Environmental Fiscal Reform and Fiscal Consolidation: The Quest for the Third Dividend in Portugal*

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Abstract

This paper explores the capacity for environmental fiscal reform to reduce CO_2 *emissions, stimulate economic performance, and promote fiscal sustainability. Simulation results suggest that reforms based on* CO_2 *taxation stimulate GDP when tax revenues are used to promote private or public investment and stimulate employment when used to finance reductions in personal income taxation or firms' social security contributions. More generally, reforms allow for reductions in the costs of climate policy, a weaker realization of the second dividend. In addition, several reforms lead to reductions in public debt, the realization of a third dividend. When political constraints on reducing public spending are considered, however, this third dividend only materializes when revenues finance public investment or reductions in the firms' social security contributions. Overall, our results suggest that low growth and high public debt need not be regarded as hindrances for environmental fiscal reform but can actually be seen as catalysts.*

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1. INTRODUCTION

Environmental tax reform has gained momentum as an important part of a package of policy instruments for reducing greenhouse gas emissions in a cost-effective manner. These policies replace revenue from existing taxes with revenue from taxes on pollution. The presence of distortions in the tax system gives rise to the potential for simultaneous improvements in environmental outcomes and economic performance called a double dividend (e.g. Goulder 1995; Parry and Williams 1999; Parry and Bento 2000; Goulder, Bovenberg, and Jacobsen 2008; Fullerton and Kim 2008). The key factors determining the existence of a double dividend are the magnitude of existing inefficiencies and the extent to which reform shifts taxes from more efficient to less efficient factors, making potential efficiency gains dependent on the structure of the tax system (e.g. Bovenberg and Goulder 1995). This has lead to the analysis of environmental tax reform for economies and public sectors with different structures (e.g. Farmer and Steininger 1999; Takeda 2007; Conefrey et al. 2008).

The focus of the literature has expanded from simple environmental tax reform to more general environmental fiscal reform by considering the impact of tax deductible spending, partial corporate income tax integration, and public debt financing (e.g. Parry and Bento 2000; Metcalf 2005; Conferey et al. 2008). This paper continues this line of research by studying environmental fiscal reforms that include the traditional tax policies but also include tax expenditure, renewable energy and public expenditure policies, policies not previously examined in the literature.

This more comprehensive analysis of revenue recycling options is especially pertinent and timely. Programs, including those in the EU, the Regional Greenhouse Gas Initiative and the Western Climate Initiative, now advocate the use of CO_2 permit revenue to support the deployment of renewable energies, job training and social transfers, among others options (see, for example, WCI 2008; EU 2009; and RGGI 2011). Our analysis contributes directly to this debate through the analysis of various revenue recycling options available to Portugal in the context of emissions permit auctions in the EU Emissions Trading System.

In a different vein, and more importantly from the standpoint of this paper, we have witnessed a generalized growing concern over mounting public debt in recent years and the need to promote fiscal sustainability. CO_2 taxes and auctioned emissions permits have emerged as potentially important instruments for increasing public revenues (e.g. Metcalf and Weisbach 2008; Galston and MacGuineas 2010; Metcalf 2010; Nordhaus 2010). In this context, this paper expands the traditional focus of the literature on the double dividend to the quest for a third dividend, fiscal sustainability. We define this third dividend as a reduction in the public debt to GDP ratio resulting from revenue neutral environmental fiscal reform. This is a very strong definition in that it excludes the direct use of CO_2 tax revenue to pay down public debt, which has been the focus of much of the literature (e.g. Farmer and Steininger 1999; Conferey et al. 2008) and instead focuses on second order tax revenue and spending effects.

In this paper we address these issues in the context of a dynamic general equilibrium model of the Portuguese economy. This model incorporates fully dynamic optimization behavior, endogenous growth, and a detailed modeling of public sector activities, both tax revenues and consumption and investment spending. Previous versions of this model have been used to evaluate the impact of tax policy (Pereira and Rodrigues 2004), social security reform (Pereira and Rodrigues 2007) and, more recently, energy and environmental policy (Pereira and Pereira 2011).

The key distinguishing feature of this model in the applied climate policy literature is its focus on endogenous growth and the associated treatment of public sector optimization behavior (see Conrad 1999; Bergman 2005; for literature surveys). Productivity enhancing public sector investment in public capital and human capital, which have been largely overlooked in applied climate policy (e.g. Carraro, De Cian, and Tavoni 2009), are, in addition to private investment, the drivers of endogenous growth. Furthermore, the analysis of the interaction between fiscal policies, public capital, economic growth, and environmental performance has garnished little attention and then only in a theoretical framework (e.g. Greiner 2005; Gupta and Barman 2009). Our focus is on strategic long-term choices in a policy environment framed by concerns over both growth and fiscal consolidation. This being the case our focus on endogenous growth and on public sector behavior is most appropriate.

2. THE DYNAMIC GENERAL EQUILIBRIUM MODEL

In this section we present the dynamic general equilibrium model of the Portuguese economy in very general terms. Complete model documentation with detailed descriptions of the model equations, parameters, data, calibration, and numerical implementation, can be found in Pereira and Pereira (2012).

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 an 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. 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 is defined according to 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 the 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, 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 over the periods allowed for depreciation allowances is used and investment is assumed to grow at the same rate at which output grows. Under these assumptions, depreciation allowances simplify 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 financial link of the firm with the rest of the economy, we assume that at the end of each operating period the net cash flow is transferred to the consumers.

2.2 THE ENERGY SECTOR

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. With the taxation of primary energy consumption by firms, costs are transmitted through to consumers and consumer goods in a fashion consistent with the energy content of the good.

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. 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 the Intergovernmental Panel for Climate Change (2006) reference approach. These considerations suggest a linear relationship between CO_2 emissions and fossil fuel combustion activities.

Aggregate primary energy demand is produced with a CES technology in which crude oil, and non-transportation fuels are substitutable at a rate less than unity reflective of the dominance of petroleum products in transportation energy demand and the dominance 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 recognizing the relatively greater potential substitution effects in electric power and industry. The accumulation of wind energy infrastructure is characterized by a dynamic equation of motion where the physical capital, wind turbines, depreciates and investment is subject to adjustment costs as private capital. Wind energy investment decisions are internal to the firm while coal, natural gas and oil are imported from the foreign sector.

We limit our analysis of renewable energies in Portugal to wind energy infrastructures. Though it plays a relatively minor, albeit growing role in the energy system, wind energy infrastructure investment policies have been at the center of efforts to promote the deployment of renewable energy resources in Portugal. Regulatory constraints prevent the construction of nuclear energy facilities. As such, nuclear energy options have not been considered in the model. Hydroelectric power plays an important role in the Portuguese energy sector. Severe limits exist, however, with respect to the potential for expansion of the use of large scale hydroelectric facilities in Portugal. Thus, these capital inputs are used by the firm but we do not consider the potential for additional investment in hydroelectric facilities. In turn, solar power was excluded from the analysis due to the fact that it plays an extremely minor role in the energy system.

Optimal primary energy demand is derived from the maximization of 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 in a non-deterministic fashion. 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 the consolidated budget constraint. The objective function is lifetime expected utility subjectively discounted. Preferences are additively separable in consumption and leisure, and take on the CES form. A lower probability of survival reduces the effective discount factor 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 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 is augmented by net interest payments received on public debt, profits distributed by corporations, international transfers, and 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 and moreover allows us to write the aggregate demand for leisure as a function of aggregate consumption.

2.4 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 by increases in public debt. Total tax revenues include personal income taxes, corporate income taxes, value added taxes, and social security taxes levied on firms and workers. All of these taxes are levied on endogenously defined tax bases. Residual taxes are modeled as lump sum and are assumed to grow at an exogenous rate.

The public sector pays interest on 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 and public investment activities 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 to adjustment costs that are a fraction of the respective investment levels. The adjustment cost functions are strictly convex and quadratic.

Public sector decisions consist in choosing the trajectories for public consumption, public investment in human capital and public investment in public capital that maximize social welfare, defined as the net present value of the future stream of utility derived from public consumption, parametric on household private consumption-leisure decisions. 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. Optimal conditions are defined for public debt, for public consumption, for public investment, and for investment in human capital.

2.5 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 incorporate payments by firms for fossil fuels and are financed through foreign transfers and foreign borrowing. Foreign transfers grow at an exogenous rate. The domestic economy is assumed to be a small, open economy. This means that it can obtain the desired level of foreign financing at a rate which is determined in the international financial markets. This is the prevailing rate for all domestic agents.

2.6 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 clearing condition incorporates an exogenous structural 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, the financial market equilibrium reflects the fact that private capital formation and public indebtedness are financed by household savings and foreign financing.

We define the steady-state growth path as an intertemporal equilibrium trajectory in which all the flow and stock variables grow at the same rate, g, while market prices and shadow prices are constant. 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 g 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.

2.7 DATASET, PARAMETER SPECIFICATION, AND CALIBRATION

The model is implemented numerically using detailed data and parameters sets. The dataset reflects the GDP and stock variable values in 2008; public debt and foreign debt reflect the most recent available data. Data are from the Statistical Annex of the European Community, the Portuguese Ministry of Finance and the Portuguese Directorate General for Geology and Energy. The decomposition of the aggregate variables follows the average for the period 1990-2008 for macroeconomic aggregates and 1999-2008 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.

Over the past decades, the Portuguese economy has exhibited weak economic growth and soaring levels of public debt. The per worker real growth rate of the economic activity between 1990 and 2008 was 1.763 percent while the level of public debt reached 85.8 percent of GDP in 2008, prior even to the recent debt crisis over which public debt has grown to in excess of 115 percent of GDP. These figures underscore some of the primary concerns of the Portuguese economy as well as other small oil importing economies exhibiting weak economic growth and high levels of public indebtedness.

Primary demand for crude oil in our baseline trajectory grows to 658.8 PJ (65.0 percent of primary energy demand), coal demand to 169.1 PJ (16.7 percent of primary energy demand), demand for natural gas to 158.0 PJ (15.6 percent of primary energy demand), and wind generating capacity to 27.0 PJ (2.7 percent of primary energy demand) in 2020. These lead to a baseline projection for emissions of 71.9 Mt CO_2 in 2020. The reference trajectory does not incorporate policy constraints on emissions. This stems from the fact that our objective is to evaluate the relative impact of potential policies to be implemented and to achieve emissions reductions goals by 2020.

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 output scale parameter, and the different effective tax rates. These parameters play no direct role in the model calibration. All the other parameters are obtained by calibration; i.e., in a way that the trends of the economy for the period 1990–2008 are extrapolated as the steady-state trajectory. These calibration parameters assume two different roles. In some cases, they are chosen freely in that they are not implied by the state-state restrictions. This is the case, for example, of the discount rate, the inter-temporal elasticity of substitution, the elasticities of substitution, the shares for labor and capital in production, and the public capital externality. Although free, these parameters have to be carefully chosen since their values affect the value of the remaining calibration parameters. Accordingly, they were chosen using available data as guidance. The remaining calibration parameters are obtained using the steady-state restrictions discussed above.

3. ENVIRONMENTAL FISCAL REFORM

3.1 SIMULATION DESIGN

Our simulation experiments are designed to identify the impact of environmental fiscal reform on economic performance and the public sector account. The different revenue recycling policies are grouped according to the basic mechanism for cost containment involved, as opposed to public sector accounting conventions. The policies are grouped as follows: (1) policies that stimulate demand, namely, the value added tax replacement and public consumption financing; (2) employment oriented policies, including personal income tax replacement, firms' social security contribution replacement, and human capital investment financing; and, (3) policies that encourage investment in physical capital, including private and wind energy investment tax credits and public capital financing.

The environmental fiscal reforms under consideration are designed to be revenue neutral. By construction, the CO_2 tax revenue is directly offset by increased spending or decreased tax receipts - that is the relevant public sector tax or spending parameter decreases or increases in a manner such that the additional tax revenue from the CO_2 tax is fully compensated by either a reduction in revenue or an increase in spending of equal magnitude; this affects the tax rates and the levels of spending relative to the lump sum redistribution policy. The policies, however, are not deficit neutral. The net effect of the reform on the public sector account, and the realization of a third dividend, depends on optimal public sector spending decisions, second order tax revenue effects and tax interactions which can increase distortions in a second best setting.

3.2 ON THE EFFECTS OF DEMAND-DRIVEN RECYCLING POLICIES

We evaluate the economic and budgetary impacts of compliance with the emissions target set out in EU Decision 406/2009/EC, limiting emissions in Portugal in 2020 to a one percent increase above 2005 levels. Naturally, more aggressive policies are required to meet longer term and more ambitious targets. We begin with a discussion of the demand oriented policies, followed by employment driven policies and physical capital investment driven policies. Economic and budgetary impacts are presented as percentage point of GDP deviations from the steady state baseline; employment effects are presented as a percent of the steady state. All results are presented with respect to deviations from the steady state in 2050 unless otherwise indicated. Table 1 through 6 present the simulation results.

The lump sum revenue recycling policy scenario provides a basic reference point for our analysis of the remaining policies, in part because it serves to differentiate a weak from a strong double dividend. In spirit the lump sum replacement policy is a demand driven policy operating through an increase in income not affecting the incentive environment.

From the marginal abatement curves, we find that a tax of €16.50 per tCO_2 achieves the 2020 emission target with the lump sum replacement policy. The tax increases energy costs, which has a negative effect on the firms' net cash flow, limiting input demand. This is consistent with an overall reduction in input levels coupled with a shift in demand in favor of capital and especially labor. Given the reductions in factor demand, it is no surprise that CO_2 taxation has a negative impact on GDP and household income. Ultimately, the net effect of the dynamic feedback between income, consumption and production yields a 0.9 p.p. reduction in GDP.

On the positive side, this policy reduces public debt by 2.0 p.p. to 83.1 percent of GDP, allowing for the realization of a third dividend. Public spending reductions due to the greater opportunity cost of public funds are the driving forces behind this effect. Overall, the drop in productivity-enhancing public investment activities compounds the negative effects of CO_2 taxation on private inputs and economic activity. In turn, there is a contraction of the tax bases due to lower incomes coupled with reductions in product and factor demand. This is largely offset by the additional revenue from the CO_2 tax resulting in net increase in tax revenues.

For the two remaining demand driven reforms, the CO_2 tax revenue is used to stimulate private and public consumption activities by offsetting VAT revenues and by financing public consumption directly. Both policies require a tax of €17.00 per tCO_2 to achieve the emissions target. The resulting CO_2 tax revenues can finance either a 5.5 percent reduction in the value added tax rate or a 4.5 percent increase in public consumption relative to the lump sum policy.

These demand policies yield a small improvement in economic performance over the lump sum recycling policy, yielding a weak double dividend. In both cases, GDP falls by 0.7 p.p. while employment remains virtually unchanged in 2020 and falls by 0.2 percent in 2050. This small improvement in GDP and, relatively greater improvement in employment outcomes reflects the small distortions associated with indirect taxation.

In turn, both demand policies allow for a third dividend as a result of optimal reductions in public spending. The reductions in public debt, however, are smaller than for the lump sum recycling policy. The value added tax replacement policy leads to smaller public debt gains than the public consumption financing policy because the public sector is free to increase public consumption levels in the value added tax replacement policy while public consumption levels are fixed in the public consumption financing policy at the lump sum levels plus the additional spending made possible by the CO_2 tax receipts..

The principal distinction between the value added tax replacement policy and the public consumption financing policies lies in their impact on private and public consumption behavior. Naturally, the value added tax replacement policy stimulates increased private consumption; the public consumption financing policy, in contrast, encourages increased public consumption.

3.3 ON THE EFFECTS OF EMPLOYMENT-DRIVEN RECYCLING POLICIES

We now turn our attention to the employment driven reforms: the personal income tax replacement, firms' social security contributions replacement and human capital investment financing policies. These allow us to evaluate labor responses to reductions in the tax burden on households and firms as well as responses to financing for labor productivity enhancing public sector investment in education. These policies require a tax of €17.50 per tCO_2 to ensure compliance with climate policy objectives. The CO_2 tax revenues finance either a 18.0 percent reduction in the personal income tax rate, a 9.4 percent reduction in the employers' social security contribution rate or a 7.7 percent increase in public investment in education.

Overall, the employment driven policies generate larger improvements in economic performance and larger reductions in the costs of climate policy than do the demand driven policies. These policies result in a 0.3 p.p. drop in GDP for the personal income tax replacement policy, 0.5 p.p. for the firms' social security contributions replacement policy and 0.6 p.p. for the human capital investment financing policy. The personal income tax and firms' social security contributions replacement policies result in a strong double dividend with respect to employment that is, an improvement in environmental performance together with employment gains, while the human capital investment financing does not. Employment increases by 0.5 percent in the personal income tax replacement policy and by 0.3 percent in the firms' social security contributions replacement while it falls by 0.2 percent in the human capital financing policy.

The main difference between the personal income tax replacement and the remaining two employment policies is the effect on wages. The firms' social security contribution replacement policy represents a labor demand shock which leads to a 0.6 percent increase in wages. In contrast, the increase in labor supply for the personal income tax replacement policy represents a labor supply shock which yields a 0.8 percent drop in wages. Similarly, human capital investment serves as a relative substitute for worker hours. These factors allow for larger employment and private consumption gains in the personal income tax replacement policy.

Both the personal income tax replacement and the firms' social security replacement policies allow for a third dividend while the human capital investment financing policy does not. Public debt falls by 1.8 p.p. in the personal income tax replacement policy and by 1.7 p.p. in the firms' social security contribution replacement policy and increases by 1.2 p.p. in the human capital investment financing policy.

The impact of these policies on employment and wages, by affecting private consumption decisions, leads to differences in public sector expenditure patterns. Public expenditure falls by less in the social security contributions replacement policy due primarily to smaller reductions in public consumption but also due to smaller reductions in public investment in education. The similarities in public debt effects between the two tax policies results from greater levels of revenues, particularly employees' social security contributions in the firms' social security contributions replacement policy. Naturally, the human capital investment financing policy yields larger levels of public expenditure.

3.4 ON THE EFFECTS OF INVESTMENT-DRIVEN RECYCLING POLICIES

Finally, we consider the cases that use CO_2 tax revenues to finance investment in physical capital, namely a private capital and wind energy infrastructure investment tax credit, and public capital investment financing. Climate objectives can be achieved with a CO_2 tax of €14.50 per tCO_2 when tax revenues are used to finance a wind energy investment tax credit. In contrast, both the private investment tax credit policy and the public investment policy require a tax of €18.50 per tCO_2. The resulting tax revenues could be used to finance either a 188 times larger wind energy investment tax credit, a 5.9 times larger private investment tax credit financing or a 20 percent increase in public investment relative to the lump sum policy.

The private investment tax credit policy stimulates a 0.9 p.p. increase in private investment, boosting GDP by 0.3 p.p. by 2020 and 1.5 p.p. by 2050. In turn, the public investment financing policy crowds in private investment by 0.2 p.p. and yields a 0.3 p.p. expansion in economic activity in 2020 and 4.4 p.p. in 2050. Accordingly, both policies yield a strong double dividend. In addition, over the long term both policies lead to an increase in employment. Employment increases by 0.1 percent, in 2050, in the private investment tax credit financing policy and by 0.4 percent for the public capital financing policy. These employment gains, however, occur only after somewhat substantial short term losses in employment, particularly for the public capital financing policy. The case of the wind energy investment tax credit policy differs in that it only yields a weak double dividend.

The relative merits of the private capital investment tax credit and public investment financing policies depends primarily on the marginal products of each type of capital investment, its depreciation rate and adjustment costs. In both policies, the marginal increase in investment financing is equal to the CO_2 tax revenue. As a result, the public investment policy is subject to greater adjustment costs due to the relatively smaller stock. Over the long term, however, the lower depreciation rate and slightly larger marginal product provide for a substantial contribution towards economic growth. As more investment in wind energy is undertaken this will yield substantial adjustment costs, nonlinearities in the substitutability of wind energy for other energy resources, and a diminishing marginal product consistent with the fact that additional capacity is more likely to be installed in less productive locations.

Of the three policies, only the wind energy investment tax credit financing yields, albeit only very marginally, a third dividend, reducing public debt by 0.4 p.p. The public investment financing policy increases public debt by 8.1 p.p. while the private investment tax credit financing policy increases public debt by 2.5 p.p. The increases in public debt result from substantial increases in public consumption and public investment in the public investment financing policy while in the private investment tax credit financing policy they are the outcome of more modest public consumption increases together with weaker revenue growth, particularly over the short term as firms employ less labor.

4. SENSITIVITY ANALYSIS

4.1 ON THE RELEVANCE OF ENDOGENOUS PUBLIC SPENDING

In the previous sections, we considered optimal adjustments to public sector spending decisions, often in the form of reductions in public spending, which led to favorable budgetary outcomes. It is well understood, however, that political realities may not allow for such spending reductions. Here we explore the implications of maintaining pre-reform public consumption and public investment levels. Table 7 presents simulation results which highlight the role of public sector spending decisions on the realization of a second and third dividend. The overarching message is that only in a very limited number of cases can positive budgetary outcomes be sustained through the combination of revenue raised directly by the CO_2 tax and net positive second order effects. That is, curtailing spending, particularly public consumption, is an essential component of fiscal reform policies capable of producing the third dividend.

Exogenous public consumption decisions affect both the magnitude and the nature of the second dividend, particularly with respect to employment. Exogenous public consumption decisions can produce marginally favorable labor market outcomes and allow for a realization of the strong double dividend that would not materialize in the presence of optimal adjustments to public consumption. This is most notable for the public consumption financing policy and the wind energy investment tax credit financing policy in which a strong employment dividend materializes in the presence of an exogenous public consumption trajectory.

Exogenous public sector investment decisions also affect the magnitude of the second dividend. By preventing policy induced reductions in investment spending, we observe positive economic growth effects, suggesting lower policy costs than in the presence of the endogenous growth mechanisms. In this context, the human capital investment financing policy yields marginal long term GDP gains and a strong form of the double dividend. Generally, however, the exogenous public investment levels serve to dampen the effects of the policies.

Consider now the third dividend. An exogenous trajectory for public consumption implies that, in most cases, optimal reductions in public consumption do not materialize. This effectively eliminates the gains in fiscal consolidation in all but the firms' social security contributions option. In contrast, lower levels of public consumption in the public investment financing policy allow for a third dividend where it did not exist before. In general, it is clear that responsible public consumption decisions are critical for the third dividend to materialize.

More generally, the exogenous public consumption case allows us to gain additional insight into the relative merits of the private and public capital investment financing policies. For the public capital investment financing policy, expanding tax bases contribute to positive second order tax revenue effects. Thus, if public consumption activities do not expand, this policy can lead to emissions reductions, increased employment and GDP growth and fiscal consolidation. The same effect does not materialize for the private investment tax credit policy due to the fact that the substitution of private capital for labor inputs is more pronounced, leading to short term losses in personal income tax revenue and social security contributions.

In turn, with exogenous public investment trajectories, which eliminate the mechanisms of endogenous growth, any meaningful public debt gains are neutralized in all but the public consumption financing policy. Although under the personal income tax replacement and the firms' social security contributions replacement a third dividend can still be identified, it is rather small and certainly substantially smaller than under our central assumption.

It is important to note that although reducing social security contributions by employers may have the potential to generate positive budgetary effects, these can have an undesirable effect on the sustainability of social security account. The firms' social security contributions recycling option generates positive second-order tax revenue effects as a result of the increase in wages and employment levels. This leads to an increase in workers social security contributions. In practice, this is one of the more robust policies in terms of producing the three dividends.

4.2 ON THE IMPORTANCE OF THE ELASTICITIES OF SUBSTITUTION

It is widely recognized in the literature that the elasticity of substitution between value added and energy as well as among energy inputs play a significant role in a general equilibrium analysis of energy-related matters (e.g. Jacoby et al. 2006; Schubert and Turnovsky 2010; Pereira and Pereira 2011). This is because the appropriate choice for the elasticity of substitution parameters can yield smooth continuous approximations consistent with engineering estimates from bottom up representations of the energy system (Gerlagh et al. 2002; Kiuila and Rutherford 2010). The magnitude of the results, though not the ranking of the policies nor general considerations regarding the realization of the third dividend, are most sensitive to restrictions on the ease with which firms can substitute away from energy in production[1]. Generally, the order of magnitude of the changes in the economic and budgetary results due to differences in the elasticities of substitution, particularly in the effect of moving to a Cobb-Douglas specification – a widely understood effect – are on par with the changes generated by the endogenous growth mechanisms and endogenous public sector behavior – effects largely ignored in the literature. Overall, this reinforces our methodological contention that ignoring endogenous public sector decisions and endogenous long-term growth would lead to a serious misrepresentation of the effects on fiscal reform on economic activity and on the public budget.

5. SUMMARY AND CONCLUDING REMARKS

This paper examines the extent to which environmental fiscal reform can be designed to produce three dividends: lower emissions, lower climate policy costs, and fiscal consolidation. All policy options achieve, by design, the first dividend, i.e., a reduction in CO_2 emissions consistent with the 2020 climate policy target. Under the lump sum reference recycling option this requires a tax of €16.50 per tCO_2. Most of the remaining policy options require taxes between €17.00 and €18.50 due to the existence of small rebounds in emissions. These figures are in line with the current value of forward contracts for 2020 emission permits reflective of expected revenue levels for permit auctions in phase III of the EU-ETS.

In terms of the second dividend, our results are very suggestive. All reforms considered reduce climate policy costs compared to the reference lump sum case and thereby allow for the realization of a weak double dividend. More importantly, we show that environmental fiscal reform can stimulate output through private and public investment financing policies - an increase in GDP of 1.1 p.p. and 4.4 p.p., respectively - and generate employment gains through reductions in the personal income tax rate and firms' social security contributions - of 0.2 percent and 0.1 percent, respectively. These are cases of a strong realization of the second dividend.

These results contribute to the mounting evidence that environmental fiscal reforms that encourage private capital formation provide greater economic gains than those that encourage final demand (e.g. Bovenberg and Goulder 1995; Farmer and Steininger 1999; Takeda 2007). A novel feature of our analysis is that we show that recycling policies that promote public investment can also lead to very strong gains. Furthermore, we find significant differences between subsidies that stimulate employment and investment.

The costs of meeting the 2020 emissions targets in Portugal have been computed in different modeling environments. The median estimate across six models is a welfare reduction of 0.5 percent with a single notable outlier at 5.5 percent (see Tol 2012). The estimates are fairly close to the EU average. Our analysis centers primarily on GDP effects, as opposed to welfare effects. Our central results are somewhat larger that those reported in the literature, reflecting the importance of the mechanisms of endogenous growth and the relatively conservative elasticity of substitution employed here. With an entirely exogenous public sector, that is, both exogenous public consumption and investment, our results are in line with those in the literature. Naturally, under the more favorable policies examined here, the economic impacts are positive.

Analyses of the potential double dividend from reductions in employers' social security contributions generally yield conflicting results. In the context of the Kyoto Protocol, Conrad and Schmidt (1997) suggests that a double dividend, with respect to GDP, is feasible and suggests far larger positive labor market effects for the Portuguese economy under an optimal EU wide policy environment. Babiker, Metcalf, and Reilly (2003), however, report that for the various small European countries including Portugal that no double dividend materializes for the Kyoto Protocol and recycling via labor taxes implies welfare costs of 1.2 percent of GDP.

In terms of the third dividend, our results are even more suggestive. A reduction in public debt occurs under several of the revenues recycling options. This is due to optimal reductions in public expenditure associated with the increasing opportunity cost of public funds. Generally, analyses of the public debt implications of these reforms focus on using CO_2 tax revenue to finance the purchase of debt and find that the costs of these policies exceed those of other revenue recycling options (e.g. Conferey et al. 2008; Farmer and Steininger 1999). Given that our recycling policies are revenue neutral, their impact on public debt is completely determined by second order tax revenue effects and public sector spending decisions. Where political constraints would prevent such optimal reductions in public spending only the firms' social security contributions and the public investment recycling options yield the third dividend. This highlights the critical importance of flexible and responsible spending decision in achieving budgetary consolidation in a framework of environmental fiscal reform.

At this point it should be highlighted that although the analysis and results in this paper are directly relevant for policy making in Portugal, their interest and applicability is far from parochial. Concerns over economic growth and fiscal sustainability are at the forefront of policy discussion in many countries. Against this backdrop environmental policies are regarded with concern if not dismissed outright as untimely. Our results, however, make it clear that it is possible to design policies that achieve environmental objectives while at the same time promoting economic performance and fiscal consolidation. This implies that, the current economic and fiscal woes do not have to be viewed as a hindrance to the implementation of environmental policies but can actually be regarded as a catalyst for such policies.

Finally, this paper opens several interesting avenues for future research and should be regarded as just the starting point of a new line of inquiry. An analysis of the sectoral effects of environmental fiscal reform policies would provide for the distributional implications of policies and their political economy ramifications. An energy process and activity focus for the model could allow for an analysis of revenue recycling policies that focus on promoting technological development and deployment. Given the importance of public debt, future research should incorporate endogenous interest rate mechanisms. Finally, due to the importance of employment concerns in the current policy environment, an endogenous unemployment rate would allow for a more detailed analysis of the labor market implications of policies.

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1. Detailed results for the sensitivity analysis with respect to the elasticity of substitution between value added and energy and between oil and other energy resources are available upon request.

REFERENCES

Babiker, Mustafa H., Gilbert Metcalf, and John Reilly. 2003. Tax distortions and global climate policy. Journal of Environmental Economics and Management 46 (2): 269-287.

Bergman, Lars 2005. CGE modeling of environmental policy and resource management. In Handbook of Environmental Economics (Volume 3), Karl-Göran Mäler and Jeffery R. Vincent, ed., 1273-1306. Amsterdam: North Holland.

Bovenberg, Lans and Lawrence H. Goulder. 1995. Costs of environmentally motivated taxes in the presence of other taxes: general equilibrium analyses. National Bureau of Economic Research Working Paper 5117, Cambridge, MA.

Carraro, Carlo, Enrica De Cian and Massimo Tavoni. 2009. Human capital formation and global warming mitigation: evidence from an integrated assessment model. CESifo Working Paper 2874, Munich.

Conefrey, Thomas, John Gerald, Laura M. Valeri and Richard Tol. 2008. The impact of a carbon tax on economic growth and carbon dioxide emissions in Ireland. Economic and Social Research Institute Working Paper 251, Dublin.

Conrad, Klaus and Tobias Schmidt. 1997. Double dividend of climate protection and the role of international policy coordination in the EU: an applied general equilibrium analysis with the GEM-E3 model. Center for European Economic Research Discussion Paper 97-26, Mannheim.

Conrad, Klaus. 1999. Computable general equilibrium models for environmental economics and policy analysis. In Handbook of Environmental and Resource Economics Jeroen van den Bergh, ed., Cheltenham: Edward Elgar.

Direcção Geral de Energia e Geologia. Ministerio da Economia. 2012. Factura Energética. www.dgeg.pt

EU Decision No 406/2009/EC of the European Parliament and of the Council of April 23.

European Commission. Directorate General for Economic and Financial Affairs (ECFIN). 2012 Statistical annex of the European economy. Spring 2012 European Economy. Brussels.

Farmer, Karl and Karl Steininger. 1999. Reducing CO_2 – emissions under fiscal retrenchment: a multi-cohort CGE-model for Austria. Environmental and Resource Economics 13 (3): 309-340.

Fullerton, Don and Seung-Rae Kim. 2008. Environmental investment and policy with distortionary taxes, and endogenous growth. Journal of Environmental Economics and Management 56 (2): 141-154.

Gabinete de Planeamento, Estrategia, Avaliacao e Relacoes Internacionais, Ministerio das Financas. 2012. Estatistica das Financas Publicas. http://www.gpeari.min-financas.pt/

Galston, William and Maya MacGuineas. 2010. The future is now: a balanced plan to stabilize public debt and promote economic growth. The Brooking Institution.

Gerlagh, Reyer, Bob van der Zwaan, Ger Klaassen and Leo Schrattenholzer. 2002. Endogenous technological change in climate change modelling. Energy Economics 24 (1): 1-19.

Goulder, Lawrence H. 1995. Environmental taxation and the 'double dividend': a reader's guide. International Tax and Public Finance 2(2):157-183.

Goulder, Lawrence H., Lans Bovenberg, and Mark Jacobsen. 2008. Costs of alternative environmental policy instruments in the presence of industry compensation requirements. Journal of Public Economics 92 (5-6): 1236-1253.

Greiner, Alfred. 2005. Fiscal policy in an endogneous growth model with public capital and pollution. The Japanese Economic Review 56 (1): 67-84.

Gupta, Manash R., and Trishita R. Barman. 2009. Fiscal policies, environmental pollution and economic growth. Economic Modelling. 26 (5): 1018-1028.

Jacoby, Henry D., John M. Reilly, James R. McFarland, and Sergey Paltsev. 2006. Technology and technical change in the MIT EPPA model. Energy Economics. 28 (5-6): 610-631.

Kiuila, Olga and Thomas Rutherford. 2010. Abatement options and the economy-wide impact of climate policy. International Energy Workshop 21-23 June Stockholm Sweden.

Metcalf, G. 2005. Tax reform and environmental taxation. National Bureau of Economic Research Working Paper 11665, Cambridge, MA.

Metcalf, Gilbert. 2010. Submission on the use of carbon fees to achieve fiscal sustainability in the federal budget. Available at: http://works.bepress.com/gilbert_metcalf/86.

Metcalf. Gilbert, and David Weisbach. 2008. The design of a carbon tax. Discussion Papers Series, 0727, Department of Economics, Tufts University.

Nordhaus, William D. 2010. Carbon taxes to move toward fiscal sustainability. The Economists' Voice 7 (3) Article 3.

Parry, Ian and Roberton C. Williams III. 1999. A second-best evaluation of eight policy instruments to reduce carbon emissions. Resource and Energy Economics. 21 (3-4): 347-373.

Parry, Ian and Antonio M. Bento. 2000. Tax deductions, environmental policy, and the "double dividend" hypothesis. Journal of Environmental Economics and Management. 39 (1):67-96.

Pereira, Alfredo, and Rui Pereira. 2011. On the environmental, economic and budgetary impacts of fossil fuel prices: a dynamic general equilibrium analysis of the Portuguese case. College of William and Mary Economics Working Paper 110.

Pereira, Alfredo, and Rui Pereira. 2012. DGEP - a dynamic general equilibrium model of the Portuguese economy: model documentation. The College of William and Mary, Working Paper 127.

Pereira, Alfredo, and Pedro Rodrigues. 2004. Strategies for fiscal reform in the context of the EMU: the case of Portugal. Review of Development Economics. 8 (1): 143-165.

Pereira, Alfredo, and Pedro Rodrigues. 2007. Social security reform in Portugal: A Dynamic General Equilibrium Analysis. Portuguese American Development Foundation, Lisbon.

Regional Greenhouse Gas Initiative. 2011. Investment of proceeds from RGGI CO_2 allowances. http://www.rggi.org/docs/Investment_of_RGGI_Allowance_Proceeds.pdf

Schubert, Stefan, and Stephen J. Turnovsky. 2010. The impact of oil prices on an oil-importing developing economy. Journal of Development Economics. 94 (1): 18-29.

Takeda, Shiro. 2007. The double dividend from carbon regulations in Japan. Journal of the Japanese and International Economies. 21(3): 336-364

Western Climate Initiative. 2008. Design recommendations for the WCI regional cap-and-trade Program. http://www.westernclimateinitiative.org/

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Table 1: The Economic Impact of 2020 Emissions Limits: Demand-Driven Policies

(Percentage points of GDP relative to steady state)

	2010	2020	2030	2040	2050
Lump Sum Recycling					
Growth Rate	-0.05	-0.03	-0.02	-0.02	-0.01
GDP	-0.39	-0.92	-1.44	-2.01	-2.67
Consumption	-0.25	-0.28	-0.31	-0.35	-0.39
Investment	-0.39	-0.44	-0.53	-0.65	-0.81
Wind Energy Investment	0.02	0.02	0.02	0.02	0.02
Private Capital	-0.61	-3.22	-5.47	-7.72	-10.22
Wind Energy Capital	0.03	0.15	0.25	0.34	0.42
Foreign Debt	-1.38	-8.27	-12.67	-15.47	-17.08
Employment (percentage deviation from baseline)	-0.16	-0.35	-0.47	-0.56	-0.64
Wage (percentage deviation from baseline)	-0.18	-0.02	0.09	0.18	0.25
Value Added Tax Replacement					
Growth Rate	-0.04	-0.03	-0.02	-0.01	-0.01
GDP	-0.25	-0.67	-1.06	-1.49	-1.97
Consumption	-0.06	-0.07	-0.08	-0.10	-0.11
Investment	-0.32	-0.36	-0.42	-0.52	-0.64
Wind Energy Investment	0.02	0.02	0.02	0.02	0.02
Private Capital	-0.50	-2.63	-4.43	-6.21	-8.16
Wind Energy Capital	0.03	0.16	0.26	0.36	0.45
Foreign Debt	-0.50	-5.39	-8.37	-10.18	-11.18
Employment (percentage deviation from baseline)	0.11	-0.03	-0.12	-0.18	-0.23
Wage (percentage deviation from baseline)	0.04	0.16	0.23	0.29	0.34
Public Consumption Financing					
Growth Rate	-0.04	-0.03	-0.02	-0.01	-0.01
GDP	-0.26	-0.67	-1.07	-1.50	-1.99
Consumption	-0.51	-0.60	-0.72	-0.85	-1.01
Investment	-0.32	-0.36	-0.42	-0.52	-0.64
Wind Energy Investment	0.02	0.02	0.02	0.02	0.02
Private Capital	-0.50	-2.64	-4.45	-6.24	-8.21
Wind Energy Capital	0.03	0.16	0.26	0.36	0.45
Foreign Debt	-1.05	-6.16	-9.32	-11.27	-12.37
Employment (percentage deviation from baseline)	0.11	-0.04	-0.13	-0.19	-0.24
Wage (percentage deviation from baseline)	-0.42	-0.30	-0.22	-0.16	-0.11

Table 2: The Budgetary Impact of 2020 Emissions Limits: Demand-Drive Policies

(Percentage points of GDP relative to steady state)

	2010	2020	2030	2040	2050
Lump Sum Recycling					
Public Debt	-0.16	-2.03	-3.20	-3.90	-4.25
Total Expenditure	-0.47	-0.55	-0.64	-0.75	-0.89
Public Consumption	-0.36	-0.41	-0.47	-0.55	-0.64
Public Investment	-0.08	-0.10	-0.11	-0.14	-0.17
Human Capital Investment	-0.03	-0.04	-0.05	-0.06	-0.08
Public Capital	-0.13	-0.81	-1.57	-2.41	-3.40
Human Capital	-0.01	-0.05	-0.12	-0.21	-0.33
Total Tax Revenue	0.30	0.21	0.16	0.10	0.05
Personal Income Tax	-0.02	-0.08	-0.13	-0.18	-0.24
Corporate Income Tax	0.00	-0.03	-0.06	-0.08	-0.11
Value Added Tax	-0.10	-0.12	-0.14	-0.16	-0.19
Firms' Social Security Contributions	-0.05	-0.08	-0.12	-0.16	-0.21
Workers' Social Security Contributions	-0.05	-0.09	-0.13	-0.18	-0.23
Carbon Tax	0.52	0.62	0.73	0.87	1.03
Value Added Tax Replacement					
Public Debt	0.27	-1.13	-1.98	-2.48	-2.72
Total Expenditure	-0.35	-0.41	-0.48	-0.56	-0.67
Public Consumption	-0.26	-0.30	-0.35	-0.40	-0.48
Public Investment	-0.07	-0.08	-0.09	-0.11	-0.13
Human Capital Investment	-0.03	-0.03	-0.04	-0.05	-0.06
Public Capital	-0.11	-0.66	-1.26	-1.93	-2.70
Human Capital	-0.01	-0.04	-0.09	-0.16	-0.26
Total tax revenue	-0.16	-0.30	-0.43	-0.58	-0.74
Personal Income Tax	-0.02	-0.06	-0.10	-0.14	-0.19
Corporate Income Tax	0.00	-0.03	-0.05	-0.06	-0.09
Value Added Tax	-0.59	-0.70	-0.83	-0.99	-1.18
Firms' Social Security Contributions	-0.04	-0.07	-0.10	-0.13	-0.17
Workers' Social Security Contributions	-0.04	-0.08	-0.11	-0.14	-0.19
Carbon Tax	0.54	0.64	0.75	0.90	1.07
Public Consumption Financing					
Public Debt	-0.19	-1.87	-2.96	-3.67	-4.09
Total Expenditure	0.07	0.10	0.13	0.17	0.21
Public Consumption	0.17	0.21	0.27	0.33	0.40
Public Investment	-0.07	-0.08	-0.09	-0.11	-0.13
Human Capital Inv.	-0.03	-0.03	-0.04	-0.05	-0.06
Public Capital	-0.11	-0.66	-1.27	-1.94	-2.72
Human Capital	-0.01	-0.04	-0.09	-0.17	-0.26
Total Tax Revenue	0.32	0.26	0.23	0.21	0.19
Personal Income Tax	-0.02	-0.06	-0.11	-0.15	-0.20
Corporate Income Tax	0.00	-0.03	-0.05	-0.07	-0.09
Value Added Tax	-0.12	-0.14	-0.16	-0.19	-0.23
Firms' Social Security Contributions	-0.04	-0.07	-0.10	-0.13	-0.17
Workers' Social Security Contributions	-0.04	-0.08	-0.11	-0.14	-0.19
Carbon Tax	0.54	0.64	0.75	0.90	1.07

Table 3: The Economic Impact of 2020 Emissions Limits: Employment-Driven Policies

(Percentage points of GDP relative to steady state)

	2010	**2020**	**2030**	**2040**	**2050**
Personal Income Tax Replacement					
Growth Rate	-0.03	-0.02	-0.02	-0.02	-0.01
GDP	-0.03	-0.34	-0.67	-1.06	-1.53
Consumption	0.00	0.01	0.03	0.06	0.09
Investment	-0.23	-0.27	-0.34	-0.44	-0.57
Wind Energy Investment	0.02	0.02	0.02	0.02	0.02
Private Capital	-0.35	-1.92	-3.40	-4.99	-6.86
Wind Energy Capital	0.03	0.17	0.28	0.37	0.47
Foreign Debt	-1.31	-6.59	-10.32	-12.89	-14.47
Employment **(percentage deviation from baseline)**	0.58	0.45	0.35	0.27	0.20
Wage **(percentage deviation from baseline)**	-0.94	-0.80	-0.68	-0.57	-0.47
Firms' Social Security Contributions Replacement					
Growth Rate	-0.04	-0.02	-0.02	-0.01	-0.01
GDP	-0.10	-0.45	-0.81	-1.21	-1.68
Consumption	-0.17	-0.20	-0.22	-0.25	-0.28
Investment	-0.26	-0.30	-0.37	-0.47	-0.60
Wind Energy Investment	0.02	0.02	0.02	0.02	0.02
Private Capital	-0.40	-2.18	-3.77	-5.43	-7.34
Wind Energy Capital	0.03	0.17	0.27	0.37	0.47
Foreign Debt	-1.22	-6.40	-9.90	-12.22	-13.61
Employment **(percentage deviation from baseline)**	0.42	0.29	0.19	0.12	0.05
Wage **(percentage deviation from baseline)**	0.42	0.56	0.66	0.75	0.84
Human Capital Financing					
Growth Rate	-0.02	0.00	0.01	0.02	0.02
GDP	-0.36	-0.55	-0.58	-0.48	-0.25
Consumption	-0.25	-0.29	-0.34	-0.39	-0.46
Investment	-0.29	-0.24	-0.19	-0.14	-0.08
Wind Energy Investment	0.02	0.02	0.02	0.02	0.02
Private Capital	-0.47	-2.13	-2.93	-3.17	-2.97
Wind Energy Capital	0.03	0.17	0.28	0.39	0.49
Foreign Debt	0.40	1.67	4.05	6.40	8.14
Employment **(percentage deviation from baseline)**	-0.15	-0.20	-0.18	-0.12	-0.05
Wage **(percentage deviation from baseline)**	-0.27	-0.42	-0.62	-0.84	-1.07

Table 4: The Budgetary Impact of 2020 Emissions Limits: Employment-Driven Policies

(Percentage points of GDP relative to steady state)

	2010	2020	2030	2040	2050
Personal Income Tax Replacement					
Public Debt	-0.35	-1.77	-2.73	-3.35	-3.69
Total Expenditure	-0.28	-0.33	-0.38	-0.46	-0.54
Public Consumption	-0.14	-0.15	-0.17	-0.19	-0.21
Public Investment	-0.05	-0.06	-0.08	-0.10	-0.12
Human Capital Investment	-0.09	-0.11	-0.14	-0.17	-0.21
Public Capital	-0.08	-0.51	-1.01	-1.60	-2.31
Human Capital	-0.02	-0.15	-0.33	-0.58	-0.90
Total Tax Revenue	-0.10	-0.20	-0.31	-0.44	-0.59
Personal Income Tax	-0.56	-0.70	-0.86	-1.04	-1.26
Corporate Income Tax	0.00	-0.02	-0.03	-0.05	-0.07
Value Added Tax	-0.03	-0.04	-0.04	-0.05	-0.06
Firms' Social Security Contributions	-0.03	-0.05	-0.08	-0.11	-0.14
Workers' Social Security Contributions	-0.03	-0.05	-0.08	-0.12	-0.16
Carbon Tax	0.55	0.65	0.78	0.92	1.10
Firms' Social Security Contributions Replacement					
Public Debt	-0.28	-1.72	-2.66	-3.25	-3.56
Total Expenditure	-0.15	-0.17	-0.20	-0.24	-0.28
Public Consumption	-0.03	-0.02	-0.01	-0.01	0.00
Public Investment	-0.06	-0.07	-0.08	-0.10	-0.12
Human Capital Investment	-0.07	-0.09	-0.11	-0.13	-0.16
Public Capital	-0.09	-0.56	-1.10	-1.72	-2.46
Human Capital	-0.02	-0.11	-0.25	-0.43	-0.68
Total Tax Revenue	0.04	-0.04	-0.13	-0.22	-0.32
Personal Income Tax	0.03	-0.01	-0.04	-0.07	-0.10
Corporate Income Tax	0.00	-0.02	-0.04	-0.05	-0.07
Value Added Tax	-0.06	-0.07	-0.08	-0.10	-0.12
Firms' Social Security Contributions	-0.51	-0.63	-0.76	-0.92	-1.11
Workers' Social Security Contributions	0.04	0.03	0.02	0.00	-0.02
Carbon Tax	0.55	0.65	0.78	0.92	1.10
Human Capital Financing					
Public Debt	0.43	1.21	2.14	2.96	3.50
Total Expenditure	0.39	0.48	0.59	0.71	0.85
Public Consumption	-0.08	-0.09	-0.11	-0.13	-0.16
Public Investment	-0.05	-0.04	-0.03	-0.02	-0.01
Human Capital Investment	0.51	0.61	0.72	0.86	1.02
Public Capital	-0.07	-0.41	-0.65	-0.80	-0.84
Human Capital	0.09	0.59	1.28	2.20	3.41
Total Tax Revenue	0.34	0.37	0.46	0.61	0.82
Personal Income Tax	-0.03	-0.05	-0.05	-0.05	-0.03
Corporate Income Tax	-0.01	-0.03	-0.04	-0.05	-0.04
Value Added Tax	-0.07	-0.07	-0.07	-0.08	-0.08
Firms' Social Security Contributions	-0.05	-0.06	-0.07	-0.07	-0.06
Workers' Social Security Contributions	-0.05	-0.07	-0.08	-0.08	-0.07
Carbon Tax	0.55	0.65	0.78	0.93	1.10

Table 5: The Economic Impact of 2020 Emissions Limits: Investment-Driven policies

(Percentage points of GDP relative to steady state)

	2010	2020	2030	2040	2050
Private Investment Tax Credit Financing					
Growth Rate	0.08	0.04	0.02	0.01	0.01
GDP	-0.30	0.31	0.75	1.14	1.53
Consumption	0.03	0.04	0.05	0.07	0.09
Investment	0.90	0.92	1.02	1.18	1.40
Wind Energy Investment	0.02	0.02	0.02	0.02	0.03
Private Capital	1.39	7.06	11.38	15.24	19.19
Wind Energy Capital	0.03	0.18	0.31	0.43	0.55
Foreign Debt	2.58	9.88	13.35	14.98	15.67
Employment (percentage deviation from baseline)	-0.35	-0.09	0.04	0.10	0.14
Wage (percentage deviation from baseline)	-0.22	-0.39	-0.48	-0.52	-0.55
Wind Energy Investment Tax Credit Financing					
Growth Rate	-0.03	-0.01	0.00	0.00	0.00
GDP	-0.26	-0.50	-0.69	-0.87	-1.08
Consumption	-0.31	-0.37	-0.44	-0.52	-0.61
Investment	-0.25	-0.23	-0.24	-0.27	-0.32
Wind Energy Investment	0.33	0.53	0.65	0.77	0.91
Private Capital	-0.39	-1.86	-2.86	-3.70	-4.57
Wind Energy Capital	0.20	1.94	5.13	9.18	13.79
Foreign Debt	-0.55	-2.89	-3.65	-3.96	-4.14
Employment (percentage deviation from baseline)	-0.02	-0.08	-0.10	-0.10	-0.11
Wage (percentage deviation from baseline)	-0.28	-0.21	-0.17	-0.14	-0.11
Public Capital Financing					
Growth Rate	0.08	0.09	0.08	0.07	0.05
GDP	-0.54	0.26	1.38	2.76	4.40
Consumption	0.49	0.59	0.71	0.86	1.04
Investment	-0.10	0.22	0.50	0.80	1.13
Wind Energy Investment	0.02	0.02	0.02	0.03	0.03
Private Capital	-0.21	0.25	2.58	6.14	10.72
Wind Energy Capital	0.03	0.19	0.32	0.46	0.60
Foreign Debt	4.25	20.95	33.91	42.72	47.71
Employment (percentage deviation from baseline)	-0.82	-0.47	-0.12	0.19	0.44
Wage (percentage deviation from baseline)	0.16	-0.14	-0.42	-0.66	-0.87

Table 6: The Budgetary Impact of 2020 Emissions Limits: Investment-Driven policies

(Percentage points of GDP relative to steady state)

	2010	2020	2030	2040	2050
Private Investment Tax Credit Financing					
Public Debt	0.80	2.50	3.35	3.77	3.95
Total Expenditure	0.09	0.11	0.13	0.16	0.19
Public Consumption	0.09	0.09	0.10	0.11	0.13
Public Investment	0.00	0.02	0.03	0.04	0.05
Human Capital Investment	0.01	0.01	0.01	0.02	0.02
Public Capital	-0.01	0.05	0.21	0.44	0.74
Human Capital	0.00	0.01	0.03	0.05	0.07
Total Tax Revenue	-0.20	-0.03	0.09	0.18	0.27
Personal Income Tax	-0.09	-0.02	0.03	0.06	0.09
Corporate Income Tax	-0.70	-0.78	-0.90	-1.06	-1.26
Value Added Tax	0.10	0.10	0.11	0.13	0.16
Firms' Social Security Contributions	-0.04	-0.01	0.01	0.03	0.05
Workers' Social Security Contributions	-0.05	-0.01	0.01	0.03	0.05
Carbon Tax	0.58	0.69	0.83	0.98	1.17
Wind Energy Investment Tax Credit Financing					
Public Debt	0.08	-0.36	-0.51	-0.57	-0.59
Total Expenditure	-0.25	-0.29	-0.33	-0.39	-0.46
Public Consumption	-0.19	-0.22	-0.26	-0.31	-0.37
Public Investment	-0.05	-0.05	-0.05	-0.05	-0.06
Human Capital Investment	-0.01	-0.02	-0.02	-0.03	-0.03
Public Capital	-0.07	-0.42	-0.77	-1.11	-1.49
Human Capital	0.00	-0.02	-0.05	-0.09	-0.13
Total Tax Revenue	-0.18	-0.27	-0.35	-0.42	-0.50
Personal Income Tax	0.00	-0.04	-0.06	-0.08	-0.10
Corporate Income Tax	-0.50	-0.61	-0.73	-0.86	-1.02
Value Added Tax	-0.06	-0.05	-0.06	-0.06	-0.08
Firms' Social Security Contributions	-0.04	-0.05	-0.06	-0.08	-0.09
Workers' Social Security Contributions	-0.04	-0.06	-0.07	-0.09	-0.10
Carbon Tax	0.46	0.54	0.63	0.75	0.89
Public Capital Investment Financing					
Public Debt	1.88	8.06	12.56	15.48	17.03
Total Expenditure	1.21	1.43	1.69	1.99	2.35
Public Consumption	0.69	0.80	0.93	1.07	1.25
Public Investment	0.48	0.58	0.70	0.84	1.01
Human Capital Investment	0.04	0.05	0.06	0.08	0.09
Public Capital	0.74	4.73	9.30	14.57	20.66
Human Capital	0.01	0.06	0.13	0.23	0.37
Total Tax Revenue	0.52	0.88	1.35	1.93	2.61
Personal Income Tax	-0.05	0.02	0.12	0.24	0.38
Corporate Income Tax	-0.04	-0.03	0.00	0.04	0.10
Value Added Tax	0.16	0.23	0.29	0.37	0.46
Firms' Social Security Contributions	-0.06	-0.01	0.05	0.13	0.23
Workers' Social Security Contributions	-0.06	-0.01	0.06	0.15	0.25
Carbon Tax	0.58	0.69	0.83	0.99	1.19

Table 7: On the Impact of Public Spending Decisions on the Second Dividend

(Percentage points of GDP relative to steady state)

	Central		Exogenous Public Consumption		Exogenous Public Investment	
	2020	2050	2020	2050	2020	2050
Second Dividend - GDP Effects						
Demand Policies						
Lump Sum Recycling	-0.92	-2.67	-0.81	-2.28	-0.79	-1.66
Value Added Tax Replacement	-0.67	-1.97	-0.57	-1.63	-0.56	-1.17
Public Consumption Financing	-0.67	-1.99	-0.55	-1.56	-0.57	-1.21
Employment Policies						
Personal Income Tax Replacement	-0.34	-1.53	-0.30	-1.38	-0.23	-0.60
Firms' Social Security Contributions Replacement	-0.45	-1.68	-0.45	-1.68	-0.33	-0.77
Human Capital Investment Financing	-0.55	-0.25	-0.51	-0.14	-0.45	0.04
Investment Policies						
Private Investment Tax Credit Financing	0.31	1.53	0.28	1.44	0.31	1.30
Wind Energy Investment Tax Credit Financing	-0.50	-1.08	-0.43	-0.82	-0.42	-0.62
Public Capital Investment Financing	0.26	4.40	0.04	3.68	0.42	5.36
Second Dividend - Employment Effects						
Demand Policies						
Lump Sum Recycling	-0.35	-0.64	-0.21	-0.41	-0.43	-0.54
Value Added Tax Replacement	-0.03	-0.23	0.08	-0.05	-0.09	-0.15
Public Consumption Financing	-0.04	-0.24	0.11	0.01	-0.11	-0.18
Employment Policies						
Personal Income Tax Replacement	0.45	0.20	0.49	0.28	0.38	0.30
Firms' Social Security Contributions Replacement	0.29	0.05	0.29	0.05	0.22	0.15
Human Capital Investment Financing	-0.20	-0.05	-0.16	0.01	-0.20	-0.02
Investment Policies						
Private Investment Tax Credit Financing	-0.09	0.14	-0.12	0.09	-0.06	0.12
Wind Energy Investment Tax Credit Financing	-0.08	-0.11	0.00	0.03	-0.10	-0.06
Public Capital Investment Financing	-0.47	0.44	-0.75	-0.01	-0.53	0.53
Third Dividend - Public Debt Effects						
Demand Policies						
Lump Sum Recycling	-2.02	-4.25	2.30	11.03	-0.53	-1.15
Value Added Tax Replacement	-1.13	-2.72	1.94	8.17	0.08	-0.22
Public Consumption Financing	-1.86	-4.09	2.57	11.58	-1.19	-3.35
Employment Policies						
Personal Income Tax Replacement	-1.76	-3.69	-0.16	1.68	-0.53	-0.97
Firms' Social Security Contributions Replacement	-1.71	-3.56	-1.44	-3.03	-0.46	-0.86
Human Capital Investment Financing	1.20	3.50	2.11	6.79	1.83	4.49
Investment Policies						
Private Investment Tax Credit Financing	2.50	3.95	1.53	0.85	2.30	3.30
Wind Energy Investment Tax Credit Financing	-0.36	-0.59	1.91	7.57	0.38	0.81
Public Capital Investment Financing	8.04	17.03	0.02	-10.78	9.52	19.83