral habits in the two regions of the national economy encourages further attempts in this direction. However the sensitivity analysis confirms the results.

Appendix 1

Dynamic CGE model specification

The dynamic CGE model developed in this paper is calibrated on the SAM integrated with environmental data. It is solved using the GAMS (General Algebraic Modeling System) software to find the equilibrium prices, quantities and incomes over the time.

Given the structure of the economy described by the SAM, to determine prices and quantities which maximize producers' profits and consumers' utility, we solve the Arrow-Debreu (1954) problem as an optimization problem of the consumer subject to income, technology and feasibility constraints. When programming on GAMS usually, this maximization problem is turned into a Mixed Complimentary Problem (MCP) and solved (solver used MILES) as a system of non-linear equation. In our model, the optimization problem for all the consumers (Böhringer et al. 1997) has been settled as:

$$\max \sum_{t=0}^{T} \left(\frac{1}{1+\rho} \right)^{t} u\left[C_t\right] \tag{4}$$

subject to:

$$C_t = x\left(K_t, L_t, M_t, Ta_t\right) - I_t - E_t \tag{5}$$

$$K_{t+1} = (1-\delta)K_t + I_t \tag{6}$$

The first order conditions deriving from this maximization problem are:

$$P_t = \left(\frac{1}{1+\rho}\right)^t \frac{\delta u\,(C_t)}{\delta C_t} \tag{7}$$

$$PK_t = (1-\delta)PK_{t+1} + P_t \frac{\delta x\,(K_t, L_t, M_t, Ta_t)}{\delta K_t} \tag{8}$$

$$P_t = PK_{t+1} \tag{9}$$

Than the corresponding mixed complimentary problem can be formulated as a sequence of market clearing, zero profit and budget constraint conditions.

Market clearing conditions holds for all commodities and primary factors markets. Analytically, we can summarize the conditions as follow:

$$X_t \geq B_t, d\,(P_t, RA) + I_t + E_t,\ P_t \geq 0,\ \ P_t\,(X_t - B_t, d\,(P_t, RA) - I_t - E_t) = 0 \tag{10}$$

$$L_t \geq X_t \frac{\delta C\,(RK_t, PL_t, PM_t, Ta_t)}{\delta PL_t},$$
$$PL_t \geq 0,\ PL_t \left(L_t - X_t \frac{\delta C\,(RK_t, PL_t, PM_t, Ta_t)}{\delta PL_t}\right) = 0 \tag{11}$$

$$K_t \geq X_t \frac{\delta C\,(RK_t, PL_t, PM_t, Ta_t)}{\delta RK_t},$$
$$RK_t \geq 0,\ \ RK_t \left(K_t - X_t \frac{\delta C\,(RK_t, PL_t, PM_t, Ta_t)}{\delta RK_t}\right) = 0 \tag{12}$$

$$M_t \geq X_t \frac{\delta C\,(RK_t, PL_t, PM_t, Ta_t)}{\delta PM_t},$$
$$PM_t \geq 0,\ PM_t \left(K_t - X_t \frac{\delta C\,(RK_t, PL_t, PM_t, Ta_t)}{\delta PM_t}\right) = 0 \tag{13}$$

Zero profit conditions posits that total supply in each commodity market is determined by the perfect competitive market condition, that is to say, price equals average total cost (profit are zero). In a general equilibrium model, the price that clear the market (demand equals to supply) also equals average total costs for each commodity. Analytically, we can summarize the conditions as follow:

$$P_t \geq PK_{t+1},\ I_t \geq 0,\quad I_t\,(P_t - PK_{t+1}) = 0 \tag{14}$$

$$PK_t \geq RK_t + (1-\delta)\,PK_{t+1},\ K_t \geq 0,\ K_t(PK_t - RK_t - (1-\delta)\,PK_{t+1} = 0 \tag{15}$$

$$C\,(RK_t, PL_t, PM_t, Ta_t) \geq P_t,\ X_t \geq 0,\ X_t\,(C\,(RK_t, PL_t, PM_t, Ta_t) - P_t) = 0 \tag{16}$$

Income balance conditions derive from the budget constraint:

$$RA \geq PK_0K_0 + \sum_{t=0}^{T}(PL_tL_t + PM_tM_t - Ta_t) - PK_{t+1}K_{t+1}, \; RA \geq 0 \qquad (17)$$

The variables are:

t	Time periods
T	Terminal period
ρ	Individual time-preference parameter
u	Utility
C_t	Consumption in period t
x	Production function
X_t	Total output in period t
K_t	Capital in period t
L_t	Labour in period t
M_t	Imports in period t
Ta_t	All taxes payed by sectors in period t
I_t	Investment in period t
E_t	Exports in period t
δ	Capital depreciation rate
γ	interest rate
P_t	Price of output in period t
d	Demand function
PK_t	Price of capital in period t
RK_t	Rental of capital in period t
PL_t	Wage in period t
PM_t	Price of imports in period t
RA	Consumer's disposable income

Appendix 2

Results from sensitivity analysis

See Tables 3 and 4.

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