The Impact of a Carbon Tax on Economic Growth and Carbon Dioxide Emissions in Ireland

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Abstract: This paper analyses the medium-term effects of a carbon tax on growth and CO_2 emissions in Ireland, a small open economy. We find that a double dividend exists if the carbon tax revenue is recycled through reduced income taxes. If the revenue is recycled by giving a lump-sum transfer to households, a double dividend is unlikely. We also determine that a greater incidence of the carbon tax falls on capital than on labour. When combined with a decrease in income tax, there is a clear shift of the tax burden from labour to capital. Finally, most of the effect on the economy is due to changes in the competitiveness of the manufacturing and market services sectors. These results hold even if we allow changes in energy prices to have an enhanced (detrimental) effect on Ireland's competitiveness.

Key words: carbon tax; Ireland; double dividend; tax incidence

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1. Introduction

The Government of the Republic of Ireland is contemplating the introduction of a carbon tax to help meet the emission reduction targets imposed by the European Union. The *Programme for Government 2007-2012* states that "[a]ppropriate fiscal instruments, including a carbon levy, will be phased in on a revenue-neutral basis over the lifetime of this Government."[1] In this paper, we analyse the implications of a carbon tax for the economy and for carbon dioxide emissions.

The cheapest way to meet any emission target is to set the marginal cost of emission equal for every source (Baumol and Oates, 1971). The easiest way to establish a uniform price for emissions is to impose the same emission tax on all sources (Baumol, 1972; Pearce, 1991).[2] This implies that the marginal cost of emission reduction is equal across all sectors of the economy. If marginal costs are not equalised, total economic costs are higher than necessary.[3] For example, if it were cheaper to reduce an additional tonne of carbon in the electricity sector than in the transport sector, then emissions should be reduced further in power generation and less far in transport (while total emission reduction should stay the same). This way national reduction costs are minimised. A uniform tax also adheres to the basic notion of fairness that like cases should be treated alike. As there is no difference between a tonne of carbon dioxide emitted by power generation and a tonne emitted by transport, it is fair to tax emissions from both at the same level. A carbon tax is therefore an appropriate instrument for emissions reduction.

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[1] http://www.taoiseach.gov.ie/attached_files/Pdf%20files/Eng%20Prog%20for%20Gov.pdf
[2] Tradable permits are an alternative for creating a uniform price (Montgomery, 1972) but, for stock pollutants such as greenhouse gases, taxes are more robust under uncertainty (Weitzman, 1974; Pizer, 1999).
[3] This is not the case if there are market imperfections and prior tax distortions, and the carbon tax interacts with these imperfections and distortions (Baumol and Bradford, 1970). Our understanding of these matters in an Irish context is incomplete.

The desirable level of the carbon tax is a complicated issue. Some would argue for a cost-benefit analysis, and then set the tax equal to the social cost of carbon (Tol, 2005). Others would argue that the tax should be set at a level that is sufficiently high to meet the emission target with reasonable certainty (den Elzen *et al.*, 2007). Yet others would argue that the carbon tax should not exceed the level that is acceptable to the electorate (cf. Li *et al.*, 2004). This debate is beside the point. Ireland's emissions are a tiny fraction of global emissions. A carbon tax in Ireland will not stop climate change – indeed, it is unlikely to have a measurable direct impact on global warming. A carbon tax is important because it signals Ireland's commitment to international climate policy. A carbon tax also gives the important signal to companies and households that climate policy is serious and here to stay.

A carbon tax should be uniform across sectors to ensure that the cost of reducing emissions is minimised. However, some 45 per cent of Ireland's carbon dioxide emissions (and 30 per cent of total greenhouse gas emissions[4]) are already regulated by a price mechanism (Ellerman and Buchner, 2007). The EU Emissions Trading System (ETS) sets a price for carbon dioxide emission permits for power generation, the production of cement and alumina, along with other sectors. Therefore, the carbon tax should be set equal to the permit price. In that way, the price of emissions is uniform across all sectors of the economy.[5]

Matching the carbon tax to the price of emission permits in the EU ETS is not a trivial task. The EU ETS spot price of carbon dioxide emission permits varies daily, whereas a carbon tax is constant for a budget period, or varies according to a fixed schedule. However, there is also a futures market for emission permits, where prices are less volatile. The carbon tax of the following year could be announced in the Budget, and set

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[4] In addition to carbon dioxide, the most important other greenhouse gases are methane and nitrous oxide.
[5] We would in fact prefer to replace the ETS with a carbon tax, or extend the ETS to cover all emissions. Neither option appears politically feasible.

equal to the futures price of the final trading day in November.[6] In that case, at least in expectation, the carbon tax would equal the permit price.

The proposed rule – a carbon tax set equal to the futures price of tradable permits – is fair and economically efficient as every source pays the same amount per emitted tonne. The proposed rule has a third advantage. Climate change is a long-term problem. The transition to a zero-carbon economy will take a century. Investment and research cycles are much longer than electoral cycles. For these reasons, climate policy should not be subject to the short-term considerations of the economic or political cycle. Reminiscent of the Central Bank's situation, the proposed rule makes the carbon tax independent, to some degree, of day-to-day political and economic issues.

Carbon dioxide emissions from power generation[7] and several other sectors are already regulated by the EU ETS. These emissions should be exempt from the carbon tax. As a matter of principle, double regulation should be avoided. In this particular case, imposing a domestic tax on sectors subject to European regulation would be ineffective and expensive. A domestic tax on emissions in the EU ETS would reduce emissions in Ireland, but because the emission cap is Europe-wide, every tonne reduced in Ireland would be emitted elsewhere. The net effect on emissions would be zero. Furthermore, because the domestic tax would distort the market for emission permits, the costs of emission reduction would increase in Ireland (Tol, 2007; Boehringer *et al*., forthcoming) while it would fall marginally in the rest of the EU, without any commensurate benefit in terms of reducing EU-wide emissions.

Carbon dioxide emissions not regulated by the EU ETS by and large come from fossil fuel combustion. The carbon tax is therefore best administered as a duty on fuels, with very low administrative costs. The duty should be proportional to the carbon content of the fuel.[8]

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[6] The exact carbon tax of January would be announced in December only. This is not a problem, if the carbon tax equals the futures price as a rule. Futures prices for carbon permits are public knowledge, and the futures price in early June (say) is similar to the futures price in late November.

[7] Including power generation by bodies other than electricity utilities.

[8] The carbon content of fuels is readily available from Sustainable Energy Ireland. These numbers are also used for Ireland's emission accounting, which follows internationally agreed rules under the UN Framework Convention on Climate Change.

Based on these considerations, the rest of the paper analyses the implications of a carbon tax for the Irish economy, both in terms of growth and of carbon dioxide emissions. We isolate the effect of a carbon tax from ongoing (and unrelated) changes in the economy. We determine that a carbon tax is able to yield a double dividend for Ireland, by both reducing emissions and accelerating growth, if the revenue is properly recycled to reduce existing taxes. We describe the channels through which the taxes are effective and determine that in the case of a carbon tax the tax burden is shifted from labour to capital. Section 2 reviews the previous literature. Section 3 describes the HERMES model. Section 4 discusses the macro-economic effects of a carbon tax and its impact on emissions. Previous studies have highlighted how the effects of tax reforms depend on the pre-existing tax structure and the specific way in which the revenue collected by any new taxes is used. In section 4 we therefore distinguish between the effects due to the introduction of a carbon tax and those driven by different revenue recycling scenarios. Section 5 suggests that economic growth would be enhanced and emissions reductions would be subdued in a real-case scenario based on recent forecasts of the Irish economy. Section 6 concludes.

2. Previous research

There is a large literature on the economic impact of greenhouse gas emission reduction (Barker *et al*., 2006), and a substantial share of these papers uses carbon taxes as the policy instrument. Starting in the 1990s there has been a growing literature on the double-dividend potential of environmental taxes: a carbon tax would reduce emissions and, in addition, the recycled revenue could accelerate economic growth and increase employment by reducing existing taxes on labour and capital. A weak version of the double-dividend hypothesis, which states that welfare is greater when pre-existing distortionary taxes are reduced than when the revenue is returned to tax payers as a lump-sum, is generally accepted (Goulder, 1995). The strong version, which claims that there are no costs (or even negative costs) to implementing an environmental tax is more controversial, although it is the one of most interest from a policy perspective. The rest of the paper refers to the strong version of the double-dividend hypothesis.

Earlier studies, using partial equilibrium models or one-factor general equilibrium models, and assuming competitive markets (e.g., Pearce, 1991; Bovenberg and De Mooij, 1994) found rather stark results on double dividends: either large or zero. In fact, it is not possible to have a double dividend in a one-factor model because there is no distortion by definition (Bovenberg and De Mooij, 1994; Goulder et al., 1997).

Later analyses with multiple production factors and distorted labour markets found more nuanced results. Two-factor models introduce the possibility of inefficiencies in the tax system. The marginal excess burden (MEB) – that is, the loss of overall production efficiency due to taxation – of a tax depends on its level and on how sensitive labour and capital are to changes in the price they are paid. For labour the sensitivity is measured by the wage elasticity of labour supply. For capital (in a closed economy), it is measured by the intertemporal elasticity of substitution in consumption. In both cases the distortion is larger if the elasticity is larger. Replacing a high MEB tax with a low MEB tax reduces the distortion in the economy and stimulates growth. The gain is larger if (1) the difference in MEBs is larger; (2) the burden of the environmental tax falls mainly on the undertaxed factor; and (3) the recycling of revenues mainly reduces the burden of the overtaxed factor (Goulder, 1995).

The efficiency gain has to overcome the negative effects of a carbon tax. Besides the higher cost of energy, there are distortions arising from a carbon tax. The broader the tax base, the lower the distortion. A carbon tax, however, has a relatively narrow base, as it is meant to change specific behaviour. In fact the more effective a tax is at reducing carbon dioxide emissions, the more distortionary it tends to be, since its effectiveness is based on its ability to change consumers' behaviour significantly (Goulder, 1995). Taxes on intermediate inputs generally have larger welfare costs than do taxes on primary factors because the former distort both the intermediate input choice and factor markets (Goulder, 1995).

Substitution elasticities between labour, capital and energy are also important, as they determine the effective incidence of a carbon tax, as well as the size of the deadweight loss caused by the higher cost of energy. In developed economies, capital and energy are closer substitutes than are labour and energy (van der Werf, 2008) so a carbon tax would shift the tax burden from labour to capital. In Ireland, labour taxes are high relative to

taxes on capital low and, as shown below, existing studies on Ireland find a double dividend effect.

The situation is different in the USA. Goulder (1995), Bovenberg and Goulder (1997), and Jorgenson and Wilcoxen (1993) investigate the results of a revenue neutral environmental tax reform using an intertemporal general equilibrium model. The first two studies find no evidence of a double dividend. The environmental tax is always more distortionary than the tax it replaces. The main reason is the narrowness of the environmental tax. Jorgenson and Wilcoxen (1993) do find a double dividend, but only under certain conditions. The Congressional Budget Office (2000) found that under emissions trading, if the permits were auctioned and the revenue used to cut corporate taxes there would be the greatest potential for gains in economic efficiency.[9] Van Heerden et al. (2006) find a double dividend for South Africa if energy taxes replace food taxes.[10]

Another strand of the double dividend literature looks at the possibility that revenue recycling might reduce involuntary unemployment. Bovenberg and Van der Ploeg (1998) use a search model with employer-employee bargaining. Strand (1998) assumes a monopoly union that sets the wage, after firms determine employment. In Koskela et al. (1998), a monopolistic firm determines employment, after bargaining over wages with a small trade union. In these papers, a double dividend depends on the effect of the green tax reform on the bargaining positions of firms and workers. Employment increases if labour costs fall. This happens if the relative bargaining power of workers decreases, which is the case if workers have less (desirable) alternatives or if the firm's labour demand becomes more elastic with respect to wages. Wages also fall if the tax burden is shifted to the unemployed. Some studies (e.g. Carraro et al., 1996) find that when a double dividend exists, it tends to be associated with smaller improvements in environmental outcomes.

Most of the studies presented above refer to closed economies; they are not concerned with trade. For a small open economy, Holmlund and Kolm (2000) show that a carbon

[9] The other alternative considered was a lump sum payment to households.
[10] In fact, van Heerden et al. (2006) find a triple dividend: a reduction in the gap between rich and poor.

tax that is recycled to lower income taxes (in the presence of a fixed labour force) increases employment in the non-traded sector, but reduces employment in the traded sector. Overall they find little evidence of a double dividend, since GDP is not enhanced. Bossier et al. (2002) use a macroeconometric model for Belgium and show that there is a double dividend in the medium-run (although not in the short-run) if the revenue from carbon taxes is recycled to lower social security contributions. Palatnik and Schechter (2008) assess the results of a carbon tax for another small open economy: Israel. They find that if the labour market displays involuntary unemployment, a double dividend is achieved quite easily through a substitution away from energy intensive inputs towards labour and capital intensive ones. Finally Bye (2002) determines the effects of a carbon tax for a small open economy where there is involuntary unemployment and energy is imported. Using a dynamic model, she finds that the carbon tax acts as an implicit tariff and improves the terms of trade. This allows a double dividend to arise in the short-run, although long-run effects are uncertain.

For Ireland, Bergin *et al*. (2004), using the model described in Fitz Gerald *et al.* (2002), find that a carbon tax of €20/tCO_2 would modestly reduce carbon dioxide emissions, mostly from power generation.[11] Recycling the revenue through a reduction in VAT or social insurance would accelerate economic growth, while lump-sum transfers to households or companies would slow growth. Fitz Gerald and McCoy (1992) find similar results. Using a completely different model and set of data, Wissema and Dellink (2007) also find that a carbon tax with lump sum recycling would slow economic growth.

The earlier results for the effect of a carbon tax for Ireland suggest that a double dividend is possible but is by no means certain or automatic. Existing taxes and distortions in the labour and capital markets, together with the specific form of the tax reform, determine the ultimate outcome (Fullerton and Metcalf, 2001). That is, a double dividend can be achieved if the tax reform takes account of existing distortions to capital and labour markets and recycles the revenue wisely.

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[11] Conniffe *et al*. (1997) also conclude that emission reduction is relatively cheap in power generation, and relatively expensive elsewhere in the economy.

This study differs from the papers reviewed above in several ways. We use a simulation model of the economy of Ireland, but abstract from changes in the economy due to factors unrelated to the changes in taxation by keeping the economic structure fixed at its 2005 level. Moreover the effects of a carbon tax and the effects of recycling the tax are analysed separately. In the following section we show the results of imposing three types of tax calibrated to have an identical impact on government borrowing as a percentage of GNP: a carbon tax, a lump sum tax on households and a change in income tax. We then consider the combined effects of a carbon tax where the revenue is recycled through either a lump sum tax rebate or a reduction in income tax rates.

3. The model

The *HERMES* macroeconomic model has been used to develop medium-term forecasts of the Irish economy since 1987. This model of the Irish economy was originally part of an EU-wide system of macroeconometric models - *HERMES* - that was specifically designed to deal with supply side issues arising from the oil price shocks of the 1970's (CEC, 1993). The Irish version of the *HERMES* model was modified to deal with the special characteristics of the Irish economy and has undergone significant changes since its first use in 1987.

As implemented, the simulation model of the Irish economy displays a labour market where there is generally limited involuntary unemployment in the long run as wages tend to adjust to gradually clear that market. Labour supply is unusually elastic, with female participation and migration being responsive to domestic wage rates. An increasing share of the output of the market services sector is traded. There is substantial foreign direct investment in both the manufacturing and the market services sectors with, as a result, repatriation of profits earned in Ireland by the foreign multinationals operating there. Firms in the market services sector are price setters, passing on any cost increase (or decrease) to final consumers, be they domestic or foreign. Manufacturing, on the other hand, is a price taker and mostly sells on the international market. Finally, since it is a small economy, government debt (or financial assets) is funded on international markets.

The model focuses initially on the output or production relationships and examines the downstream expenditure and income consequences. The key mechanisms within the *HERMES* model are:[12]

1. The exposed tradable sector is driven by world demand, elements of domestic demand and cost competitiveness. The exposed sector refers to those sectors of the economy that are exposed to international competitive trade and consists of manufacturing and business and financial services. The equations determining long-run output in the tradable sector are shown in Appendix 1. Manufacturing is a price taker, whereas the business and financial services sector is a price setter. The latter passes on any cost increases or decreases to the final consumer.

2. Energy is imported and enters the production function within a composite materials variable (including services inputs). In manufacturing, within the materials inputs factor, energy and other raw materials are assumed to be used in a fixed proportion. Energy does not enter the production function of services.

3. The sheltered market sector (building and part of market services) is driven by domestic demand.

4. The public sector is policy driven - decisions on tax rates and expenditure are treated as exogenous. However, borrowing and debt accumulation are endogenous.

5. Labour demand is derived from the factor demand systems for the individual sectors of the economy. Labour supply is modelled as a function of migration and participation decisions. The long run stock of migrants is modelled as a function of the factors affecting the relative attractiveness of the Irish and foreign labour markets. This, in turn, affects labour supply. Labour supply and labour demand together determine the long-term equilibrium wage rate.

As shown in Table 1 in 2005 energy inputs represented only 1 per cent of the value of manufacturing output whereas labour costs accounted for 8.7 per cent.

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[12] Appendix 1 of Fitz Gerald *et al.* (2008) provides a description of the *HERMES* model.

Table 1 about here

Major changes were made in 2002 to incorporate a sub-model of energy demand and greenhouse gas emissions from energy use (Fitz Gerald et al., 2002). The crucial price elasticities of demand for energy are shown in Table 2. The latest version of the *HERMES* model has been re-estimated using data from the CSO *National Income and Expenditure Accounts 2006.*

Table 2 about here

4. The impact of a carbon tax reform on the 2005 economy

As discussed in Section 2, theoretical studies have highlighted the channels through which a double dividend from a carbon tax might arise. Double dividends can occur through decreased distortions in the labour market, leading to higher employment; through changes in the terms of trade, improving the balance of payments; through reductions in the tax burden of the most taxed factor of production; through some combination of these three channels.

Simulations that are based on forecast models have the advantage of estimating the effects of taxes in a realistic scenario (cf. Section 5). The main drawback is that by their own nature they do not distinguish between the direct effects of tax changes and other exogenous changes that take place in the economy. In this section, we focus on the direct effects of changes in taxation. We abstract from ongoing changes in the Irish economy by simulating the effects of the tax changes where the economic structure is held constant at its 2005 level.[13] We consider three options for the use of the revenue from a carbon tax: the revenue is used to repay government debt (acquire financial assets); the revenue is used to reduce income taxes; the revenue is used to make a lump sum tax rebate to all residents.

To clarify the effects of different ways of recycling the enhanced tax revenue we first examine the effects of the three different tax changes, treated individually. The increased

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[13] This is implemented by replicating the exact values of the exogenous variables from 2005 for each of the subsequent twenty years. When the model is simulated the economy stabilizes at a fairly unchanging level of output and prices. In the case of interest rates, a constant real rate of around two per cent is assumed.

revenue from the carbon tax is used to repay government debt (or acquire financial assets). The decreased revenue due to reductions in income tax or the lump-sum transfer to residents is also compensated for by changes in government debt.

This analysis illustrates the deadweight losses involved in levying different types of taxes in Ireland today. The changes in taxes are generally calibrated so as to have an identical impact (in absolute value) on government borrowing as a percentage of GNP in each year. We then combine the carbon tax with the revenue being recycled through reduced income taxes or a lump-sum tax rebate to arrive at an estimate of the combined effects of the tax changes. The case with a carbon tax on its own is identical to the case where the tax revenue is recycled to repay government debt. In this case the tax has no further effect on the economy (and therefore there is no double dividend).

We also establish the economic incidence of the different tax instruments on capital, labour and other personal income (primarily transfer income to households). The incidence is calculated by first determining the change in real after-tax income of labour and capital in million euro (at constant prices). The incidence is then defined as the share of the overall change represented by these amounts. In the case of labour and other personal income the deflator used is that for consumption. For profits the deflator used is that for GDP at factor cost. Because of the importance of foreign firms in the Irish economy, we also distinguish between the effects of the taxes on foreign and domestic capital.

To understand the medium-term effects of a carbon tax, we analyse the effects of changes in taxes on the economy, 15 "years" after they are imposed. This gives time for the production structure to adjust fully to the change in relative prices.[14]

4.1 Carbon tax

We impose a carbon tax of €20/tonne of CO_2 in 2005 (and hold it at that level for 15 "years") and assume that the government uses the revenue to repay debt (or invest in

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[14] In the long-term we expect that the increased cost of carbon will lead to investments in R&D in new technologies and eventually to the adoption of technologies that abate emissions. The *HERMES* model is not suitable for estimating the long-term impact of a carbon tax because it does not take account of the potential reduction in emissions from the adoption of such new technologies.

financial assets). In the medium-term this tax would raise just under €600 million, equal to around 0.47 per cent of Gross National Product (GNP). When all the indirect effects on government revenue and taxation are taken into account this produces a reduction in government borrowing of 0.52 per cent of GNP.[15]

Table 3 summarises the effects of different tax changes. As can be seen in the first column, the carbon tax has a direct effect on the price of energy in Ireland. Manufacturing sees the price of energy inputs increase by about 17.0 per cent, whereas households experience a more limited rise in the price of energy of 3.30 per cent.[16] On average consumer prices, including both energy and non-energy products, rise by around 0.25 per cent. This puts upward pressure on nominal wages, which increase by a slightly smaller 0.20 per cent, thereby causing real wages to dip. Real disposable income decreases by 0.36 per cent, reducing domestic demand, and overall employment decreases slightly as well.

Table 3 about here

Irish manufacturers are price takers on the international market. In a scenario where only the Irish government is imposing a carbon tax, they still face unchanged international prices. This, together with the relative increase in their cost of labour, lowers manufacturing output, even after a shift in the demand for inputs, substituting away from raw materials (including energy) towards capital and labour. This substitution away from material inputs tends to have a positive effect on the economy because a very high proportion of the inputs used in the manufacturing sector are imported.[17]

Because the manufacturing sector cannot pass on the increased costs through higher prices and because the substitution possibilities are limited in the medium-term, profitability in the manufacturing sector is reduced. With a substantial proportion of the

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[15] Indirect effects arise from changes in revenue from other taxes and in expenditure on welfare payments that are due to changes in wage rates, prices and unemployment. As government net indebtedness changes there are also changes in debt interest payments.

[16] The price of consumption of energy for households rises by less than that for manufacturing because of the much higher tax and distribution margin in such consumption.

[17] The long-run elasticities of demand for the factors of production in manufacturing are shown in Table A.1 through Table A.3 in Appendix 1.

manufacturing sector foreign owned, there is also a significant reduction in profit repatriations. Thus some of the incidence of the carbon tax falls on foreign owners of Irish firms. The economic sustainability of this outcome is discussed further below.

Firms in the market services sector are price setters, able to pass on their increased costs to final consumers. Foreign buyers of Irish services respond to the rise in the price by reducing demand for Irish services exports by 0.26 per cent. When combined with the negative effects on consumption of the imposition of the carbon tax, this results in a reduction in output in market services of 0.24 per cent.

The price of exports rise by around 0.11 per cent as a result of the imposition of the tax in Ireland, all of this due to an increase in the price of services exports. This gives a small gain in the terms of trade. The reduction in the volume of exports, due to the loss of competitiveness, is largely offset by a fall in the volume of imports, because of reduced demand for inputs (including energy) by the manufacturing sector and because of reduced personal consumption. The balance of payments shows an increased surplus (reduced deficit) of 0.35 per cent of GNP due to the growing international investment income of the government arising from the increased tax revenue and a reduction in profit repatriations.

Aggregating all these effects, the simulations suggest that the volume of GDP at market prices would decrease by 0.21 per cent as a result of the carbon tax. Just under half of the effect of the tax in terms of lost output arises in manufacturing and the remainder occurs in market services. Total employment falls by 0.07 percentage points.

When account is taken of factor flows, including changes in profit repatriations and the government's investment income (or reduced interest payments) arising from the investment of the revenue from the carbon tax, GNP would actually be higher by 0.07 per cent (in equilibrium). If the effect of the enhanced government investment income is excluded, then GNP would be reduced by 0.05 per cent.

As shown in Table 3 the bulk of the incidence of a carbon tax will fall on capital. Where the tax is introduced at a low level or on an EU-wide basis (where the competitiveness effects are likely to be lowest) the incidence would be shared equally between domestic and foreign capital, with both sharing about 40 per cent of the tax burden.

Carbon dioxide emissions decrease with the imposition of a carbon tax (the first dividend). The reduction in CO_2 emissions from the non-traded sector (excluding electricity and aviation which are regulated by the EU-ETS) is about 2 per cent. This reduction assumes that the government uses all of the revenue to repay debt, and therefore excludes any possibility of double dividend.

The results shown above are realistic if a small carbon tax is imposed unilaterally by Ireland or if a tax is imposed at a similar rate across the EU. If the tax under consideration were a large tax (of €50 or €100 per tonne of carbon dioxide) imposed unilaterally by Ireland, the results shown above would probably underestimate the effects on the economy and on emissions. In fact the *HERMES* model is estimated using historical data for a period when energy and material prices in Ireland tended to move in line with those elsewhere in the EU. As a result, the model finds a limited impact on Irish manufacturing output from a rise in the unit cost of production due to rising material input prices, including the price of energy.

In order to build an upper bound on the effect of a carbon tax, we look at the historic effect of wage rates, which have varied independently from wage rates in competing countries over the relevant time period. First of all the coefficients on relative wages[18] are effectively rescaled to reflect the much smaller share of total cost accounted for by energy inputs relative to labour costs, as shown in Table 1. Then the adjusted coefficient is used to estimate the long-term impact on output of a rise in the cost of energy, due to a carbon tax. The standard substitution effects, as characterised in the elasticities of demand in Table 2, still remain valid.

The second column of Table 3 shows the results of the 'upper bound' simulation of the effects of a carbon tax. In this case for the same level of carbon tax, €20/tonne of carbon dioxide, the volume of GDP at market prices would fall 0.41 percentage points below the base. The volume of GNP would be 0.09 percentage points lower than in the base. This reflects the fact that the loss of competitiveness has a more detrimental effect on output in

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[18] This is done separately for the three sub-sectors of manufacturing.

the economy. Since in this case the substitution effect is higher, emissions would also decrease somewhat more rapidly, at 2.2 per cent.

More of the incidence of the tax would fall on domestic capital in this case. In fact domestic capital would shoulder 50 per cent of the tax burden in this case.

4.2 Income tax

The rate of income tax is changed so as to match the impact of the carbon tax on the government budget, including all the direct and indirect effects. This would involve a decrease in the personal income tax of about 1.45 percentage points, and a decrease of about 0.74 percentage points of GNP.

The third column of Table 3 shows the results of this decrease in income tax. As labour is assumed to bargain in terms of the real after-tax wage, nominal wage rates fall by 1.06 percentage points, less than the fall in the average tax rate. In addition, the decrease in wage rates induces a fall in consumer prices of 0.17 per cent. The combined effect of these changes is to increase real personal disposable income by 1.14 percentage points and increase the volume of consumption by 0.88 percentage points. These results reflect the fact that the elasticity of labour supply is high in Ireland by international standards,[19] so that much of the incidence of taxes on labour falls on employers.

With much of the incidence of the decrease in income tax rates falling on employers through a rise in wage rates, the competitiveness of the manufacturing sector improves. The result is an increase in output of 0.61 percentage points. Employment in manufacturing rises by 1.05 percentage points, more than the increase in output, as firms substitute labour for material inputs. The volume of services exports increases by 1.31 percentage points as a result of lower wages. When taken together with the additional consumption of domestically produced services, the positive impact on the output of the market services sector is 0.76 percentage points. Total employment increases by 0.59 percentage points.

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[19] Although it is lower than in the 1970s and 1980s (Fitz Gerald et al., 2008).

GDP at market prices rises by 0.60 percentage points and GNP by 0.37 percentage points. The increase in domestic output more than offsets the reduction in imports so that the balance of payments improves by around 0.33 percentage points of GNP.

In this case, CO_2 emissions (excluding aviation and electricity) rise by about 0.50 per cent, due to the faster economic growth.

Almost half of the incidence of the income tax change falls on labour with a somewhat lower share (37 per cent) falling on capital.

4.3 Lump sum tax refund to households

We go on to consider a lump-sum tax refund to households, which by its nature is unrelated to their labour market or consumption behaviour. Such a lump-sum tax refund is non-distortionary in the sense that it has no impact on the supply of factors of production, especially labour, and it does not directly affect the profitability of the productive sector. It is calibrated to match the impact of the carbon tax on government borrowing as a percentage of GNP – implying a decrease in revenue equal to 0.51 percentage points of GNP.

The last column of Table 3 shows that there would be minimal impact on prices and wages from such a tax refund. However, the increase in real personal disposable income of 1.24 percentage points translates into an increase in the volume of personal consumption of 0.93 per cent. While much of the change in consumption is passed through as an increase in imports, there is also a significant rise in the volume of output of the market services sector. Output in that sector grows by 0.35 per cent. There is minimal impact on the output of the manufacturing sector so that GDP at constant market prices ends up rising 0.27 percentage points. Taking account of the offsetting impact of the government's lowered investment income (or increase in debt interest payments) the volume of GNP increases by 0.20 percentage points. With the major increase in domestic consumption, and hence imports, the balance of payments deficit increases to 0.41 percentage points of GNP. In this scenario, CO_2 emissions (excluding aviation and electricity generation) increase by 0.35 per cent.

Finally, in the case of a lump sum payment to households, not surprisingly, the vast bulk of the incidence accrues to other personal income.

4.4 Net effect of a carbon tax with revenue recycling

Here we show the impact of using the revenue from a carbon tax to reduce either the burden of income tax or else to pay a lump sum tax rebate to individuals or households.

As mentioned above, double dividends might arise if tax reforms reduce the average marginal excess burden. Honohan and Irvine (1987), using data for the late 1980s in Ireland, identified high deadweight losses from income tax because of the then high marginal rates of income tax. While the marginal and average rates of income tax have fallen dramatically since the 1980s, income tax still involves a significant deadweight loss through the distortions it induces in the labour market. By contrast, a lump sum tax involves minimal distortion of the labour market and domestic production.

The effects of the different taxes on GNP, excluding changes in national debt interest, provide the best measure of the cost (or benefit) from the tax changes. The higher the social costs of taxation the higher must be the potential benefits from the use of that revenue if overall welfare is to be improved.

Part of the incidence of a carbon tax falls on foreign firms (affecting profit repatriations) and therefore has a limited distortionary impact on the domestic economy. However, if a large carbon tax was imposed unilaterally by Ireland, the incidence of the tax would shift to Irish factors of production and the social costs would be higher (as shown in Table 3).

When the revenue from a carbon tax is used to cut income tax, we find a double dividend. The results reported in the first column of Table 4 show that there would be a positive effect on both GDP and GNP, with GDP being 0.39 percentage points above its base level and GNP 0.45 percentage points above base in equilibrium. This reflects the fact that the deadweight costs from income tax due to the distortions it causes in the labour market are greater than the deadweight loss involved in a carbon tax. The net reduction in carbon dioxide emissions is 1.52 per cent.

The second column of Table 4 shows upper bound effects (as defined above). GDP would only be 0.10 per cent above base while GNP would be 0.27 per cent higher. The ultimate reduction in carbon dioxide emissions would be 2.2 per cent in this case. We therefore conclude that when the carbon tax is recycled through a lower income tax a double dividend is probable, although it is likely to be small.

Table 4 about here

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Because there are minimal deadweight gains in the case of a lump sum tax rebate, this is less likely to be beneficial. The third column of Table 4 shows that while GDP is still higher, it is by a negligible 0.05 percentage points. Emissions are reduced by 1.67 per cent. If we consider the upper bound of the effect on competitiveness, GDP actually falls by 0.23 percentage points. The results for GNP is slightly more favourable reflecting the fact that more of the incidence of carbon taxes will fall on the owners of Irish firms than would be the case for either a change in income tax on its own or a lump sum tax on its own. Emissions still fall by 2.3 per cent, but a double dividend is unlikely.

Finally, as shown earlier, if the revenue of a carbon tax is used simply to repay government debt on international markets a double dividend will not arise.

These results are broadly consistent with those found for Ireland in previous studies – Fitz Gerald and McCoy (1992), Fitz Gerald *et al.* (2002), Bergin *et al.* (2004) and Fitz Gerald *et al*. (2008) – especially if a carbon tax is small or imposed in the whole of the EU. For a large unilateral carbon tax the negative competitiveness effects are likely to be somewhat greater than found in the previous studies.

These results also illustrate the difficulty in reducing emissions from the non-tradable sector in a relatively short space of time (15 "years"). With existing technology and the existing capital stock (of houses and cars), there are limited substitution possibilities to reduce emissions.

5. The impact of a carbon tax reform on an evolving economy

Section 4 focuses on the impact of a carbon tax when the structure of the Irish economy is held constant at its 2005 level. Similar results hold if the Irish economy is allowed to evolve in line with the available forecasts, where the structure of the economy changes over time (Fitz Gerald *et al*., 2008). Following Tol *et al*. (2008), we assume that the carbon tax rate increases from €20/tCO2 in 2010 to €38/tCO2 in 2020 (in real terms).[20]

Table 5 about here

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[20] This is in line with available futures prices of CO_2 emission permits in the EU-ETS.

Table 5 summarises the results for 2020 when the carbon tax revenue is recycled to lower income taxes, to finance a lump sum transfer to households or to repay government debt. Figure 1 shows the effects on GNP over time. The most favourable outcome for the economy still occurs when income taxes are reduced. In this case GNP grows 1.1 per cent faster than in the baseline (that assumes no tax reform) and employment grows by 1.1 per cent. This increase is much larger than the GNP growth shown in Table 4, where the economy is not allowed to evolve. The reason is that the economy is projected to become more service-oriented, more export-oriented and less carbon-intensive. The first two trends enhance the positive effect of lower income taxes, while the third trend mitigates the negative effect of a carbon tax.

Under all scenarios, carbon dioxide emissions reductions are more limited. This is because the economy becomes less carbon-intensive, because energy efficiency improves and because services become relatively more important. Emission abatement ranges from a reduction of 0.1 per cent when revenue is recycled as a lump sum transfer to 1.7 per cent when revenue is used to repay debt. These changes fall far short of the EU target for Ireland, which requires a reduction of 39 per cent in the non EU-ETS sectors by 2020 (Tol *et al.*, 2008).

While equilibrium runs are the appropriate way to conduct controlled experiments, we conclude that the results from equilibrium runs give biased policy advice, because the structure of economic activity and emissions change considerably, even over a relatively short period of 15 years.

6. Discussion and Conclusion

In this paper, we analyse the effects of a carbon tax on Irish economic growth and on emissions. We isolate the effects of a carbon tax from those due to unrelated changes in the Irish and world economy by maintaining the economic structure fixed at its 2005 level. We determine the equilibrium effects of such a tax.

The result is that a double dividend in Ireland is possible if the carbon tax revenue is recycled through a reduction of income taxes. This shifts the burden of the tax from labour towards capital. In a small open economy such as Ireland, where labour is particularly mobile and labour costs are a large component of international

competitiveness, this tends to improve economic performance. No double dividend is likely to arise if the revenue is given back to households as a lump-sum payment.

We find that the main channel through which the tax changes affect the economy is in fact through changes in the international competitiveness of manufacturing and services.

When the Irish economy is allowed to evolve following recent forecasts, the effect of a carbon tax is likely to be even more favourable to the economy, whereas the results on carbon dioxide emissions will be more muted.

In the long run, the biggest impact from a carbon tax (and permit price) will be to incentivise research into new technologies (Popp, 2002, Fischer *et al.*, 2003; Fischer, 2007; but see also Adeyemi and Hunt, 2007; van Zon and Yetkiner, 2003). It is only with such development that major reductions in emissions will be possible. However, the time scale on R&D is measured in decades – and thus beyond the scope of this paper.

If the carbon tax is limited to Ireland, the incentives to do R&D and develop new technologies would be very weak. However, if the price of carbon is similar across the EU, a very large market, substantial R&D would take place and new technologies may be developed. If the increase in the price of carbon were worldwide (as with oil prices) or applied across the OECD, then the effect on R&D would be even greater. Whatever the effect on R&D, as shown here, it is likely to have a limited effect on emissions in the first decade. It is only really in the longer term that major change would be seen with the introduction of new technologies developed because of the carbon tax.

A carbon tax that equals the expected price of CO_2 emission permits on the European market would guarantee that the emissions are reduced in a cost-effective manner. It would also imply that Ireland over-complies with its emission reduction target under the EU Emissions Trading Scheme (EU ETS), and misses its target outside the EU ETS. Fungibility between the separate targets is therefore in Ireland's interest – but is not foreseen in the initial EU policy proposals. Under this carbon tax, Ireland will also miss its implied aggregate emissions target, and so will have to import emission reduction credits from abroad.

There are a number of caveats. The *HERMES* model is essentially linear. However, as taxes are ramped up it is likely that the distortions of the carbon tax would be more than proportional (Giavazzi et al., 2000; Honohan and Irvine, 1987). This is particularly the

case if the price of carbon in Ireland were to be significantly different than in its neighbour countries. We address this by building a proxy for an 'upper bound' for effects of a carbon tax. Under this scenario the effect on emission reduction is slightly larger, the effect on economic growth is slightly smaller but the main qualitative results remain unchanged. Since *HERMES* does not have a detailed representation of technological substitution, the results presented here are valid only up to 10 to 15 years. We would expect that the impact of a carbon tax would be more substantial in the longer term, when the effects of new R&D take place. *HERMES* also lacks a detailed representation of the consumption side of the economy. A detailed, intertemporal, computable general equilibrium model of the Irish economy would be needed to take into account R&D effects. Whatever the full economic impact of a carbon tax, it is still the cheapest way to reduce emissions. Other policy instruments may achieve similar or larger emission reductions, but necessarily at a higher cost.

Acknowledgements

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Table 1. Factor Shares in Manufacturing Output, 2005

	Share
Labour	8.7
Capital	22.2
Energy	1.0
Non-energy material inputs	68.1

Source: CSO, *Census of Industrial Production*, enterprise data.

Table 2. Estimated price elasticities of energy demand.

Energy type and sector	Long Run Price Elasticity
Electricity Demand:	
Household[1]	-0.32
Commercial and Public[2]	-0.15
Industry[3]	-0.29
Agriculture[4]	-0.84
Non-Electricity Energy Demand:	
Household[5]	-0.35
Commercial and Public	-0.38
Fuel Demand:	
Transport – Oil[6]	-0.23
Transport – Kerosene[7]	-1.36

Notes:

[1] The elasticity is defined as the percentage change in energy for a one per cent change in the activity variable. In this case the activity variable is the stock of housing and the price variable is the real price of electricity to the consumer.

[2] The activity variable here is GDP arising in the market and the non-market sectors and the price variable is the real price of energy to industrial consumers.

[3] The activity variable here is GDP arising in industry and the price variable is the price of electricity for industry relative to the price of manufacturing output.

[4] The price variable used is the price of energy inputs in manufacturing deflated by the deflator for agricultural inputs.

[5] The activity variable here is real personal disposable income.

[6] The price elasticity is with respect to the price of petrol relative to the UK.

[7] The price elasticity is with respect to the real price of kerosene to the consumer.

Table 3. Equilibrium effects of individual tax changes, % change from baseline

	Carbon Tax	Carbon Tax upper bound	Income Tax	Lump Sum
GDP, volume	-0.21	-0.41	0.60	0.27
GNP (excl nat. debt int.), volume	-0.05	-0.19	0.49	0.32
GNP, volume	0.07	-0.09	0.37	0.20
Output				
Market services, volume	-0.24	-0.32	0.76	0.35
Manufacturing, gross volume	-0.34	-0.98	0.61	- 0.03
Price of energy, manufacturing	17.13	17.17	- 0.02	0.01
Price of energy, households	3.25	3.25	- 0.02	0.00
Employment	-0.07	-0.19	0.59	0.10
Wage rate, non-agriculture	0.20	0.12	- 1.06	0.06
Personal disposable income, real	-0.36	-0.45	1.14	1.24
Consumption, constant prices	-0.26	-0.33	0.88	0.93
Exports, price deflator	0.11	0.10	- 0.07	0.00
Imports, price deflator	0.00	0.00	0.00	0.00
Balance of payments, % of GNP	0.35	0.25	- 0.33	- 0.41
CO_2 excl. electricity & aviation	-2.02	-2.21	0.50	0.35
Tax incidence, %				
Capital, domestic	39	50	23	20
Capital, foreign	38	27	14	1
Labour	12	19	46	5
Other personal income	12	4	16	74

Table 4. Equilibrium effects of tax reform, % change from baseline

	Income Tax	Income Tax upper bound	Lump Sum	Lump Sum upper bound
GDP, volume	0.39	0.10	0.05	-0.23
GNP (excl. nat. debt int.), volume	0.44	0.26	0.27	0.09
GNP, volume	0.45	0.27	0.27	0.09
Output				
Market services, volume	0.52	0.37	0.11	-0.04
Manufacturing, gross volume	0.27	-0.57	-0.37	-1.21
Price of energy, manufacturing	17.11	20.71	17.13	20.74
Price of energy, households	3.23	3.90	3.25	3.92
Employment	0.51	0.36	0.03	-0.13
Wage rate, non-agriculture	-0.86	-0.91	0.26	0.20
Personal disposable income, real	0.79	0.60	0.88	0.70
Consumption, constant prices	0.62	0.48	0.68	0.53
Exports, price deflator	0.03	0.05	0.11	0.12
Imports, price deflator	0.01	0.00	0.00	0.00
Balance of payments, % of GNP	0.01	-0.03	-0.06	-0.10
CO_2 excl. electricity & aviation	-1.52	-2.17	-1.67	-2.32

Table 5. Effects of a tax reform on the Irish economy by 2020, % change from baseline

	Income	Lump sum	Debt repayment
GNP, volume	1.11	0.27	0.09
Employment	1.06	0.04	-0.11
CO_2 excl. electricity & aviation	-1.23	-0.12	-1.73

Source: After Tol et al. (2008)
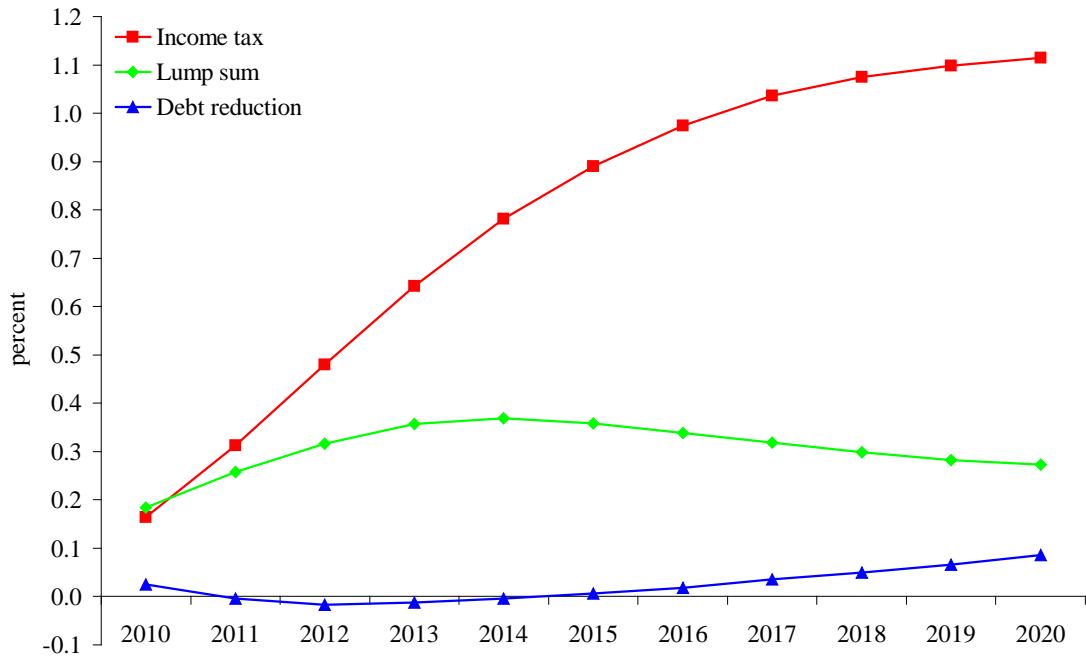
Figure 1. Effects of a tax reform on GNP in Ireland for three alternative ways to recycle the carbon tax revenue.

Appendix 1: Model of Output in Tradable Sector of the Irish Economy

These equations are taken from the latest version of the *HERMES* model of the Irish economy. The manufacturing sector is divided into three sub-sectors: high tech (metals, engineering and chemicals); food processing; and traditional (the rest of manufacturing). The unit cost of production is estimated as part of the estimation of the factor demand systems for each sub-sector, as described in Bradley, Fitz Gerald and Kearney (1993).

High Tech. manufacturing

The long-run desired level of output in Ireland (Q^*)is a function of world output Q_u (proxied by US GDP), the unit cost of production in Ireland c_i relative to the cost in the OECD area c_o (proxied by manufacturing output prices in the OECD area) and Irish wage rates (w_i) relative to wage rates in the UK (w_u). The elasticity with respect to world output is higher from 1990 onwards reflected in the dummy D which takes on the value zero up to 1989 and one thereafter.

$$Log(Q^*) = a_1 + a_2 \log(Q_U) + a_3 D \log(Q_U) + a_3 \log(\frac{c_i}{c_O}) + a_4 \log\left(\frac{w_i}{w_u}\right)$$

The estimation period is 1975 to 2005.

$\overline{R}^2 = 0.99533$ S.E.= 0.078032

Coefficient	Estimate	Standard Error	T statistic
a_1	12.88581	0.678801	18.98318
a_2	3.39785	0.218861	15.52516
a_3	0.404133	0.121479	3.326758
a_4	-0.61257	0.228735	-2.67808
a_5	-0.67154	0.198378	-3.38516

The elasticity with respect to world activity rises after 1990. What is important for the results in this paper is how output is affected by the competitiveness of the sector. The unit cost of production includes the effects of developments in all costs – materials, energy, labour, and capital - where the weights in the unit cost are estimated as part of the estimation of the factor demand system. These weights approximate the factor shares in

total cost. The coefficient on this variable, a_4, suggests that a one per cent rise in the unit cost of production, due to a rise in energy or materials costs, leads to a 0.61 per cent fall in output in the long run. However, a one per cent rise in domestic wage rates would have a substantial additional impact through the coefficient a_5.

These results suggest that the sub-sector of manufacturing is more sensitive to labour costs than to other developments. This probably reflects the fact that in the sample period, because much of the inputs of materials and energy into the sector were imported, their prices would have been similar to those in countries competing to attract the firms. However, if firms were faced with an increase in the Irish cost of energy relative to the cost of energy in other competing countries there might be stronger competitiveness effects than estimated here.

Traditional Manufacturing

The long-run desired level of output in Ireland (Q^*) is a function of world output Q_o (proxied by OECD GDP), the unit cost of production in Ireland c_i relative to the cost in the EU c_e (proxied by manufacturing output prices in the EU) and Irish wage rates (w_i) relative to wage rates in Germany (w_g).

$$Log(Q^*) = a_1 + a_2 \log(Q_o) + a_3 \log(\frac{c_i}{c_e}) + a_4 \log\left(\frac{w_i}{w_g}\right)$$

The estimation period is 1975 to 2005.

$\overline{R}^2 = 0.991976$ S.E.= 0.02635

Coefficient	Estimate	Standard Error	T statistic
a_1	-5.18063	0.461097	-11.2354
a_2	1.743797	0.039768	43.84975
a_3	-1.23471	0.110955	-11.1281
a_4	-0.14026	0.056543	-2.48065

Output in Ireland is very sensitive to output in the rest of the world. The seinstivity to changes in the unit cost of production in Ireland (relative to the outside world) is much higher than in the case of the high tech sector. While wage rates have an additional

significant direct effect on competitiveness, this is somewhat lower than in the case of the high tech. sector.

Food Processing

The long-run desired level of output in Ireland (Q^*) is a function of world output Q_u (proxied by UK GDP), the unit cost of production in Ireland c_i relative to wage rates in Germany (w_g).

$$Log(Q^*) = a_1 + a_2 \log(Q_u) + a_3 \log(\frac{c_i}{w_g})$$

The estimation period is 1975 to 2005.

$\overline{R}^2 = 0.991532$ $\quad$ S.E. $= 0.043189$

Coefficient	Estimate	Standard Error	T statistic
a_1	9.907973	0.061218	161.8485
a_2	1.522037	0.153086	9.942346
a_3	-0.30442	0.073131	-4.16271

Output in Ireland is very sensitive to output in the rest of the world. The sensitivity to changes in the unit cost of production in Ireland (relative to the outside world) is lower than in the case of the rest of the manufacturing sector.

Business and Financial Services

In the latest version of the *HERMES* model exports of services (excluding tourism), X_s, are a function of world activity Q_w (proxied by US GDP), Irish wage rates, W_i, relative to those in the UK, W_u, and the rate of corporation tax, T. The elasticity with respect to world output is higher from 1990 onwards reflected in the dummy D which takes on the value zero up to 1989 and one thereafter.

$$Log(X^*) = a_1 + a_2 \log(Q_U) + a_3 D \log(Q_U) + a_4 \log(\frac{w_i}{w_u}) + a_5 T$$

The estimation period is 1970 to 2005.

$\overline{R}^2 = 0.992975$ S.E.= 0.107962

Coefficient	Estimate	Standard Error	T statistic
a_1	14.64381	0.672874	21.76308
a_2	3.801639	0.247892	15.33588
a_3	0.922762	0.189246	4.876002
a_4	-1.29101	0.226313	-5.70453
a_5	-2.21178	0.448538	-4.93109

The estimated elasticity of services exports with respect to world activity in recent years is very high – between 4 and 5. The elasticity with respect to domestic wage rates is -1.3, which is also high relative to the manufacturing sector.

The desired level of output in Ireland in the business and financial sector, Q^*, is a function of exports of services, X, domestic demand weighted by input output coefficients, F, (McCarthy, 2005), and the price of output of the sector p_i relative to wage rates in the UK, w_u.

$$Q^* = a_1 + a_2 X + a_3 F + a_4 \left(\frac{p_i}{w_u} \right)$$

The estimation period is 1970 to 2005.

$\overline{R}^2 = 0.99764$ S.E. = 439.8

Coefficient	Estimate	Standard Error	T statistic
a_1	11145.41	4702.675	2.370015
a_2	0.205175	0.071996	2.849832
a_3	0.94035	0.221912	4.2375
a_4	-4187.07	2044.156	-2.04831
ρ	0.963129	0.015055	63.97611

When simulated as a model these equations suggest an elasticity of domestic output in the sector with respect to world activity of 1.37. The elasticity with respect to relative prices/wage rates is around -0.7.

Demand for Factors of Production, Manufacturing

The own and cross-elasticities of demand for the three factors of production (energy is considered part of the materials inputs) are shown below for the three sub-sectors of manufacturing. These estimates are derived for 2005 from the re-estimation of the model of factor demand described in Bradley, Fitz Gerald and Kearney, 1993.

Table A.1. Hi-tech manufacturing elasticities of substitution, long-run

	LABOUR	MATERIALS	CAPITAL
LABOUR	-1.00	0.79	0.21
MATERIALS	0.08	-0.32	0.23
CAPITAL	0.06	0.62	-0.68

For this sector materials, including energy, are a substitute for labour and capital in the long run (when capital is variable). For the carbon tax simulation described in this paper the price of energy inputs in manufacturing rises by around 17 per cent causing the materials input price (including energy) to rise by 0.56 per cent. If all other prices were constant (the price of labour is also affected in the simulation) this would lead to a fall in materials inputs of 0.18 per cent in volume and a rise in capital inputs of 0.13 per cent.

Table A.2. Traditional manufacturing elasticities of substitution, long-run

	LABOUR	MATERIALS	CAPITAL
LABOUR	-0.29	0.44	-0.15
MATERIALS	0.07	-0.54	0.47
CAPITAL	-0.07	1.32	-1.25

The own price elasticity for materials is significantly higher in this sector than in the high tech. sector.

Table A.3. Food processing elasticities of substitution, long-run

	LABOUR	MATERIALS	CAPITAL
LABOUR	-0.93	-0.42	1.35
MATERIALS	-0.04	-0.51	0.56
CAPITAL	0.63	2.60	-3.22

The response of factor demand to a change in the price of materials in this sector is similar to that in the traditional sector with the exception that materials and labour are slight complements rather than substitutes.

Year	Number	Title/Author(s) ESRI Authors/Co-authors *Italicised*
2008	250	The Distributional Implications of a Carbon Tax in Ireland *Tim Callan, Sean Lyons, Susan Scott, Richard S.J. Tol and Stefano Verde*
	249	Measuring Material Deprivation in the Enlarged EU *Christopher T. Whelan, Brian Nolan* and *Bertrand Maître*
	248	Marginal Abatement Costs on Carbon-Dioxide Emissions: A Meta-Analysis Onno Kuik, Luke Brander and *Richard S.J. Tol*
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