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On the Optimal Use of Revenues from a CO_2 Tax and the Importance of Labor Market Conditions

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Abstract

This paper focuses on the environmental, economic and budgetary impacts of a carbon tax in the presence of mixed recycling strategies and a detailed modelling of labor market conditions, both employment and involuntary unemployment. This focus matches the terms of the policy debate in many small energy-importing economies. The revenue-recycling policies that appear most promising are those that use carbon tax revenue to finance investment tax credits, reductions in social security contributions and reductions in personal income taxes. Although none of these mechanisms would individually lead to simultaneous improvements in the three margins, a mixture of the three would. Our sensitivity analysis suggests that labor markets conditions are a critical factor in determining the possibility of generating these positive effects. Ignoring labor supply responses, employment and unemployment effects leads to systematic underreporting of the three dividends and thereby undermines the political viability of environmental tax reform.

Keywords

carbon taxation, economic effects, budgetary effects, dividends, optimal recycling mix, dynamic general equilibrium, endogenous growth, endogenous unemployment

1. Introduction

Concerns about the health of labor markets, economic growth and unsustainable levels of public indebtedness have been at the center of policy discussion in the European Union (EU). Unemployment in the Euro area was 10.9% of the labor force in 2015. In Greece and Spain, unemployment rates have been substantially higher, 24.6% and 22.1%, respectively, while in Portugal and Italy, it has reached 12.5% and 12.0%. Economic growth, more generally, has been relatively weak, growing at an average annual rate of 0.7% in the Euro area between 2011 and 2015. More strikingly, in the same period Greece saw its economy contract at an average rate of 3.8% per year, Portugal at 0.9% and Spain at 0.1%. Public debt levels have also reached historic levels during the period with public debt in Greece at 176.9% of its GDP, in Italy at 132.7%, and in Portugal at 129.0%. In this context, the design of environmental policies must necessarily operate in a framework that pays special attention to economic and budgetary concerns.

At the same time, this focus also reflects the reality of many environmental policy programs around the world. CO_2 taxes and auctioned emissions permits have emerged as potentially important policy instruments for increasing public revenues (see, for example, Metcalf & Weisbach, 2008; Galston & MacGuineas, 2010; Metcalf, 2010; Nordhaus, 2010). The use of these revenues is often defined by regulators to address the many important and multidimensional concerns that countries face in implementing these policies, including equity considerations, the need for public support for research and development and deployment of new energy-saving and renewable energy technologies. The EU ETS Directive [2003/87/EC], for example, provides that at least 50% of auction proceeds be used by Member States for climate and energy related purposes. In 2014, total revenues from auctioning EU-ETS allowances amounted to €3.2 billion, 87% of which was used for climate and energy related purposes, largely to support domestic investment in climate and energy. Under the current economic and budgetary conditions, however, understanding the optimal use of these revenues across various possible revenue recycling alternatives is critical from an economic and a budgetary perspective if environmental policies stand a chance of being adopted and effectively implemented.

In this article, we focus on the environmental, economic, and budgetary effects of CO_2 taxation under different revenue recycling policies. Our goal is to identify the allocation of revenues from the CO_2 tax that will best address economic and budgetary concerns. We are particularly interested in identifying how labor market conditions—labor supply and involuntary unemployment, affect the search for the optimal recycling mix for CO_2 tax revenue.

Consistent with this policy framework, we focus on the issue of the multiple dividends of a CO_2 tax and the role of recycling the revenues of this tax to generate such dividends (see, for example, Goulder, 1995; Rausch, 2013; Pereira, A. & Pereira, R., 2014a). Clearly a CO_2 tax would reduce emissions, and thereby generate a first dividend, an environmental dividend. It would, however, negatively affect economic performance and possibly worsen the budgetary position. These negative side-effects of the CO_2 tax can, however, be mitigated—or even reversed—in the context of revenue-neutral tax reform where the carbon tax revenues are recycled in a way that alleviates distortions at other tax margins. As both a matter of theoretical and practical importance, CO_2 taxation has the potential to generate a second dividend, an economic dividend, a strong realization of which is the possibility of an actual improvement in economic performance compared to the pre-tax situation. In addition, CO_2 taxation can produce a third dividend, a budgetary dividend, a strong version of which is an overall reduction in the public-debt-to-GDP ratio, compared to the pre-tax situation. In light of the terms of the policy debate—the quest for economic growth and the ongoing need for fiscal consolidation—we focus on identifying cases of strong realizations of the second and third dividends.

These issues are addressed in this paper using a dynamic general equilibrium model of the Portuguese economy. The model incorporates fully-dynamic optimization behavior, endogenous growth mechanisms, and a detailed modeling of the tax system in Portugal. Previous versions of this model have been used to evaluate the impact of tax policy (see Pereira & Rodrigues, 2002, 2004) public pension reform (see Pereira & Rodrigues, 2007), as well as energy and climate policy (see Pereira, A. & Pereira, R., 2014a, 2014b, 2016a, 2016b).

This model brings together three important strands of the taxation literature (see the above applications of this model for a detailed list of the references). On one hand, it follows in the footsteps of computable general-equilibrium modeling. It shares with this literature the ability to consider the tax system in great detail. This is important, given the evidence that both the costs and the effectiveness of climate policies are influenced by existing tax distortions (see, for example, Goulder, 1995; Goulder et al., 1999; Goulder et al., 2008; Marron & Toder, 2014; Parry, 2014). On the other hand, it incorporates many of the insights of the endogenous growth literature. In particular, it recognizes that public policies have the potential to affect the fundamentals of long-term growth, and not just for generating temporary level effects (see, for instance, Xepapadeas, 2005; Fullerton & Kim, 2008; Oueslati, 2014, 2015). Finally, this paper also builds upon a substantial body of work on optimal taxation. The optimal tax mix will minimize the excess burden of the tax system by equalizing the marginal excess burden across commodities taxed (see, for example, Ramsey, 1927). In the context of environmental tax reform, the possibility of a double dividend arises exactly from the possibility that taxes on pollution can replace more distortionary taxes on labor inputs (see, for example, Bovenberg & Goulder, 1996).

The implementation of the dynamic general equilibrium in this paper brings two important innovations relative to previous applications, one methodological the other procedural. In this sense this paper can be thought of as a direct follow up on Pereira, A. and Pereira, R. (2014a). The central methodological innovation is in the specification of the labor markets. We allow for both exogenous and endogenous labor supply decisions. More importantly, we consider endogenous involuntary unemployment through a macroeconomic closure consistent with Okun's Law defining the relationship between growth rate of GDP and changes in the unemployment rate. Operationally, we find the optimal use of the revenues from the carbon tax through an extensive grid search. We consider the allocation of these revenues among an increase in the investment tax credit for corporations, a reduction in social security contributions, and a reduction in the person income tax rate. This grid search allows us to select the revenue recycling mix that maximizes the environmental, economic or budgetary effects of the CO_2 tax. Due to the important differences in these margins we do not consider a single objective function but instead focus on each dividend individually and identify the cases that produce a strong form of the triple dividend.

The remainder of this article proceeds as follows. In Section 2 we present the dynamic general-equilibrium model. In Section 3, we discuss the environmental, economic, and budgetary effects of a carbon tax, under the assumption that its tax revenues are recycled in a lump-sum manner. In Section 4, we consider the carbon tax under a variety of alternative individual and mixed revenue-recycling mechanisms to identify key strategies that mitigate or reverse any potential negative economic and budgetary effects of this tax. In Section 5, we present sensitivity analysis with respect to the two major labor market assumptions, namely, endogenous unemployment and endogenous labor supply. Finally, in Section 6, we provide a summary of the results and discuss some of their policy implications.

2. The Dynamic General-Equilibrium Model of the Portuguese Economy

In this section we present the model in very general terms. Complete model documentation—of the model equations, parameters, data, calibration, and numerical implementation—can be found in Pereira, A. and Pereira, R. (2012). The new features of the modelling in this paper refer to the specification of labor market conditions, in particular of endogenous unemployment.

We consider a decentralized economy in a dynamic general-equilibrium framework. All agents are price-takers and have perfect foresight. With money absent, the model is framed in real terms. There are four sectors in the economy—the production sector, the household sector, the public sector and the foreign sector. The first three have endogenous behavior, but all four sectors are interconnected through competitive market equilibrium conditions, as well as the evolution of the stock variables and the relevant shadow prices. All markets are assumed to clear.

The trajectory for the economy is described by the optimal evolution of eight stock and five shadow price variables—private capital, wind energy capital, public capital, human capital, and public debt, together with their shadow prices, and foreign debt, private financial wealth, and human wealth. In the long term, endogenous growth is determined by the optimal accumulation of private capital, public capital and human capital. The last two are publicly provided.

2.1 The Production Sector

Aggregate output is produced with a CES technology, linking value added and primary energy demand. Value added is produced according to a Cobb-Douglas technology exhibiting constant returns to scale in the reproducible inputs—effective labor inputs, private capital, and public capital. See Figure 1. Only the demand for labor and the private capital stock are directly controlled by the firm, meaning that, if public investment is absent, then decreasing returns set in. Public infrastructure and the economy-wide stock of knowledge are publicly financed and are positive externalities. Primary energy demand is produced according to a CES technology using crude oil inputs and non-transportation energy sources. The production of non-transportation energy follows a Cobb-Douglas technology using coal, natural gas and wind energy inputs.

Private capital accumulation is characterized by a dynamic equation of motion where physical capital depreciates. Gross investment is dynamic in nature with its optimal trajectory induced by the presence of adjustment costs. These costs are modeled as internal to the firm—a loss in capital accumulation due to learning and installation costs—and are meant to reflect rigidities in the accumulation of capital towards its optimal level. Adjustment costs are assumed to be non-negative, monotonically increasing, and strictly convex. In particular, we assume adjustment costs to be quadratic in investment per unit of installed capital.

The firms' net cash flow represents their after-tax position when revenues from sales are netted of wage payments and investment spending. After-tax net revenues reflect the presence of a private investment and wind energy investment tax credits, as well as taxes on corporate profits and Social Security contributions paid by the firms on gross salaries.

Buildings make up a fraction of total private investment expenditure. Only this fraction is subject to value-added and other excise taxes, the remainder is exempt. The corporate income tax base is calculated as revenues from the sale of output, net of total labor costs, and net of fiscal depreciation allowances over past and present capital investments. A straight-line fiscal depreciation method is used, and investment is assumed to grow with output. Under these assumptions, depreciation allowances are simply proportional to the difference of two infinite geometric sums.

Optimal production behavior consists in choosing the levels of investment and labor that maximize the present value of the firms' net cash flows, subject to the equation of motion for private capital accumulation. The demands for labor and investment are obtained from the current-value Hamiltonian function, where the shadow price of private capital evolves according to the respective co-state equation. Finally, with regard to the firm's financial link with the rest of the economy, we assume that at the end of each operating period the net cash flow is transferred back to the households.

2.2 The Energy Sector

We consider the introduction of CO_2 taxes levied on primary energy purchased by firms. This is consistent with the nature of the existing policy environment in Portugal in which CO_2 permits may now be auctioned off to firms. Furthermore, evidence suggests that administrative costs are substantially lower the further upstream the tax is administered. By considering taxation at the firm level, the additional costs induced by CO_2 taxes are transmitted through the economy in a fashion consistent with the energy content of the different goods. Not levying the CO_2 tax on consumers therefore avoids a double taxation of the carbon content of a good. Finally, Portugal is a net exporter of oil products in secondary form and imports virtually no coal or natural gas in any secondary form. Accordingly, there is no loss of generality in considering a tax on primary energy.

The energy sector is an integral component of the firms' optimization decisions. We consider primary energy consumption by firms for crude oil, coal, natural gas and wind energy. Primary energy demand refers to the direct use of an energy vector at the source, in contrast to energy resources that undergo a conversion or transformation process. No other forms of non-renewable energy are considered as the main policy focus in Portugal has been on wind energy. The use of hydro power has been relatively constant while other forms of renewables have residual relevance. It should also be mentioned that there are no nuclear plants in Portugal.

Primary energy consumption provides the most direct approach for accounting for CO_2 emissions from fossil fuel combustion activities. Carbon is released from fossil fuel upon combustion. Although burning fuels generates other greenhouse gas emissions, we focus exclusively on carbon dioxide emissions. Together, the quantity of fuel consumed, its carbon factor, oxidation rate, and the ratio of the molecular weight of CO_2 to carbon are used to compute the amount of CO_2 emitted from fossil fuel combustion activities in a manner consistent with a reference approach suggested by the Intergovernmental Panel for Climate Change (2006). These considerations suggest a linear relationship between CO_2 emissions and fossil fuel combustion activities.

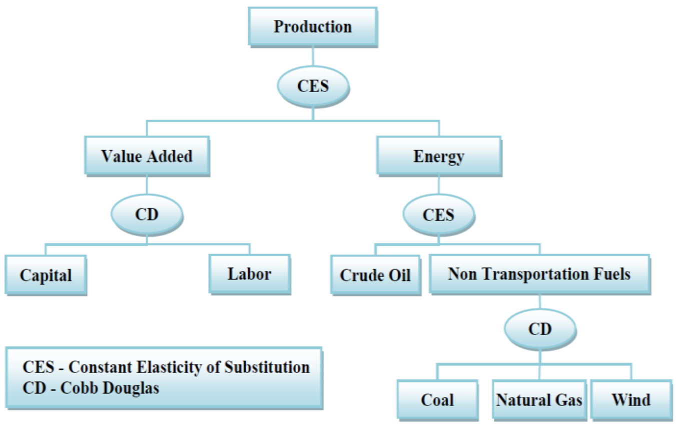

Figure 1. Overview of the Production Structure

Fossil fuels are hydrocarbons defined by the relative amounts of carbon and hydrogen in each molecule. In the combustion reaction, the compound reacts with an oxidizing element, such as oxygen. Thus, the amount of carbon relative to hydrogen in the fuel determines the fuel's carbon emissions factor, i.e., the amount of carbon emitted per unit of energy. The molecular weight of carbon dioxide CO_2 is 44/12 times greater than the weight of carbon alone (the molecular weight of carbon is 12 and that of oxygen is 16 which give CO_2 a weight of 44 moles and carbon of 12 moles). The fuel's CO_2 emission factor can be computed from the product of its carbon-emission factor, in tons of oil equivalent, the fraction of carbon oxidized and the ratio of the molecular weight of carbon dioxide to carbon. For each ton of oil equivalent consumed, crude oil yields 3.04 tCO_2, and natural gas yields 2.34 tCO_2. For each ton of oil equivalent consumed coal yields 3.78 tCO_2, an average based on the IPCC framework and annual inventories for Portugal, which reflects the fact that in Portugal virtually all non-coking coal consumption is of the "other bituminous" type.

Aggregate primary-energy demand is produced with a CES technology, in which crude oil, and non-transportation fuels are substitutable at a rate of less than unity, which reflects the dominance of petroleum products in transportation energy demand, and the ubiquity of coal, natural gas and—to a lesser extent—wind energy, in electric power and industry. Non-transportation fuels are produced with a Cobb-Douglas technology that takes into account the relatively greater potential for substitution in electric power and industry. See Figure 1. The accumulation of wind energy infrastructure is governed by a dynamic equation of motion where physical capital—wind turbines—depreciates, and investment is subject to adjustment costs, just as in the case of private capital. Wind energy investment decisions are internal to the firm, while coal, natural gas and oil are imported.

Optimal primary energy demand is derived by maximizing the present value of the firms' net cash flows, as discussed above. In turn, the demand for coal and natural gas are defined through the nested dual problem of minimizing energy costs, given the production function and optimal demand for these energy vectors in electric power and industry. Finally, the variational condition for optimal wind energy investment and the equation of motion for the shadow price of wind energy are defined by differentiating the Hamiltonian with respect to wind energy investment and its stock.

2.3 The Households

An overlapping-generations specification was adopted in which the planning horizon is finite but non-deterministic. A large number of identical agents are faced each period with a probability of survival. The assumption that the probability of survival is constant over time and across age cohorts yields a perpetual youth specification. Without loss of generality, the population, which is assumed to be constant, is normalized to one. Therefore, per capita and aggregate values are equal.

The household chooses consumption and leisure streams that maximize intertemporal utility, subject to a consolidated budget constraint. The objective function is subjectively discounted lifetime-expected utility. Preferences are additively separable in consumption and leisure, and take on the CES form. A lower probability of survival reduces the effective discount factor, thus making the household relatively more impatient.

The budget constraint reflects a value-added tax on consumption, and states that the households' expenditure stream, discounted at the after-tax market real interest rate, cannot exceed total wealth. The loan rate at which households borrow and lend among themselves is greater than the after-tax interest rate, thus reflecting the probability of survival.

Total wealth is age-specific and is composed of human wealth, net financial worth, and the present value of the firm. Human wealth represents the present discounted value of the household's future labor income stream, net of personal income taxes and workers' social security contributions. The household's wage income is determined by its endogenous decision of how much labor to supply out of a total time endowment, and by the stock of knowledge or human capital that is augmented by public investment in education. Labor earnings are discounted at a higher rate, reflecting the probability of survival.

A household's income increases with net interest payments received on public debt, profits distributed by corporations, international transfers, and also with public transfers. On the spending side, debts to foreigners are serviced, taxes are paid and consumption expenditures are made. Income, net of spending, adds to net financial wealth. Under the assumption of no bequests, households are born without any financial wealth. In general, total wealth is age-specific due to age-specific labor supplies and consumption streams.

Assuming a constant real interest rate, the marginal propensity to consume out of total wealth is age-independent and aggregation over age cohorts is greatly simplified. This allows us to write the aggregate demand for leisure as a function of aggregate consumption.

2.4 The Labor Market: Macroeconomic Closure

We consider endogenous unemployment behavior through a macroeconomic closure representing an Okun's Law relationship between changes in output and changes in the unemployment rate. The general approach to modelling involuntary unemployment in a general equilibrium analysis of environmental taxes ultimately relies on a reduced form representation of the relationship between wages and the unemployment rate (Rivers, 2013). These reduced forms are derived from wage bargaining models and job search models among other micro-founded formulations. We rely on a macroeconomic closure in the form of the relationship described by Okun (1962) in large part because it reflects a strong, empirically stable macroeconomic relationship. The parameters defining Okun's law are estimated for Portugal using annual macroeconomic data from 1983 to 2015 with the natural rate of unemployment calibrated to reflect the steady state trajectory for the dynamic model. The estimation results indicate that a one percentage point increase in the growth rate of GDP is associated with a 0.3 percentage point decrease in the unemployment rate. These results are consistent with those estimated in the literature (see, for example, Ball et al., 2013).

2.5 The Public Sector

The equation of motion for public debt reflects the fact that the excess of government expenditures over tax revenues has to be financed with further public debt. Total tax revenues include personal income taxes, corporate income taxes, value-added taxes, and social security taxes levied on firms as well as on workers. All of these taxes are levied on endogenously-determined tax bases. Residual taxes are modeled as lump sum, and are assumed to grow at an exogenous rate.

The public sector pays interest to service its public debt, and transfers funds to households in the form of pensions, unemployment subsidies, and social transfers, which grow at an exogenous rate. In addition, it engages in public consumption activities—here considered exogenous and growing at the same rate as output—and public investment in both public capital and human capital.

Public investments are determined optimally, respond to economic incentives, and constitute an engine of endogenous growth. The accumulations of human capital and public capital are subject to depreciation and adjustment costs, which are a fraction of the respective investment levels. The adjustment cost functions are strictly convex and quadratic.

Public-sector decisions consist of choosing the trajectories for public investment in human capital and public investment in public capital that maximize output growth. The optimal choice is subject to three constraints, the equations of motion of the stock of public debt, the stock of public capital, and the stock of human capital. The optimal trajectories depend on the shadow prices of public debt, public capital, and human capital stocks, respectively.

2.6 The Foreign Sector

The equation of motion for foreign financing provides a stylized description of the balance of payments.

Domestic production and imports are absorbed by domestic expenditure and exports. Net imports, which incorporate payments for fossil fuels imports, are financed through foreign transfers, net foreign investment, and foreign borrowing. Foreign transfers and net foreign investment are assumed to grow at an exogenous rate. Portugal is modeled as a small, open economy. This means that it can obtain the desired level of foreign financing at a rate which is determined in international financial markets. This is the prevailing rate for all domestic agents.

2.7 The Intertemporal Market Equilibrium

The intertemporal path for the economy is described by the behavioral equations, by the equations of motion of the stock and shadow price variables, and by the market equilibrium conditions. The labor-market conditions incorporate an endogenous unemployment rate. The product market equalizes demand and supply for output. Given the open nature of the economy, part of domestic demand is satisfied through the recourse to foreign production. Finally, equilibrium in the financial market reflects the fact that private capital formation and public indebtedness are financed by household savings and foreign financing.

We define the steady-state path as an equilibrium trajectory in which all the flow and stock variables grow at the same rate while market prices, both domestic and in the international markets, as well as shadow prices are constant. Implicitly, any factors relevant for environmental policies, such as domestic policies or international fossil fuel prices, also remain unaltered.

There are three types of restrictions imposed by the existence of a steady state. First, it determines the value of critical production parameters, like adjustment costs and depreciation rates, given the initial capital stocks. These stocks, in turn, are determined by assuming that the observed levels of investment of the respective type are such that the ratios of capital to GDP do not change in the steady state. Second, the need for constant public-debt and foreign debt-to-GDP ratios implies that the steady-state public-account deficit and the current -account deficit are a fraction of the respective stocks of debt. Finally, the exogenous variables, such as public transfers or international transfers, have to grow at the steady-state growth rate.

2.8 Dataset, Parameter Specification, and Calibration

The model is implemented numerically using detailed data and parameters sets. Economic data are from the Statistical Annex of the European Community (European Commission, 2014d), budgetary data from the Portuguese Ministry of Finance (GPEARI, 2014), and energy and environmental data from the Portuguese Ministry of Economy (DGEG, 2014). The decomposition of the aggregate variables follows the average for the period 2000-2013 for macroeconomic data, as well as for the energy variables. This period was chosen to reflect the most recent available information and to cover several business cycles, thereby reflecting the long-term nature of the model. Public debt and foreign debt, and capital stocks, reflect values as of the end of 2013.

Parameter values are specified in different ways. Whenever possible, parameter values are taken from the available data sources or the literature. This is the case, for example, of the population growth rate, the probability of survival, the share of private consumption in private spending, and the different effective tax rates. All the other parameters are obtained by calibration; i.e., in a way that the trends of the economy for the period 2000-2013 are extrapolated as the steady-state trajectory. In some cases, the calibration parameters are chosen freely, in that they are not implied by the state-state restrictions. Although free, these parameters have to be carefully chosen since their values affect the value of the remaining calibration parameters. Accordingly, they were chosen either using central values or using available data as guidance. For instance, the elasticity of substitution parameters are consistent with those values often applied in climate policy analysis (see, for example, Manne & Richels, 1992; Paltsev et al., 2005; Koetse et al., 2008). The remaining calibration parameters are implied by the steady-state restrictions.

3. On the Effects of a CO_2 Tax without Revenue Recycling

We now examine the environmental, economic, and budgetary effects of a CO_2 tax. Throughout this paper, we consider a tax of $15 per ton of CO_2emissions. This value, which is used for illustrative purposes and without loss of generality, is in line with what is suggested in Anderson, Speck and Gee (2013) and what is used in Pereira, A. and Pereira, R. (2014a). We consider first the effects of this CO_2 tax in its simplest form, i.e., where tax revenues are distributed through lump-sum transfers to households. Detailed results are presented in Table 1.

A CO_2 tax works primarily through two mechanisms. First, by affecting relative prices, the CO_2 tax induces firms to adjust their input structure, which in turn affects the marginal productivity of factor inputs. Second, the CO_2 tax increases energy expenditure, and reduces the firms' net cash flow, household income, and domestic demand. These substitution and scale effects are central in understanding how CO_2 taxation affects energy consumption, emissions, economic performance and the public-sector account.

The CO_2 tax increases the price of fossil fuels relative to renewable energy resources, and changes the relative price of the different fossil fuels to reflect their carbon content. This has a profound impact on the energy sector, driving a reduction in fossil fuel consumption of 11.11% and an increase in the stock of wind energy infrastructure of 13.81% by 2030. The impact of the CO_2 tax on aggregate fossil fuel demand, however, masks important changes in the fuel mix. In particular, we observe a 32.98% reduction in coal consumption, while crude oil falls by 7.34% and natural gas by 3.46%. As such, the tax induces a shift in the energy mix, which favors wind energy, at the expense of coal. Ultimately, CO_2 emissions are 12.30% lower in 2030 than in the reference scenario.

CO_2 taxation, by increasing energy-system costs, has a negative impact on the firms' net cash flow which limits the firms' demand for inputs. Employment falls by 0.40% in 2030, less than the reduction in private investment of 2.16% and the associated drop in private capital of 1.35%, and certainly substantially less than the drop in fossil fuel demand. This is consistent with an overall reduction in input levels, coupled with a shift in the firms' input structure away from energy inputs, and an increasing role for capital and, especially, labor.

Given the reductions in factor demand, it is of no surprise that the tax has a negative impact on economic growth and activity levels. The reduction in the firms' net cash flow has a direct impact on household income since it is an integral part of total wealth. This drives down private consumption, and initiates an important dynamic feedback between income, consumption and production. As a result, private consumption falls by 1.34%. The net effect of this interaction is a reduction in GDP levels of 1.14% by 2030.

Table 1. Detailed Effects of a Carbon Tax with Lump-Sum Recycling

(Percent Change with Respect to Reference Scenario)

	2020	2025	2030	2050
Energy				
Total Energy Demand	-7.54	-7.42	-7.47	-8.02
Demand for Fossil Fuels	-10.51	-10.86	-11.11	-11.83
Crude Oil	-6.82	-7.10	-7.34	-8.05
Coal	-32.34	-32.73	-32.98	-33.56
Natural Gas	-2.54	-3.10	-3.46	-4.30
Investment in Wind Energy	20.12	16.81	15.08	13.02
Wind Energy Infrastructures	9.24	11.99	13.18	13.50
Carbon Dioxide Emissions from Fossil fuel Combustion	-11.71	-12.05	-12.30	-13.00
Economy				
GDP	-0.59	-0.89	-1.14	-1.90
Private Consumption	-1.34	-1.34	-1.34	-1.29
Private Investment	-1.91	-2.03	-2.16	-2.75
Private Capital	-0.69	-1.05	-1.35	-2.20
Imported Energy	-7.83	-8.16	-8.42	-9.14
Foreign Debt/GDP	-2.64	-4.31	-5.76	-9.87
Labor Markets				
Unemployment Rate	1.63	2.50	3.23	5.44
Employment	0.00	-0.22	-0.40	-0.98
Human Capital	-0.04	-0.06	-0.09	-0.21
Wages	-0.90	-0.96	-0.99	-1.06
Public Sector				
Public Debt/GDP	-1.50	-2.86	-4.36	-11.81
Public Expenditures	-0.77	-0.96	-1.13	-1.65
Public Consumption	-0.68	-0.95	-1.18	-1.86
Public Investment	-1.69	-1.83	-1.98	-2.62
Investment in Human Capital	-0.54	-0.59	-0.63	-0.79
Public Capital	-0.75	-1.12	-1.41	-2.22
Human Capital	-0.04	-0.06	-0.09	-0.21
Tax Revenues	0.10	-0.16	-0.38	-1.08
Personal Income Tax	-0.76	-1.31	-1.80	-3.62
Corporate Income Tax	-0.46	-0.84	-1.14	-1.97
Value Added Tax	-1.38	-1.41	-1.44	-1.54
Social Security Contributions	-0.93	-1.23	-1.48	-2.24

By 2030, fossil fuel imports are 8.42% lower than the reference levels. The reduction in domestic demand, coupled with lower expenditure on energy imports stemming from demand adjustments, suggests that foreign-debt-to-GDP levels fall by 5.76% in 2030, relative to reference levels.

The CO_2 tax in this simple implementation affects fiscal consolidation positively. Simulation results suggest that the CO_2 tax leads to a 4.36% decrease in the public debt to GDP ratio by 2030. This effect is fundamentally due to a moderate reduction in public outlays, coupled with a much smaller decrease in overall tax revenues. On the expenditure side, we observe a reduction in overall spending of 1.13% in 2030. This closely follows the evolution of GDP itself, with the small differences induced by the evolution of interest payments on outstanding public debt. On the revenue side, a reduction in income, consumption and private inputs results in contracting tax bases. Accordingly, personal income tax revenues are 1.80% lower, corporate income tax revenue are 1.14% lower, value-added tax receipts are 1.44% lower, and Social Security contributions are 1.48% lower than steady state levels in 2030. These reductions are partially offset by the carbon tax receipts. As a result, total tax revenue, in absolute terms, is only 0.38% lower in 2030.

Overall, the effects of CO_2 taxation without an accompanying revenue recycling policy can be summarized as follows. The first dividend of lower emissions is achieved. This is, however, at the cost of weaker economic performance, both in terms of GDP and labor market indicators. i.e., no second dividend materializes. Finally, the budgetary effects are positive and directly linked to the fact that a new carbon tax just means greater tax revenues, i.e., a third dividend is trivially achieved.

4. On the Effects of a CO_2 Tax with Revenue Recycling

4.1 The Different Recycling Mechanisms

The undesirable economic effects of the CO_2 tax in its simplest form can conceivably be eliminated, or even reversed, through careful recycling of the revenues it generates. In all cases, and in keeping with the institutional and political terms of the policy debate, we assume that all recycling strategies satisfy strict tax-revenue neutrality on impact. The revenues generated by the carbon tax are used to finance concomitant reductions in other tax margins. The assumption used to frame this issue is one of tax-revenue neutrality and not one of general budgetary neutrality. Specifically, we do not consider other possible recycling strategies that would involve using the carbon tax revenues to finance increases in the different types of public expenditure.

We consider four revenue recycling mechanisms, i.e., four different tax margins that can be reduced with the revenues raised from the tax on carbon—the Value-Added Tax (VAT), Personal-Income Tax (PIT), Social Security Contributions paid by firms on their payrolls (SSC) and an Investment Tax Credit (ITC) in the context of the corporate-income tax. These four alternative recycling strategies cover all the main tax margins in the economy. More importantly, they cover the main economic mechanism that can stimulate economic performance operating through three separate channels—demand-driven policies (VAT), employment-driven polices (PIT on the labor supply side and SSC on the labor demand side), and investment-driven policies (ITC).

Table 2. Summary of Effects of a Carbon Tax under Alternative Recycling Mechanisms

(Percent Change with Respect to Reference Scenario)

	Carbon Dioxide Emissions		**Employment**		**Unemploym. Rate**		**GDP**		**Public Debt/GDP**	
	2030	**2050**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**
Lump Sum	-12.30	-13.00	-0.40	-0.98	3.23	5.44	-1.14	-1.90	-4.36	-11.81
VAT/Value Added Tax	-12.07	-12.50	-0.16	-0.47	2.56	3.87	-0.88	-1.33	0.87	0.94
PIT/Personal Income Tax	-11.84	-12.65	**0.29**	-0.33	2.50	5.09	-0.63	-1.51	0.72	1.55
SST/Social Sec, Taxes	-11.98	-12.73	**0.07**	-0.52	2.69	5.08	-0.78	-1.60	**-0.97**	**-2.90**
ITC/Invest. Tax Credit	-10.48	-9.87	**0.35**	**0.84**	**-4.31**	**-6.36**	**0.91**	**1.63**	0.22	0.66

Note. Strong realizations of the second and third dividends are highlighted in boldface.

4.2 On the Effects of the Different Individual Recycling Mechanisms

The effects of the four individual recycling strategies are presented in Table 2. We start examining the effects of using the revenues from the CO_2 tax to finance a reduction in the VAT. This is a demand-driven policy, as carbon tax revenues are used to boost private consumption by offsetting VAT revenues. The CO_2 tax under the VAT recycling strategy yields negative economic effects and therefore fails to generate the second dividend. GDP falls by 0.88%, while employment decreases by -0.16% and unemployment increases by 2.56%. This small improvement in economic performance relative to the lump-sum case reflects the small distortions associated with indirect taxation. In turn, the carbon tax with VAT recycling increases public debt by 0.87% by 2030 and, therefore, also fails to generate a third dividend.

The PIT and the SSC recycling cases are employment-driven policies**.** These allow us to evaluate labor demand and supply responses to reductions in the tax burden on households and firms. Overall, these two policies result in a 0.63% reduction in GDP for the PIT recycling policy and 0.78% for the SSC recycling policy by 2030. This is because in these two recycling policies, the CO_2 tax increases employment in the near term only but still increases unemployment due to increase in labor force participation. Finally, the two cases differ in an important manner in terms of their impact on public debt. The PIT policy fails to generate the third dividend, resulting in an increase in the debt-to-GDP ratio of 0.72%. The SSC policy leads to a strong realization of the third dividend with a 0.97% reduction in the debt-to-GDP ratio by 2030.

Finally, we examine the case of the ITC recycling policy, in which CO_2 tax revenues are used to promote private investment. The ITC policy stimulates private investment, reduces unemployment, increases employment, and ultimately leads to greater GDP performance. This means that the second dividend is achieved: employment increases by 0.37%, unemployment decreases by 4.37% while GDP increases by 0.93% by 2030. The ITC policy, however, leads to an increase, albeit rather small, in the public-debt-to GDP ratio of 0.23% in 2030, thereby failing to produce the third dividend. This slight increase in public indebtedness is the result of a moderate increase in public expenditures that slightly exceeds the moderate increase in tax revenues resulting from improved economic conditions.

There are three important ideas that arise from the results obtained for the individual recycling strategies. First, each of the four recycling cases under consideration mitigate, albeit to different degrees, the negative economic effects of the carbon tax compared to the lump sum case, generating a weak form of the double dividend. At the same time, and essentially by design, they also greatly dampen the positive budgetary effects present in the lump sum case.

Second, the VAT recycling policy fails to substantially mitigate the negative economic effects of the carbon tax compared to the lump sum case. Furthermore, it actually reverses the positive budgetary effects identifies in the lump sum case. This being the case we omit this recycling mechanism from the subsequent analysis. While much of the same can also be said about the PIT recycling strategy, the positive effects on employment under this strategy justify further consideration given the importance of labor market concerns in the policy debate.

Third, the differences in the economic and budgetary effects of the SSC and the ITC policies suggests that it should be possible to combine these policies in a way that simultaneously encourages economic performance—through investment in physical capital—and lowers the unemployment rate while contributing to fiscal consolidation.

The results found here are also generally consistent with those found in the literature. Looking at 191 simulations in 61 studies, Patuelli, Nijkamp and Pels (2005) find that the average results indicate a 0.44% increase in employment and a -0.05% reduction in GDP with an environmental tax reform policy. They further find that SSC recycling acts significantly better than other tax parameters, including the personal income tax. With SSC recycling the mean employment gain is of 1.04% and GDP increases by 0.15%. Our results also highlight the fact that allowing the mechanisms of endogenous growth are important in assessing the magnitude of the effects of the tax reform, an important differentiating element of our analysis relative to the 61 studies cited.

4.3 On the Effects of Mixed Revenue Recycling Strategies

We now consider the search for the optimal recycling mix by allowing the revenues generated by the CO_2 tax to be used to simultaneously reduce the personal income tax rate, social security contributions and finance an increase in the investment tax credit. Optimal recycling is heuristically defined as the recycling mix that leads to the best results in terms of either its environmental impacts or economic impacts or budgetary impacts, among the feasible set of mixed recycling strategies that lead to the three dividends. The basic idea is that while the need to reduce CO_2 emissions—achieving the first dividend—is the principal motivation for considering a carbon tax in the first place, the current macroeconomic environment is such that no carbon tax would be even remotely considered unless it would bring with it economic and budgetary benefits, i.e., would also generate a second or a third

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dividend. Among the mixed revenue recycling polices that yield the three dividends there is room for different policy perspectives emphasizing the environmental, economic, or budgetary impacts.

We seek the optimal use of the revenues from the CO_2 tax through an extensive grid search. We consider the allocation of these revenues among an increase in the investment tax credit for corporations, a reduction in social security contributions by employers, and a reduction in the person income tax rate. To identify the optimal recycling mix we start by determining the set of all strategies that yield the three dividends by performing a grid search. We consider all possible allocations among these uses in 5 percentage point increments, constrained by the fact that the sum of the three percentages must equal one, for a total of 231 possible cases ($\frac{22!}{20!2!}$). This grid search allows us to select the revenue recycling mix that maximizes the environmental, economic and budgetary effects of the policy. Due to the important differences in these margins we do not consider a single objective function but instead focus on each dividend individually and identify the cases that produce a strong form of the triple dividend. Full details of the search grid are available from the authors upon request. The results generally highlight a trade-off between greater levels of economic growth, higher debt levels and marginally less environmentally effective tax measures. From inspection of the results identified for the individual tax margins, the Investment Tax Credit (ITC) generates the strongest gains in economic activity, at a short-run cost in terms of employment and long-run increases in public debt levels. The employment-driven policies produce generally more positive labor market outcomes and contribute towards fiscal consolidation.

The positive effects on economic performance increase with the share of the ITC replacement in the mix. A strong second dividend results from an allocation of more than 45% of the carbon tax revenue to finance the investment tax credit. In turn, lower ITC shares produce more frequent realization of the third dividend. No cases of a positive third dividend occur for shares in excess of 80%.

The reverse pattern can be observed for the share of PIT and SSC in the mix. The second dividend disappears for when these two components of the allocation exceed 60%. On the other hand, the third dividend is more likely for a greater allocation of the tax proceeds to reducing these tax margins. Finally, for any given allocation to the ITC, more revenue allocated to the SSC tends to produce less favorable outcomes with respect to the second dividend but more favorable outcomes with respect to the third dividend.

The summary of the results for the twenty cases in which the three dividends are achieved—less than 10% of all the grid search cases—are presented in Table 3. In all cases, the share of ITC exceeds 50%, the share of the revenues allocated to the SSC is between 20% and 50% and the share allocated to the PIT is under 20%. The mixed strategy that maximizes both the environmental impact and the budgetary impact is 50% for ITC and 50% for SSC. By 2030, emissions are 11.21% lower than steady state levels and public debt reduced by 0.39% while the GDP gains are marginal, 0.08%, and the employment gains and unemployment gains small at 0.22% and -0.89%, respectively. In turn, the optimal mix from the standpoint of the second dividend is 80% for ITC and 20% for SSC reductions. While the gains in emissions reductions are just 10.76% and the benefits on the public debt negligible, the economic gains are substantial. By 2030, GDP increases by 0.59% relative to steady state levels, employment by 0.31% and unemployment decreases by 3.00%.

Table 3. Summary of Effects of a Carbon Tax under Mixed Recycling Mechanisms

(Percent Change with Respect to Reference Scenario)

			Carbon Dioxide Emissions		**Employment**		**Unemploym. Rate**		**GDP**		**Public Debt/GDP**	
ITC	**SST**	**PIT**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**
Lump Sum			-12.30	-13.00	-0.40	-0.98	3.23	5.45	-1.14	-1.90	-4.36	-11.81
0.80	0.20	0.00	**-10.76**	**-10.40**	**0.31**	**0.60**	**-3.00**	**-4.23**	**0.59**	**1.03**	**-0.02**	**-0.03**
0.75	0.25	0.00	**-10.83**	**-10.55**	**0.30**	**0.53**	**-2.65**	**-3.67**	**0.51**	**0.87**	**-0.08**	**-0.21**
0.70	0.25	0.05	**-10.90**	**-10.68**	**0.29**	**0.47**	**-2.32**	**-3.10**	**0.43**	**0.71**	**-0.06**	**-0.18**
0.70	0.30	0.00	**-10.91**	**-10.69**	**0.28**	**0.46**	**-2.30**	**-3.09**	**0.42**	**0.70**	**-0.14**	**-0.40**
0.65	0.25	0.10	**-10.97**	**-10.82**	**0.29**	**0.42**	**-1.98**	**-2.54**	**0.36**	**0.55**	**-0.03**	**-0.14**
0.65	0.30	0.05	**-10.98**	**-10.83**	**0.28**	**0.40**	**-1.97**	**-2.53**	**0.35**	**0.55**	**-0.12**	**-0.36**
0.65	0.35	0.00	**-10.98**	**-10.84**	**0.26**	**0.39**	**-1.95**	**-2.52**	**0.34**	**0.54**	**-0.20**	**-0.58**
0.60	0.25	0.15	**-11.04**	**-10.96**	**0.28**	**0.35**	**-1.64**	**-1.97**	**0.28**	**0.40**	**-0.01**	**-0.10**
0.60	0.30	0.10	**-11.05**	**-10.97**	**0.27**	**0.34**	**-1.63**	**-1.96**	**0.27**	**0.39**	**-0.10**	**-0.32**
0.60	0.35	0.05	**-11.05**	**-10.98**	**0.26**	**0.33**	**-1.61**	**-1.95**	**0.26**	**0.38**	**-0.18**	**-0.55**
0.60	0.40	0.00	**-11.06**	**-10.98**	**0.25**	**0.32**	**-1.60**	**-1.94**	**0.25**	**0.37**	**-0.27**	**-0.77**
0.55	0.30	0.15	**-11.11**	**-11.11**	**0.27**	**0.28**	**-1.28**	**-1.39**	**0.19**	**0.23**	**-0.07**	**-0.29**
0.55	0.35	0.10	**-11.12**	**-11.12**	**0.25**	**0.27**	**-1.27**	**-1.38**	**0.18**	**0.22**	**-0.16**	**-0.51**
0.55	0.40	0.05	**-11.13**	**-11.12**	**0.24**	**0.26**	**-1.26**	**-1.37**	**0.18**	**0.22**	**-0.24**	**-0.73**
0.55	0.45	0.00	**-11.14**	**-11.13**	**0.23**	**0.25**	**-1.25**	**-1.36**	**0.17**	**0.21**	**-0.33**	**-0.95**
0.50	0.30	0.20	**-11.18**	**-11.25**	**0.26**	**0.22**	**-0.94**	**-0.81**	**0.11**	**0.07**	**-0.05**	**-0.25**
0.50	0.35	0.15	**-11.19**	**-11.26**	**0.25**	**0.21**	**-0.93**	**-0.80**	**0.11**	**0.07**	**-0.14**	**-0.47**
0.50	0.40	0.10	**-11.20**	**-11.26**	**0.24**	**0.20**	**-0.92**	**-0.79**	**0.10**	**0.06**	**-0.22**	**-0.69**
0.50	0.45	0.05	**-11.21**	**-11.27**	**0.23**	**0.19**	**-0.90**	**-0.79**	**0.09**	**0.05**	**-0.30**	**-0.92**
0.50	0.50	0.00	**-11.21**	**-11.27**	**0.22**	**0.18**	**-0.89**	**-0.78**	**0.08**	**0.04**	**-0.39**	**-1.14**

Note. Strong realizations of the first, second, and third dividends are highlighted in boldface.

Table 4. Detailed Effects of a Carbon Tax with 50% ITC and 50% SST

(Percent Change with Respect to Reference Scenario)

	2020	2025	2030	2050
Energy				
Total Energy Demand	-7.06	-6.58	-6.34	-6.20
Demand for Fossil Fuels	-10.03	-10.02	-10.01	-10.07
Crude Oil	-6.32	-6.24	-6.19	-6.22
Coal	-31.97	-32.09	-32.14	-32.24
Natural Gas	-2.01	-2.18	-2.26	-2.40
Investment in Wind Energy	21.85	18.84	17.29	15.72
Wind Energy Infrastructures	9.75	12.89	14.44	15.70
Carbon Dioxide Emissions from Fossil fuel Combustion	-11.23	-11.23	-11.21	-11.27
Economy				
GDP	-0.06	0.03	0.08	0.04
Private Consumption	-0.04	-0.03	-0.03	0.00
Private Investment	1.45	1.32	1.23	0.95
Private Capital	0.60	0.83	0.96	1.03
Imported Energy	-7.34	-7.31	-7.28	-7.33
Foreign Debt/GDP	0.62	0.68	0.60	-0.11
Labor Markets				
Unemployment Rate	-0.51	-0.75	-0.89	-0.78
Employment	0.12	0.18	0.22	0.18
Human Capital	-0.02	-0.04	-0.05	-0.11
Wages	0.02	0.06	0.09	0.16
Public Sector				
Public Debt/GDP	-0.05	-0.22	-0.39	-1.14
Public Expenditures	-0.16	-0.11	-0.08	-0.14
Public Consumption	-0.03	0.04	0.09	0.05
Public Investment	-0.37	-0.26	-0.23	-0.39
Investment in Human Capital	-0.32	-0.33	-0.35	-0.42
Public Capital	-0.27	-0.28	-0.27	-0.31
Human Capital	-0.02	-0.04	-0.05	-0.11
Tax Revenues	-0.06	0.02	0.06	0.03
Personal Income Tax	-0.30	-0.16	-0.08	-0.13
Corporate Income Tax	-9.01	-8.81	-8.69	-8.61
Value Added Tax	0.16	0.15	0.15	0.12
Social Security Contributions-employers	-3.75	-3.66	-3.61	-3.64
Social Security Contributions-employees	0.12	0.21	0.26	0.22

Table 5. Detailed Effects of a Carbon Tax with 80% ITC and 20% SST

(Percent Change with Respect to Reference Scenario)

	2020	2025	2030	2050
Energy				
Total Energy Demand	-6.93	-6.27	-5.87	-5.29
Demand for Fossil Fuels	-9.91	-9.71	-9.55	-9.19
Crude Oil	-6.19	-5.92	-5.71	-5.30
Coal	-31.88	-31.86	-31.79	-31.57
Natural Gas	-1.88	-1.85	-1.75	-1.44
Investment in Wind Energy	22.53	19.74	18.34	17.16
Wind Energy Infrastructures	9.92	13.25	14.97	16.81
Carbon Dioxide Emissions from Fossil fuel Combustion	-11.11	-10.92	-10.76	-10.40
Economy				
GDP	0.08	0.37	0.59	1.03
Private Consumption	0.44	0.45	0.46	0.51
Private Investment	3.16	3.07	3.04	3.03
Private Capital	1.24	1.78	2.14	2.80
Imported Energy	-7.22	-6.99	-6.81	-6.42
Foreign Debt/GDP	2.44	3.43	4.11	5.16
Labor Markets				
Unemployment Rate	-1.54	-2.37	-3.00	-4.23
Employment	-0.05	0.16	0.31	0.60
Human Capital	0.00	0.00	0.01	0.02
Wages	-0.01	0.07	0.14	0.26
Public Sector				
Public Debt/GDP	0.13	0.04	-0.02	-0.03
Public Expenditures	0.13	0.32	0.46	0.72
Public Consumption	0.16	0.42	0.62	1.01
Public Investment	0.15	0.43	0.59	0.79
Investment in Human Capital	0.05	0.06	0.07	0.10
Public Capital	-0.11	0.04	0.21	0.66
Human Capital	0.00	0.00	0.01	0.02
Tax Revenues	0.04	0.28	0.46	0.82
Personal Income Tax	-0.54	-0.13	0.18	0.76
Corporate Income Tax	-14.28	-13.83	-13.51	-12.92
Value Added Tax	0.79	0.81	0.82	0.89
Social Security Contributions - employers	-1.61	-1.32	-1.10	-0.67
Social Security Contributions - employees	-0.06	0.24	0.46	0.89

The fact that the optimal mix from an environmental perspective is the same as that from a budgetary perspective and is associated with the smallest economic benefits is not coincidental. There is clearly a trade-off between the environmental and economic effects due to a rebound effect. Recycling the revenue from the carbon tax reduces the environmental effects of the policy by improving economic conditions relative to the lump sum replacement policy and thereby leads to greater energy consumption and emissions. Accordingly, the recycling strategies that maximize the environmental effects implicitly also minimize the economic benefits. In turn, by minimizing the economic benefits, fewer additional tax revenues are generated by the recycling strategy. These also reduce public spending, both exogenous public consumption—which is a fixed share of GDP—and the marginal benefits of endogenous public spending. Both forces result in a greater improvement in budgetary outcomes for those policies that produce greater environmental benefits.

These trade-offs between the environmental and economic effects as well as between the economic and budgetary effects are clear in Table 3. They can be further highlighted by considering the detailed effects of the two optimal mix recycling strategies identified above. These detailed results are presented in Tables 4 and 5.

5. Sensitivity Analysis

We now consider the sensitivity of our results to labor market conditions/assumptions. We have assumed endogenous unemployment as well as endogenous labor supply. In both cases, a certain degree of labor market flexibility is assumed. We consider here, in succession, the cases of exogenous unemployment, which can be thought of as a sclerotic labor market, and the case of exogenous labor supply, which recognizes the limits imposed by population stagnation. The results for the recycling policies previously identified as yielding the three dividends and presented in Table 3, are reported under the two alternative labor market assumptions in Tables 6 and 7.

The results are striking. Under both exogenous unemployment and exogenous labor supply, the economic and budgetary benefits of the revenue recycling strategies are greatly reduced to the point that both the second and third dividend occur much less frequently. Indeed, the second and third dividends now only occur simultaneously in three cases under exogenous unemployment—and in four cases under exogenous labor supply. To be noted these are the only simultaneous realizations of the second and third dividend in the whole grid search and not just among the sixteen cases initially identified.

These results support the argument that labor markets rigidities will produce conditions under which CO_2 taxation is less likely to lead to a reduction in pollution coupled with job creation. At an extreme, perfectly inelastic labor supply by households would result in no misallocations relative to the efficient outcome and thus leave little avenue for CO_2 taxation, in a second-best setting, to shift the tax burden away from more distortionary tax margins and produce employment gains. More flexibility in labor markets create an environment in which the reduction in labor market distortions resulting from income and labor taxes can yield a second dividend for environmental tax reform.

Table 6. Summary of Effects of a Carbon Tax: Exogenous Unemployment Case

(Percent Change with Respect to Reference Scenario)

			Carbon Dioxide Emissions		**Employment**		**Unemploym. Rate**		**GDP**		**Public Debt/GDP**	
ITC	**SST**	**PIT**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**
Lump Sum			-12.09	-12.41	-0.18	-0.37	0.00	0.00	-0.90	-1.24	-4.84	-12.97
0.80	0.20	0.00	**-10.99**	**-10.86**	**0.05**	**0.12**	**0.00**	**0.00**	**0.34**	**0.52**	0.41	0.94
0.75	0.25	0.00	**-11.04**	**-10.94**	**0.06**	**0.11**	**0.00**	**0.00**	**0.28**	**0.42**	0.30	0.63
0.70	0.25	0.05	**-11.08**	**-11.02**	**0.08**	**0.12**	**0.00**	**0.00**	**0.23**	**0.34**	0.27	0.54
0.70	0.30	0.00	**-11.09**	**-11.02**	**0.07**	**0.11**	**0.00**	**0.00**	**0.22**	**0.33**	0.18	0.32
0.65	0.25	0.10	**-11.13**	**-11.09**	**0.10**	**0.12**	**0.00**	**0.00**	**0.18**	**0.25**	0.24	0.46
0.65	0.30	0.05	**-11.14**	**-11.10**	**0.09**	**0.11**	**0.00**	**0.00**	**0.17**	**0.24**	0.15	0.23
0.65	0.35	0.00	**-11.14**	**-11.11**	**0.08**	**0.10**	**0.00**	**0.00**	**0.16**	**0.24**	0.07	0.01
0.60	0.25	0.15	**-11.17**	**-11.17**	**0.12**	**0.13**	**0.00**	**0.00**	**0.13**	**0.16**	0.21	0.37
0.60	0.30	0.10	**-11.18**	**-11.18**	**0.11**	**0.12**	**0.00**	**0.00**	**0.12**	**0.15**	0.12	0.14
0.60	0.35	0.05	**-11.19**	**-11.18**	**0.10**	**0.11**	**0.00**	**0.00**	**0.11**	**0.15**	0.04	-0.08
0.60	0.40	0.00	**-11.19**	**-11.19**	**0.09**	**0.10**	**0.00**	**0.00**	**0.10**	**0.14**	**-0.05**	**-0.31**
0.55	0.30	0.15	**-11.23**	**-11.26**	**0.13**	**0.12**	**0.00**	**0.00**	**0.07**	**0.07**	0.10	0.06
0.55	0.35	0.10	**-11.23**	**-11.26**	**0.12**	**0.11**	**0.00**	**0.00**	**0.06**	**0.06**	0.01	-0.17
0.55	0.40	0.05	**-11.24**	**-11.27**	**0.11**	**0.10**	**0.00**	**0.00**	**0.05**	**0.05**	**-0.08**	**-0.39**
0.55	0.45	0.00	**-11.25**	**-11.27**	**0.10**	**0.09**	**0.00**	**0.00**	**0.04**	**0.05**	**-0.16**	**-0.62**
0.50	0.30	0.20	**-11.27**	**-11.33**	**0.15**	**0.12**	**0.00**	**0.00**	0.01	-0.02	0.07	-0.03
0.50	0.35	0.15	**-11.28**	**-11.34**	**0.14**	**0.11**	**0.00**	**0.00**	0.01	-0.03	**-0.02**	**-0.26**
0.50	0.40	0.10	**-11.29**	**-11.34**	**0.13**	**0.10**	**0.00**	**0.00**	0.00	-0.03	**-0.11**	**-0.48**
0.50	0.45	0.05	**-11.29**	**-11.35**	**0.12**	**0.09**	**0.00**	**0.00**	-0.01	-0.04	**-0.19**	**-0.71**
0.50	0.50	0.00	**-11.30**	**-11.36**	**0.11**	**0.08**	**0.00**	**0.00**	-0.01	-0.05	**-0.28**	**-0.93**

Note. Strong realizations of the first, second, and third dividends are highlighted in boldface.

Table 7. Summary of Effects of a Carbon Tax: Exogenous Labor Supply

(Percent Change with Respect to Reference Scenario)

			Carbon Dioxide Emissions		Employment		Unemploym. Rate		GDP		Public Debt/GDP	
ITC	**SST**	**PIT**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**
Lump Sum			-12.09	-12.30	-0.20	-0.25	1.88	2.43	-0.90	-1.11	-4.78	-13.12
0.80	0.20	0.00	**-10.85**	**-10.71**	**0.21**	**0.27**	**-2.02**	**-2.54**	**0.49**	**0.68**	0.13	0.43
0.75	0.25	0.00	**-10.93**	**-10.83**	**0.18**	**0.23**	**-1.76**	**-2.19**	**0.40**	**0.55**	0.08	0.23
0.70	0.25	0.05	**-11.02**	**-10.95**	**0.16**	**0.19**	**-1.49**	**-1.81**	**0.30**	**0.42**	0.12	0.28
0.70	0.30	0.00	**-11.01**	**-10.94**	**0.16**	**0.19**	**-1.50**	**-1.83**	**0.31**	**0.42**	0.02	0.02
0.65	0.25	0.10	**-11.10**	**-11.07**	**0.13**	**0.15**	**-1.22**	**-1.43**	**0.21**	**0.28**	0.17	0.34
0.65	0.30	0.05	**-11.10**	**-11.06**	**0.13**	**0.15**	**-1.23**	**-1.45**	**0.21**	**0.29**	0.07	0.08
0.65	0.35	0.00	**-11.10**	**-11.05**	**0.13**	**0.15**	**-1.24**	**-1.47**	**0.21**	**0.29**	**-0.04**	**-0.18**
0.60	0.25	0.15	**-11.19**	**-11.19**	**0.10**	**0.11**	**-0.95**	**-1.04**	**0.11**	**0.14**	0.22	0.39
0.60	0.30	0.10	**-11.19**	**-11.18**	**0.10**	**0.11**	**-0.96**	**-1.07**	**0.11**	**0.15**	0.12	0.13
0.60	0.35	0.05	**-11.18**	**-11.17**	**0.10**	**0.11**	**-0.97**	**-1.09**	**0.11**	**0.16**	0.01	-0.13
0.60	0.40	0.00	**-11.18**	**-11.17**	**0.10**	**0.12**	**-0.98**	**-1.11**	**0.12**	**0.17**	**-0.09**	**-0.39**
0.55	0.30	0.15	**-11.27**	**-11.30**	**0.07**	**0.07**	**-0.68**	**-0.68**	**0.01**	**0.02**	0.17	0.19
0.55	0.35	0.10	**-11.27**	**-11.29**	**0.07**	**0.07**	**-0.69**	**-0.70**	**0.02**	**0.02**	0.06	-0.07
0.55	0.40	0.05	**-11.27**	**-11.29**	**0.07**	**0.08**	**-0.70**	**-0.72**	**0.02**	**0.03**	**-0.04**	**-0.33**
0.55	0.45	0.00	**-11.26**	**-11.28**	**0.07**	**0.08**	**-0.71**	**-0.75**	**0.02**	**0.04**	**-0.15**	**-0.59**
0.50	0.30	0.20	**-11.36**	**-11.42**	**0.04**	**0.03**	**-0.41**	**-0.30**	-0.08	-0.12	0.22	0.24
0.50	0.35	0.15	**-11.36**	**-11.42**	**0.04**	**0.03**	**-0.42**	**-0.32**	-0.08	-0.11	0.11	-0.02
0.50	0.40	0.10	**-11.35**	**-11.41**	**0.04**	**0.04**	**-0.43**	**-0.34**	-0.08	-0.11	0.01	-0.28
0.50	0.45	0.05	**-11.35**	**-11.40**	**0.05**	**0.04**	**-0.44**	**-0.36**	-0.07	-0.10	**-0.10**	**-0.54**
0.50	0.50	0.00	**-11.35**	**-11.40**	**0.05**	**0.04**	**-0.45**	**-0.38**	-0.07	-0.09	**-0.20**	**-0.80**

Note. Strong realizations of the first, second, and third dividends are highlighted in boldface.

This is consisted with the evidence in the literature. Generally, taxes are more distortionary and generate a larger excess burden for tax bases that are more elastic. Specifically, the scope of achieving employment dividends is conditioned by the flexibility in labor supply and wage formation, and by unemployment and market clearing assumptions (see, for example, Bovenberg & Van der Ploeg, 1996, 1998a, 1998b; Carraro et al., 1996; and Faehn, Gomez, & Kverndokk, 2009).

6. Summary and Final Remarks

This paper focuses on the environmental, economic and budgetary impacts of a CO_2 tax in the presence of mixed recycling strategies and a detailed modelling of labor market conditions, employment and unemployment. This focus is intended to match the terms of the policy debate in many small energy-importing economies, in which environmental objectives are often perceived as clashing with the need to promote output growth and improve labor market conditions and occur in a context of serious concerns about public debt. We use a dynamic endogenous growth general equilibrium model of the Portuguese economy to illustrate our points.

The introduction of a CO_2 tax without accompanying revenue-recycling policies reduces CO_2 emissions, but has a negative effect on economic performance, both in terms of output and in terms of employment and unemployment. Such a tax would not be viable in a policy environment in which employment and growth are central concerns. Nonetheless, with the aid of numerical simulations, we have shown that it is possible to design a revenue-neutral CO_2 tax package that yields three dividends. Specifically, the introduction of a CO_2 tax with accompanying reductions in distortionary tax rates can reduce emissions, while producing long-term economic and budgetary effects that are positive or, at a minimum, neutral. We find that the realization of the second and third dividends crucially depends on the judicious use of the revenues generated by the carbon tax.

The revenue-recycling policies that appear most promising in terms of simultaneously yielding the three dividends are those that use the revenue raised from the CO_2 tax to finance investment tax credits, a reduction in Social Security contributions, and a reduction in the personal income tax rate. Although none of these recycling mechanisms would individually lead to the three dividends, the use of the CO_2 tax revenue in a way that exploits a mixture of these three mechanisms allows the three dividends to materialize. Specifically, we find that allocating 80% of the revenues to investment tax credits and 20% to reductions of social security contributions maximizes the economic effects of the carbon tax, while a 50-50 distribution of revenues between investment tax credits and social security contributions maximizes the environmental and budgetary effects.

Finally, our analysis suggests that the specification of labor markets—or the nature of the actual labor markets—is a critical factor in the determining the possibility of generating the three dividends. This is an important point from both a methodological and applied policy perspective. From a methodological perspective, it highlights the fact that ignoring employment and unemployment effects are not innocuous assumptions. They lead to a systematic undervaluation of the benefits of revenue recycling and to underreporting in terms of the occurrence of the three dividends and thereby the political viability of carbon taxation under revenue recycling. From a policy perspective, this suggests another reason why labor market reforms may be important as they can reduce the persistence in unemployment patterns or increase the responsiveness of labor supply to market conditions.

To conclude, it should be mentioned that, although this article illustrates these issues in the context of the Portuguese case, its interest and applicability is far from parochial. Naturally, climate and energy are at the forefront of the policy concerns and objectives in the EU (see, for example, European Commission, 2014a, 2014b) and, as such, all EU countries need to deal with these issues, albeit to different extents. In addition, there is a growing chorus of institutional voices urging all countries to adopt green taxes and to recycle their revenues to jump start their economies (see, for example Euro

Group, 2014; IMF, 2014; OECD, 2014; Parry et al., 2014; and World Bank, 2014). Furthermore, the interactions between climate policy, economic growth and the public-sector account are fundamental in the evaluation of policy, since they correlate to the most important policy constraints faced by many economies in their pursuit of sound climate policies: the need to pursue public policies that not only promote long-term economic growth, but also strengthen their public budgets.

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