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Simulations with a General Equilibrium Model of the Italian Economy

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Summary

A dynamic general equilibrium model of the Italian economy is used to assess the impact of carbon taxation (or auctioned carbon permits), where additional revenue is used to cut either existing taxes on labour or on capital income. Simulation results do not support the existence of the so-called "double dividend" when labour taxes are reduced, whereas lower tax rates on capital have mild positive effects on growth and welfare, with progressivity properties on income distribution. These findings hinge on the assumptions of open economy, given world interest rate, and capital mobility.

Keywords: Applied general equilibrium models, double dividend, environmental taxation, Italy

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1. Introduction

The Kyoto Protocol specifies targets for emissions of carbon dioxide and other greenhouse gases, to be reached by signatory countries in the period 2008-2012. National governments are substantially free to choose the specific domestic initiatives that could achieve the prescribed objective (for Italy, see Montini (2000)), determining how "pollution rights" are explicitly or implicitly distributed within each country (Bohm (2000)).

One policy option that has been much discussed in scientific and political debates is the use of carbon tax (or auctioned carbon permits) revenues for reducing distortionary labour income taxation. It is often argued that a "double dividend" could be reaped in this way: a better environment and a lower level of unemployment. The double dividend hypothesis in its weak form proposes that this revenue-neutral fiscal policy can reduce the overall cost of controlling greenhouse emissions. The strong form of the double dividend hypothesis asserts that not only environmental quality but also non-environmental welfare could be improved.

In their seminal paper, Bovenberg and De Mooij (1994) have shown, in a simple general equilibrium model, that the double dividend hypothesis, in its strong form, does not generally hold. This is because labour supply is driven by real, not nominal, wages, and the tax swap amounts to replacing explicit labour taxes by higher implicit labour taxes (indirect taxes that reduce the purchasing power), thereby exacerbating distortions and eroding the tax base. This contribution has triggered a substantial body of literature, recently summarized by Bovenberg (1999), based on both theoretical and applied models (e.g., Schwartz and Repetto (2000), Parry and Bento (2000), Kahn and Farmer (1999))[1].

However, although there is now a vast literature on the double dividend issue, most of the literature has focused on labour tax recycling, disregarding alternative redistribution

[1] Some contributions explicitly consider the possible existence of involuntary unemployment, pointing out that the interest in this issue (especially in Europe) springs mainly from the existence of high and persistent unemployment. These papers typically find that a tax reform alleviates unemployment if the tax burden is shifted away from workers to the unemployed, making the formal labour sector relatively more attractive (Bovenberg and van der Ploeg (1994), Schneider (1997), Scholz (1998), Koskela and Schöb (1998), Marsiliani and Rengstöm (2000a)).

schemes based on other distorted markets, like those of capital goods (a notable exception is Jorgenson and Wilcoxen (1995)). This is most surprising, since there are significant contributions, in growth theory, showing that capital taxation may have substantial effects on growth rates, consumption and welfare. These include both theoretical (e.g., Lucas (1990), Rebelo (1991)) and computational models (Auerbach and Kotlikoff (1987))[2]. The usefulness of these models for policy analysis is, however, limited by the adoption of rather unrealistic assumptions. For example, the models in this tradition usually consider a closed economy, where domestic savings generate all the capital stock[3].

Also the theoretical models in the double dividend literature adopt simplifying assumptions, to make the analysis tractable. Typical hypotheses are: existence of only two consumption goods (e.g., a "clean" and a "dirty" commodity), no savings, simplified tax structure, closed economy. If a more complex model structure is introduced, there are other mechanisms through which a double dividend may emerge[4]. As stated in a recent IPCC report (2001): "it is unclear whether the empirical findings of the interaction effect are due more to the assumptions invoked for tractable general equilibrium analysis than to real-world considerations".

A more realistic analysis of the different taxation schemes rely on the use of numerical models and simulation experiments, so it is possible that some findings may not be general but contingent on the specific structure of a particular economy. Econometric (e.g., Carraro, Galeotti and Gallo (1996)) and Applied General Equilibrium models have been used to this purpose[5].

One advantage of using AGE models in this context is their explicit accounting of general equilibrium interactions, and the possibility to "isolate" the impact of fiscal policies from

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[2] Daveri and Tabelllini (1997) show also that high labour taxes, when real wages are rigid, may slow down economic growth through labour/capital substitution, which implies a lower marginal productivity of capital.

[3] See, however, Sen and Turnovsky (1990).

[4] A green tax reform could, for instance, shift the composition of the aggregated demand towards labour-intensive goods and services. Also the saving behaviour of households, and the consequent aggregate supply pattern, would be affected, and if domestic and foreign goods are imperfect substitutes, changes in the terms of traded could be induced.

[5] Many of these models highlight the existence of a positive double dividend effect, larger than suggested by the theory.

the impact of other shocks. Since theoretical studies of the double dividend hypothesis are also rooted on general equilibrium effects, qualitative findings of AGE models are directly comparable with those obtained with purely theoretical models.

Early attempts in this direction include simulations of carbon taxation with static single-country models (Bussolo and Pinelli (2001), Edwards (1996, 1998), Harrison and Kriström (1998), Pench (1998, 2001), Stampini (2001)), while dynamic and multi-country models have appeared more recently (Jensen (1998), Springer (1998), Rutherford, Böhringer and Pahlke (1998), Pench (1999), Böhringer (1998, 1999), Böhringer, Jespen and Rutherford (2000))[6].

In this context, it is often necessary to depart from the basic Arrow-Debreu paradigm of fixed endowments, closed economy and perfectly competitive markets. By explicitly considering labour markets imperfections, for example, one key ingredient of the debate on the double dividend hypothesis can be embodied into the model (Bye (1998)). Another useful amendment may be the explicit consideration of international capital movements (Roson (1998), Springer (1999)).

Policy assessment can be more effectively carried out if several household classes (distinguished by income levels or other characteristics) are considered in the models. As pointed out by Bovenberg (1999, ibid.), the existence of non-environmental distortions raises the question why governments have not reformed their tax systems to address these inefficiencies, suggesting that distributional considerations may have prevented the governments from doing this. With a disaggregated representation of the final consumption sector of the economy, AGE models can shed light in this direction, showing the distributional impact of alternative policies alongside the efficiency effects[7].

In our opinion, this aspect is especially important when dealing with capital tax reductions. Carbon taxes are generally regarded as being regressive, since higher energy prices imply more expensive basic services, like heating, lightning and transportation.

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[6] Simplified general equilibrium models have also been merged with climate and energy models in the class of Integrated Assessment Models (e.g., Nordhaus and Yang (1996), Edwards and Hutton (1999), Roson (2000)).

Capital tax recycling may then be thought to aggravate the regressivity effect (but, as it will be shown later, this may not be the case).

In this paper, a dynamic general equilibrium model of the Italian economy is illustrated and used to simulate the introduction of "tax swap" schemes, in the context of a national carbon reduction policy, aimed at reducing CO_2 emissions at the level specified by the Kyoto protocol (for Italy, 97.5% of 1990 emissions). In particular, the double dividend case of labour tax cuts will be compared with the alternative case of capital tax cuts.

As it is typical in most applied models of this type, CO_2 emissions are seen as a by-product of the consumption of energy products, both at the intermediate and at the final consumption stage. Therefore, the emissions reduction target is achieved by introducing a tax (explicitly or implicitly, as in the case of a national emission permits market[8]) on energy consumption[9], with varying rates, depending on the carbon content.

Thirty industries, one public sector, one foreign sector, and six representative households, distinguished by income class, are considered. Each household class is represented by a consumer, who maximizes his/her discounted intertemporal utility over an infinite horizon. Ten periods are considered, and it is assumed that emissions reduction measures are introduced in the third period, fixing a ceiling on total CO_2 emissions at the national level for all subsequent times. Each representative consumer has rational expectations and anticipates, since the first period, the shock occurring in the third period.

The rest of the paper is organized as follows. In the next section, the overall structure of the model and the general equilibrium conditions, which must be verified within each time period, will be presented (the model equations are reported in an appendix).

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[7] Marsiliani and Rengstöm (2000b) investigate the possible causal feedback from wealth equality to environmental protection, noticing that "egalitarian" countries generally have more stringent environmental policies.

[8] One important difference is that carbon taxes may need to be adjusted over time in order to meet the national target. Here, the model automatically does this.

[9] This means that reductions in the pollution intensity of energy consumption are not considered (primarily because of lack of data at a sufficiently disaggregated level). Substitution between different energy factors, and "end-of-pipe" abatement could reduce emissions per unit of energy input (on this, see Fullerton, Hong and Metcalf (2000)). Notice also that, because of the Leontief production technology, emission taxes are equivalent here to output taxes, with industry-variable rates.

Subsequently, the modelling of imperfections in the labour and capital markets will be illustrated. Intertemporal optimization and the consistency between static and dynamic optimality conditions will be discussed in the fourth section. Section five is devoted to presenting and commenting some results obtained by numerical simulations. Some concluding remarks will be drawn in the final section.

2. Model structure and intra-temporal equilibrium

The model simulates a dynamic path for the Italian economy as a sequence of static equilibria. This means that, on the basis of a capital stock owned by the households and the level of investments, the model computes a series of equilibria for all time periods, in which: demand equals supply in all markets for goods and services, including primary resources (taking exogenously some market imperfections); there are no extra profits in any industry (free entry), consumers maximize utility on the basis of an income constraint, the public sector has no budget surplus or deficit, and the foreign trade balance (including capital services) is in equilibrium. The link between two subsequent equilibria is given by the condition of capital adjustment: from one period to the next, a fixed share of the capital stock is lost by depreciation[10], whereas the capital is augmented through the investment. It is assumed that there are no exogenous growth factors like changes in the labour force, or in the human capital, or in the technological progress[11].

In some periods, an exogenous constraint on total emissions of carbon dioxide is imposed. CO_2 emissions are assumed to be proportional to the input of energy in

[10] The capital formation process is driven by two parameters: a reference real interest rate, which is assumed here 3.5%, and a rate of annual capital depreciation, which is here 5%.

[11] In other words, we abstract here from those exogenous processes, which may affect the economic growth, in addition to investment and capital formation. Observe, however, that environmental policies may well influence investment in research, and the introduction of cleaner technologies. This aspect is not considered here, because of lack of data: in a multisectoral model, this would require a complete specification of the new technologies and an assessment of its impact on the productivity of factors.

production and consumption[12]; as a consequence, the constraint on emissions translates into an implicit tax on energy inputs or, equivalently, on a rent on emission rights.

The structure of the model within each time period is similar to many static CGE/AGE models, with the exception of the modelling of primary markets, as it will be illustrated in the next section. Share parameters in production and utility functions are estimated via calibration, using a base year Social Accounting Matrix, whereas elasticity parameters are, in most cases, adopted from econometric studies (Roson (1998, ibid.)). The SAM matrix for the Italian economy is provided by Accardo and Cavalletti (2000) for the year 1990, and has been updated to the year 1997 through a maximum likelihood estimation procedure[13].

The following principles have been adopted in the model calibration:

- all investments are interpreted as carried out, directly or indirectly, by the households. So, for example, retained earnings by firms are distributed to the households, who subsequently re-invest in capital assets.
- the trade deficit or surplus existing in the base year is interpreted as an income transfer assigned to the households, proportional to the transfers obtained from the public sector. Both the public sector and the representative foreign consumer are assumed to devote a fixed share of their revenues to transfers to the households.
- investment in bonds and interest payments on the public debt are interpreted as income transfers. Consequently, both the households and the representative foreign agent are assumed to receive transfers (possibly negative) equal to the difference between interest revenues and net investment in bonds.

The model parameters are calibrated such that the model replicates the values of the SAM matrix as the outcome of a general equilibrium allocation in the base year. Furthermore, the model computes a series of equilibria for the subsequent periods, assuming that all

[12] The amount of emissions generated per unit of energy input is sector-specific. Parameters on emissions by activity have been estimated from the CORINAIR data - base.

[13] This procedure is based on the minimization of the sum of squared differences between corresponding cells of the two matrices, with constraints on several macroeconomic aggregates (for which information is available on official statistics), and with balance constraints on supply/demand of each good, and on the budget of each sector.

representative consumers carry out dynamic optimization under perfect information, in the absence of any exogenous shock (including policy changes). In this way, a "baseline trend" or a "business as usual" path is generated, against which policy impact simulations can be compared.

Each of the thirty industries is modelled through a representative firm, which allocates production factors on the basis of a cost minimization principle. A homogeneous labour factor is combined with a homogeneous and perfectly mobile capital factor into a value added composite, according to a CES function with industry-specific values for the substitution elasticity. The value added composite is then combined in fixed proportions with intermediate inputs in the production process. Each intermediate input is itself a composite of domestically produced and imported commodities, where the two types of good are regarded as imperfect substitutes into a CES function with variable elasticity parameters.

Six household classes are considered, on the basis of their 1990 income levels[14], and each class is modelled through a representative consumer. This agent possesses a stock of capital, determined by past savings, and a stock of labour resources. Labour is entirely allocated to production, although the stock is adjusted on the basis of an exogenously given "pseudo" supply curve. Since capital and labour are both homogeneous and mobile, the factor demand generated by the firms is allocated to the different household groups in fixed shares, reflecting the base year relative supply.

Households-consumers also receive income transfers from the public sector, and possibly from the rest of the world. Income is used to buy a composite consumption commodity and an investment good. The income share devoted to consumption or saving is determined by intertemporal optimization, but it is taken as a given within each time period. The composite consumption commodity is obtained by a Cobb-Douglas combination of goods and services, where all items are in turn CES composites of

[14] The classes are: F18 (households with annual income lower than 18 millions lire in the year 1990, corresponding to the 19.8 percentile), F27 (income between 18 and 27 millions, 19.8 – 39.8 percentile), F36 (income between 27 and 36 millions, 39.8 – 55.9 percentile), F45 (income between 36 and 45 millions, 55.9 – 67.6 percentile), F54

imports and domestic goods. The investment commodity is produced by a final demand sector, allocating the demand (in fixed proportions) to industries producing durable and investment goods.

The public sector finances its expenditure with taxes on primary factors supply[15], on value added, on domestic production, on imports, and on consumption. Tax revenue is allocated between the production of the industry "Non market services" and transfers to the households. In all simulation exercises illustrated later in this paper, an exogenous constraint ensures that the level of public expenditure remains constant in all periods.

A representative foreign agent generates a demand for exported domestic goods and services, which are imperfect substitutes with foreign goods and services[16]. In addition, positive or negative income transfers to the domestic households are considered, as a result of a base year trade deficit or surplus. The level of these transfers is kept fixed.

When supply and demand equal in all markets, when production factors are allocated so as to minimize costs in all industries, and when the representative consumers efficiently allocate their budgets, the model reaches a short-term equilibrium. The equilibrium allocation may change between periods because of: changes in the endowment of capital goods (due to capital accumulation), changes in the endowment of labour (due to labour supply adjustments), and changes in the policy regime.

In the latter case we consider the imposition of a national constraint on carbon dioxide emissions. Within the model, this constraint translates into an exogenously adjusted carbon tax, with simultaneous re-determination of other taxes or, equivalently, into the existence of an additional production factor (the emissions) owned by the households. This additional factor may be considered to be in excess supply (that is, with a zero price) when the constraint is not binding. The basic difference between the various schemes that

(income between 45 and 54 millions, 67.6 – 77.9 percentile), FOV (income above 54 millions).

15 Taxation is proportional, but the tax rates on labour and capital supply do vary by household type, depending on base income levels.

16 The two types of good enter in a CES composite. The industry-specific elasticities of substitution in this function are derived from econometrically estimated export demand elasticities.

are considered here regards the different ways in which the tax revenue, or the emission rights, are allocated.

3. Primary factors markets

Traditionally, in most Applied General Equilibrium models the capital is assumed to be in fixed supply, with endogenous determination of the interest rate. This hypothesis clearly contradicts the Small Open Economy assumption adopted throughout in this model, where the price of all imported goods, which is normalized to one, is taken as a given.

It is then more natural to assume that the interest rate, alongside world commodity prices, is imposed from abroad[17]. In this case, the price of the capital factor is fixed exogenously and domestic demand and supply of capital may not match. When domestic supply falls short of demand, capital services may be imported from the rest of the world[18]. This element must be taken into account in the determination of the trade balance, which must be in equilibrium within each time period.

Another main difference with the traditional approach followed in many AGE models concerns the modelling of the labour market. Here, wages are not set by perfect competition but by a "wage curve", linking real wages to unemployment levels (thereby accounting for a variety of labour market imperfections). Following Blanchflower and Oswald (1994), we use for the Italian economy a wage curve with a rather rigid real wage[19]:

[17] Some other CGE models adopt the alternative assumption of imperfect substitutability between domestic and foreign capital goods, allowing for non-equality of domestic and international interest rates.

[18] International capital flows are modelled here through the inclusion of two fictitious industries. One industry produces capital goods with only one input: an imported good. The second industry produces "imports", with the absorption of capital services. Complementarity conditions ensure that only one industry is active in equilibrium. For example, when capital services are imported, these services are "paid" with a trade surplus in all other goods. One fictitious industry, therefore, generates the extra demand of imports that must be matched by additional exports, to keep the trade balance in equilibrium.

[19] The elasticity parameter has been estimated econometrically.

$$U = U_B \left(\frac{\sum_i \omega_i p_i}{w} \right)^{10} \quad \sum_i \omega_i = 1$$
$$L = L_B \left(\frac{1-U}{1-U_B} \right) \tag{1}$$

Where: L and U are labour supply (endowment) and unemployment level; the subscript B refers to calibration values (where all prices are equal to one); ω stand for weights in a consumer price index; w and p are wage and market prices, respectively.

Because of the auxiliary equation (1) the model endogenously generates involuntary unemployment.

4. Dynamic optimization

The sequence of short-term equilibria described so far is contingent on the marginal propensity to saving of each representative consumer in each period. This parameter is endogenously determined in the model as a result of a Ramsey intertemporal utility maximization problem.

Ruling out negative investment, the maximization of a discounted sum of utility functions provides the following intra-temporal optimality rule, expressed as a complementarity condition:

$$I_t^h \left(U'(c_t^h) \frac{q_t}{p_t^h} - \lambda_t^h \right) = 0$$
$$I_t^h \geq 0 \quad U'(c_t^h) \frac{q_t}{p_t^h} - \lambda_t^h \geq 0 \tag{2}$$

Where: indexes h and t refer to household class and time, respectively; I stands for investment and c for consumption (determining temporal utility U); p is a consumption price index for household type h, q is the price of the investment good and λ is a costate variable, corresponding to the (undiscounted) marginal utility of capital.

Inter-temporal optimality provides a recursive definition for the costate variable:

$$\lambda_t^h = \alpha^h U'(c_{t+1}^h) \frac{r_t}{p_{t+1}^h} + \delta \alpha^h \lambda_{t+1}^h \tag{3}$$

Where: α is the subjective utility discount factor (assumed to be time-invariant), r is the capital interest rate, and δ is a capital depreciation factor.

For each household type, the model solves a series of equations (2) and (3) on the basis of two terminal conditions. The first terminal condition is the initial value of the capital stock, which is observed in the base year. The second terminal condition fixes a value for the terminal costate variable assuming, as it is customary in most applied models, that the economy reaches a steady state balanced growth path after the last period considered. This implies that the last value of costate variable can be expressed as the present value of an infinite stream of constant marginal utilities:

$$\lambda_T^h = \frac{\alpha^h}{1-\alpha^h \delta} U'(c_h^{ss}) \frac{r_T}{p_T^h} \qquad (4)$$

The functional form adopted in the model for the intertemporal utility is linear logarithmic[20], with household-specific discount factors. These factors are determined when the model is calibrated and a baseline growth path is computed. This is because the SAM matrix, used to calibrate the model, provides information both on the initial capital stocks and on investment levels in the first period. Contrary to standard Ramsey models, where investments are endogenous and discount factors are preference parameters, the information on initial investments allows the endogenous determination of discount factors[21]. However, when the model is run to generate counterfactual simulations, there is no need to replicate calibration values, so the estimated discount rates become exogenous. In principle, dynamic optimization could be carried out simultaneously with the determination of temporary equilibria. The complexity of the present model, however, makes this option computationally infeasible. The model is then solved iteratively in the following way. First a sequence of temporary equilibria is computed, taking a vector of

[20] For computational simplicity it is assumed that the argument of the logarithmic utility is the aggregate consumption level, instead of a nested CES quantity index.

[21] These range from 2.67% to 3.31%, increasing monotonically with household income levels. This phenomenon depends on the ratio of investment to capital income flows in the calibration SAM, which is indeed decreasing in income levels. One possible explanation rests on the existence of a possible inverse relationship between income and risk aversity. Another possible explanation is the existence of rents and imperfect competition, benefiting higher income households.

saving propensities per household and period as a given (these parameters are kept fixed to calibration values in the first run). This allows the determination of a set of variables, which are needed for intertemporal optimization: consumers' price indexes, investment prices and interest rates, as well as "exogenous income" (transfers and labour income, independent of capital wealth). The solution of the intertemporal program, expressed as a system of non-linear equations, allows the computation of optimal saving rates, which are used as an input for the re-determination of the sequence of temporary equilibria. The whole process is repeated until convergence[22].

5. Simulations

The model described above has been used in two simulation exercises. We consider the introduction of a carbon tax in the third period, with simultaneous adjustment of either taxes on the homogenous labour input, or of taxes on capital income. The carbon tax itself varies period by period, in order to meet the ceiling on national CO_2 emissions imposed by the Kyoto protocol. The tax reform is fully anticipated, since the first period, by all representative agents, and public expenditure, as well as income transfers to the households[23], is kept fixed in real terms.

The two simulation cases are compared against a baseline scenario. This scenario has been obtained by running the model from the calibration year onwards, using the same assumptions of the simulation exercises (e.g., in terms of public expenditure, kept constant by means of variable income taxes), but without any constraint on carbon emissions.

The interpretation of the very detailed output of the various simulations is possibly made easier by the identification of three major driving forces, shaping the results. First of all there is an *industry mix effect*, by which the structure of the economy is influenced by changes in intermediate and final demand patterns. These, in turn, are triggered by: (a)

[22] Dynamic properties of the convergence process are unknown, but convergence has been achieved in all simulation exercises, through the control of the speed of adjustment of the vector of saving propensities.

[23] Whereas constant public consumption is obtained by scaling revenue according to a specific cost index, transfers are constant when measured in terms of foreign currency.

higher relative price of energy intensive goods, (b) lower relative price of labour intensive productions when labour taxes are reduced, (c) demand shifting towards durable goods industries when savings are increased, (d) relative decline of export oriented industries when capital outflows support a trade deficit in domestic industries' products.

Both in the double dividend scenario (hereafter, DD) and in the capital tax cuts scenario (CC) the two industries displaying the strongest reduction of activity levels are the two most energy intensive industries: Energy (first period: -11.34% (DD) –11.39% (CC), last period: -17.43% (DD) –17.40% (CC)) and Chemicals (first period: -8.73% (DD) –8.76% (CC), last period: -12.16% (DD) –14.39% (CC)). However, whereas the growing industries are those associated with zero or negative carbon emissions when cuts in labour taxation are considered (Agriculture, +1.87% / +2.63%, Renting, +1.14% / +0.52%), cuts on capital income taxation stimulates investment and the growth of industries Building (+17.87% / 16.70%) and Agricultural and Industrial Machinery (+15.72% / +12.98%).

Figure 1 shows the relative impact on unemployment rates, by period, of the two policy options. Unemployment rises in both cases, although the CC scenario produces higher long-term unemployment rates and a sharper labour demand reduction immediately after the introduction of carbon taxation in the third period.

The gross cost of capital services is imposed by a fixed international interest rate, even if domestic returns on capital may vary as a consequence of changes in capital taxation. The introduction of carbon taxes has an inflationary effect, which is especially evident at the final consumption stage, causing an increase in nominal wages. In the double dividend situation, however, this effect is counteracted by labour tax cuts. Indeed, the relative price of labour to capital decreases in the steady state, relative to the baseline, by 2.56%, triggering labour/capital substitution. Since employment levels nonetheless decrease, this means that domestic industries exhibit, on average, lower activity levels.

The latter effect is due to a loss of competitiveness induced by higher production costs. By substituting domestic inputs with imported inputs, industries and consumers partly avoid the carbon tax, meaning that some carbon emissions (associated with the production of goods and services) are actually transferred abroad. The purchase of additional imports is financed by a capital outflow.

When revenues from carbon taxation are used to reduce capital taxes, the substitution effect works in the opposite direction (relative labour cost rises in the long term by 1.57%). Furthermore, the contraction of domestic activities is more severe, because production costs are higher (tax cuts have no impact on the production side since the gross rental cost of capital is fixed) and higher domestic net yields on capital stimulate a significant growth in the stock of capital assets owned by the households, generating a larger capital outflow, which is used to finance more import purchases.

There are here two effects that mitigate the overall cost of carbon emission control, and both of them are stronger when capital taxes are reduced. First, we have the "carbon leakage" phenomenon, which means that reduced domestic emissions may cause higher emissions abroad (Lee and Roland-Holst (2000), Roson (2001)). Second, since foreign and domestic goods are imperfect substitutes, there are changes in the terms of trade, implying that foreign consumers actually bear part of the carbon tax burden[24].

On the final demand side, consumption levels depend on a *permanent income effect*, and on a *temporal profile effect*. The first refers to the possibility of allocating consumption over time by an appropriate choice of savings in each period. In this way consumption levels do not depend directly on current income but on the accumulated wealth (here represented by the capital stock), as well as on current and future (discounted) incomes. A positive (negative) shock raises the global wealth and shifts upward (downward) consumption levels in all periods, so that there exists a complete correspondence between welfare effects and wealth effects, if environmental quality is not taken into account.

[24] In this paper, we focus on a single country, ignoring international policy feedbacks. However, the Kyoto protocol imposes similar reductions in CO_2 emissions for most of the Italian trade partners; if foreign prices also rise, there would be less scope for substituting domestic products with imports, and a less significant impact on the terms of trade. The two effects mentioned above would then be smaller but still present, because (1) many countries have not accepted binding commitments on emissions reductions, and (2) conditions imposed on signatory countries are different.

To highlight the impact on welfare and wealth of the different policies, it is possible to look at the relative level of steady state consumption[25] for the different household classes, which is displayed in figure 2.

The figure clearly shows that there is no double dividend in the strong form, since all households exhibit non-environmental welfare losses, quite evenly distributed among the different income classes. By contrast, some consumers obtain welfare gains in the capital tax cuts scenario, although aggregate consumption rises by only 0.13%.

Remarkably, the distributional impact of capital tax reductions benefits lower income classes. This is mainly due to the presence of constant income transfers, which constitute a significant share of total revenues for low-income households, and to the existence of different discount factors. Since labour is homogeneous, the decline of labour income has a larger impact for wealthier classes, whereas capital income increases as a consequence of higher levels of the capital stock, as shown in figure 3.

Policy shocks affects consumption levels, but also change the time profile of consumption. This can be seen more clearly by combining equations (2) and (3), assuming that investment are positive and remembering that utility functions are logarithmic. This provides a condition, determining the growth of consumption levels between two subsequent periods:

$$\frac{c_{t+1}^h}{c_t^h} = \alpha^h \frac{p_t^h}{p_{t+1}^h}\left(\frac{r_t}{q_t} + \delta\frac{q_{t+1}}{q_t}\right) \qquad (5)$$

This equation highlight that the relative growth of consumption levels is driven by relative changes in consumption and investment prices.

The introduction of a carbon tax causes an inflationary push. However, whereas consumption prices are affected by direct taxation of energy consumption, investment prices are only indirectly affected by taxes on energy inputs in the production of investment goods. This means that the introduction of carbon taxation generally cause an

[25] This is possible because of the relatively short time length of the transitory period. Although the welfare of each representative consumer is an infinite sum of discounted logarithmic utilities, the constancy of consumption from the eleventh period onwards allow the transformation of the infinite series into a sum of eleven logarithmic terms, where the weight attached to the last term is much higher than the other ones.

immediate reduction of (relative) consumption levels, even when wealth effects are positive. In addition, there may be a reduction of the net interest rate. This also affects the consumption growth, both directly and through lower consumption and investment prices. Savings emerge from the difference between current income and consumption. Figure 4 shows how the *average* marginal propensity to consumption varies over time in the two regimes, in comparison to the benchmark case. Higher returns on capital create an incentive to save more in the CC scenario, whereas "consumption smoothing" implies, in the DD scenario, higher consumption propensities, rising over time.

5. Conclusion

In this paper, a dynamic general equilibrium model of the Italian economy has been used to assess the impact of alternative tax recycling schemes. At an aggregate level, results are in line with the theoretical literature on the "double dividend hypothesis". For example, we found that a double dividend scheme do not yield non-environmental welfare. Cuts on capital income taxes, on the other hand, have mild positive effects on long-term economic growth. This effect is, however, obtained through a mechanism different from the conventional growth theory. If the economy is open and the interest rate is fixed, capital demand by domestic industries is independent from domestic capital accumulation. Excess supply in the national market for capital factors, then, becomes a way to finance the purchase of imported goods. By using imported goods instead of domestic goods, the economy avoids the generation of carbon emissions in the production sector.

The simulated impact on the income distribution of the two recycling schemes is counter-intuitive, since labour tax cuts are found to be neutral, whereas capital tax cuts turn out to be progressive. To understand how this result emerges in the model, remember that each representative consumer has three sources of income: transfers, labour and capital income.

The first component is fixed by hypothesis. Its share in total income is larger for low-income classes, which are therefore more protected in case of negative shocks, as in the DD scenario. On the other hand, when labour tax *rates* are scaled down proportionally, the richer classes benefit relatively more. This mechanism offsets the former one, producing the distributional neutrality of the double dividend policy.

When capital taxes are cut, all classes are affected by a reduction of labour income, primarily due to the increase in the unemployment rate. In the model, this implies a reduction of the labour endowment for each representative consumer. Since neither the share of capital income in the total revenue, nor the capital tax rates are sufficiently differentiated among the different income classes, the net effect is a progressive one.

The simulation exercise suggests that capital tax recycling schemes are more effective than double dividend schemes. Furthermore, this policy is not a regressive one. This result has been obtained, however, by implicitly assuming that a reduction of employment affects symmetrically all income classes, and that all consumers have the same degree of access to foreign capital markets.

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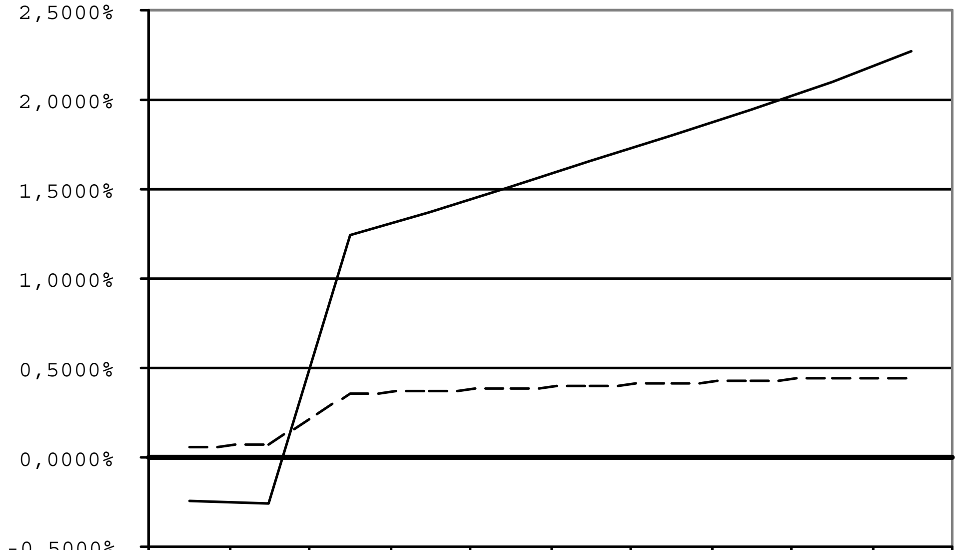
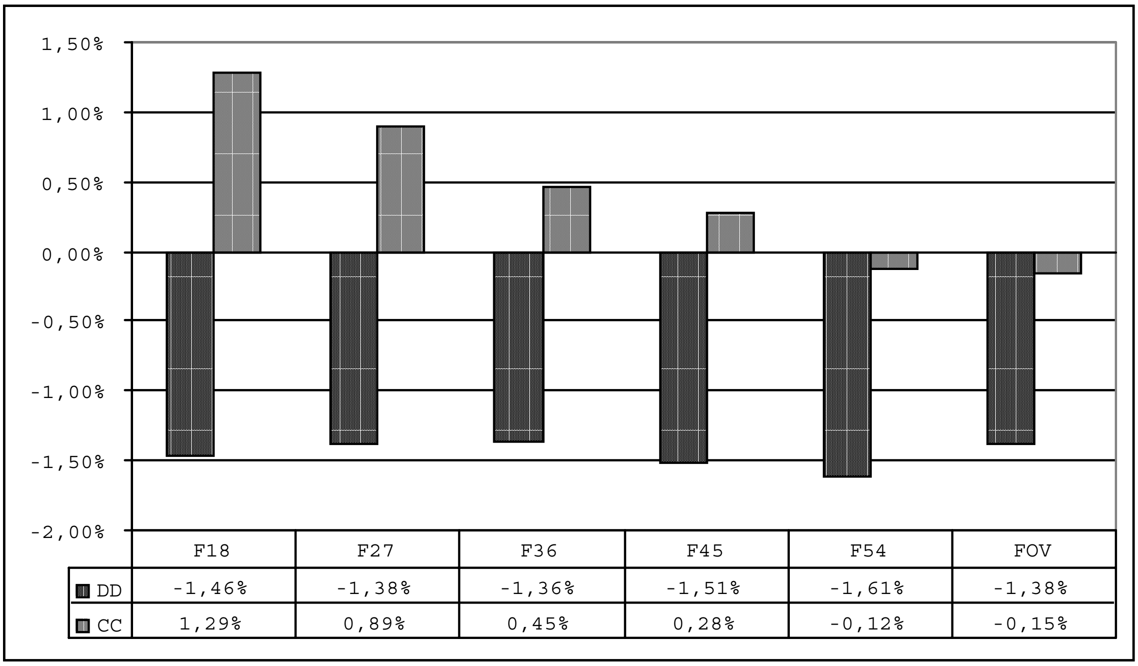


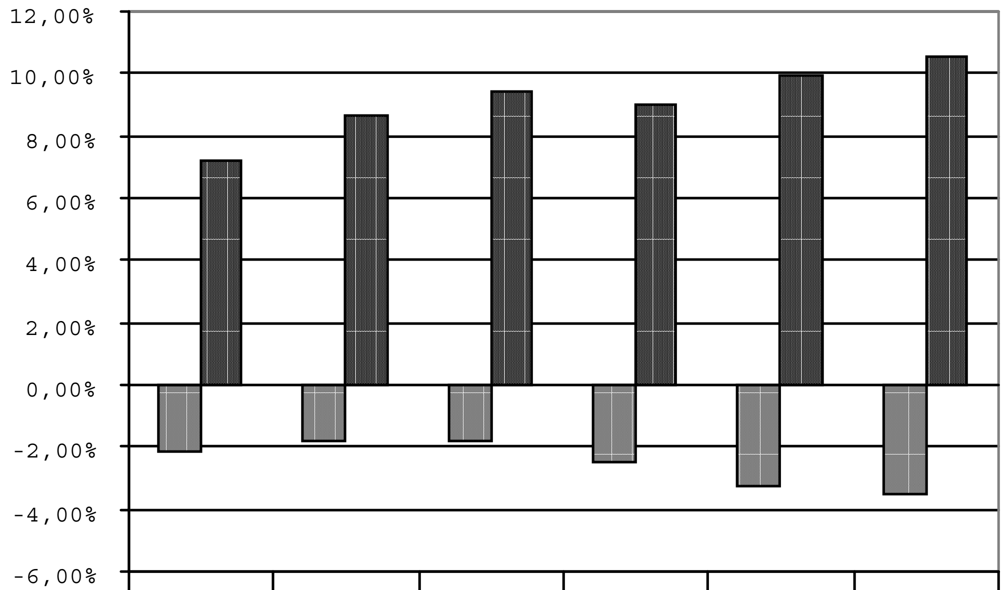
	1	2	3	4	5	6	7	8	9	10
DD	0,051	0,072	0,352	0,372	0,390	0,407	0,420	0,432	0,439	0,443
CC	-0,24	-0,25	1,247	1,376	1,511	1,651	1,797	1,949	2,106	2,270

Figure 1 – Relative variations of unemployment rates



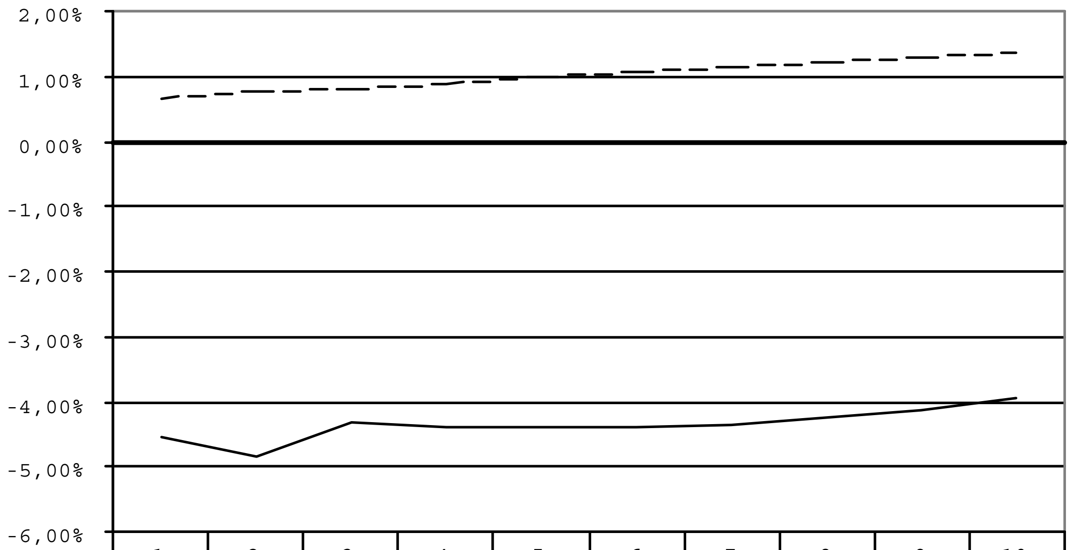
	F18	F27	F36	F45	F54	FOV
DD	-1,46%	-1,38%	-1,36%	-1,51%	-1,61%	-1,38%
CC	1,29%	0,89%	0,45%	0,28%	-0,12%	-0,15%

Figure 2 – Relative variation of steady state consumption by household class



	F18	F27	F36	F45	F54	FOV
DD	-2,17%	-1,84%	-1,82%	-2,45%	-3,26%	-3,49%
CC	7,19%	8,66%	9,42%	8,99%	9,95%	10,52%

Figure 3 – Variation of steady state capital stocks



	1	2	3	4	5	6	7	8	9	10
DD	0,65%	0,75%	0,81%	0,89%	0,97%	1,06%	1,14%	1,21%	1,29%	1,37%
CC	-4,53%	-4,82%	-4,32%	-4,38%	-4,40%	-4,39%	-4,34%	-4,25%	-4,13%	-3,96%

Figure 4 – Changes in marginal consumption propensity (averages)

APPENDIX

The Structure of the
Dynamic General Equilibrium Model

1. Notation

Production and utility functions are built as nested CES, Cobb-Douglas and Leontief functions. The following notation will be adopted:

$CES(x_1,\cdots,x_n) = \left(\sum x_i^{\rho}\right)^{1/\rho}$

$CD(x_1,\cdots,x_n) = \prod x_i^{\alpha_i} \quad \sum \alpha_i = 1$

$LEO(x_1,\cdots,x_n) = \min(a_1 x_1,\cdots,a_n x_n)$

The letters *i* and *j* will indicate the set of commodities and industries, *h* will refer to the set of households. Variables with a bar on top are exogenously given.

2. Static equilibrium equations

(A1) Domestic goods production functions of intermediate inputs, energy and value added

$x_d^i = LEO(x^{1i},\cdots,x^{ni},x^{ei},v^i)$

(A2) Energy input associated with pollution rights

$x^{ei} = LEO(\tilde{x}^{ei},pr^{ei})$

(A3) Supplied goods are Armington composites of domestic and imported goods

$x^i = CES(x_d^i,x_m^i)$

(A4) Value added is a composite of labour and capital

$v^i = CES(l^i,k^i)$

(A5) Primary factors supply has a fixed structure in terms of household contribution

$l = LEO(l^h)$

$k_d = LEO(k^h)$

(A6) Household utility (includes investment good)

$U^h = CD(CD(x^{1h},\cdots,x^{nh},x^{eh}),I^h)$

(A7) Household income (includes transfers and pollution rights rents)

$y^h = r\bar{k}^h + wl^h + trasf^h + p_{pr}pr^h$

(A7) Investment good composition
$I = LEO(x^{1I},\cdots,x^{nI},x^{eI})$

(A8) Public expenditure composition (fixed level)
$\overline{G} = CD(g, trasf)$

(A9) Public good composition
$g = LEO(x^{1g},\cdots,x^{ng},x^{eg})$

(A10) Export demand
$x^{ie} = e(p_d^i)$

(A11) Fixed world interest rate
$r = \bar{r}$

(A12) Trade balance constraint (includes capital flows, exogenous world prices and capital endowments)
$\sum \overline{p}_m^i x_m^i = \sum p_d^i x^{ie} + r(\sum_h \overline{k}^h - k)$

(A13) Labour supply (as a function of the unemployment rate and the real wage [nominal wage / consumers price index])
$l^h = l^h(u, w, cpi)$

Domestic prices are computed by equating prices and production costs.
Constant marginal tax rates are applied on the prices of: domestic supply levels, primary factors supply (differentiated by household), imports and total supply (VAT). Tax revenue finances the public expenditure.
Pollution rights are assigned to the households, but there may be excess supply (zero price) in the absence of environmental constraints.
In equilibrium, industrial supply equals intermediate and final demand (households' consumption, public demand, investment demand and exports). Markets for labour and capital clear, where the labour endowments are exogenously adjusted on the basis of the wage curve, and capital flows to/from abroad absorb excess demand or supply created by the fixed interest rate.

3. Dynamic Optimization Equations

Intertemporal optimization determines the saving rates, that is the shares of the investment good consumption in the households' budget (eq.A6). Each representative consumer maximizes an intertemporal utility function, which is a discounted sum of logarithmic sub-functions of aggregate consumption.
This problem gives raise to the following set of equations.

(A13) Marginal utility of consumption equals marginal utility of capital (costate variable)

$$\frac{1}{c_t^h}\frac{p_t^I}{p_t^{c,h}} = \lambda_t^h$$

(A14) Marginal utility of capital equals one-period discounted marginal utility of consumption (made possible by capital yield) and next period marginal utility of capital, diminished by depreciation

$$\lambda_t^h = \alpha^h\left(\frac{1}{c_{t+1}^h}\frac{r_{t+1}}{p_{t+1}^{c,h}} + \delta\lambda_{t+1}^h\right)$$

(A15) Capital accumulation

$$k_{t+1}^h = \delta k_t^h + I_t^h$$

(A16) Expenditure in consumption and investment equals capital and non-capital income

$$c_t^h p_t^{c,h} + I_t^h p_t^I = r_t k_t^h + y_t^h$$

(A17) Steady state consumption is defined under constant prices and capital stock (T stands for terminal period)

$$c_{ss}^h p_T^{c,h} + \delta k_{T+1}^h p_T^I = r_t k_{T+1}^h + y_T^h$$

(A18) Terminal condition. Last period costate variable is defined as a discounted sum of an infinite stream of marginal utility of (constant) steady state consumption

$$\lambda_T^h = \frac{\alpha^h}{1-\delta\alpha^h}\frac{1}{c_{ss}^h}\frac{r_T}{p_T^{c,h}}$$

(A19) The initial capital stock is given

$$k_1^h = \bar{k}_1^h$$

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