STRATHCLYDE

DISCUSSION PAPERS IN ECONOMICS

INCORPORATING SUSTAINABILITY INDICATORS INTO A COMPUTABLE GENERAL EQUILIBRIUM MODEL OF THE SCOTTISH ECONOMY

BY

LINDA FERGUSON, PETER G MCGREGOR, J KIM SWALES, KAREN R TURNER & Y PING YIN

NO. 04-13

DEPARTMENT OF ECONOMICS
UNIVERSITY OF STRATHCLYDE
GLASGOW

INCORPORATING SUSTAINABILITY INDICATORS INTO A COMPUTABLE GENERAL EQUILIBRIUM MODEL OF THE SCOTTISH ECONOMY[1]

by

Linda Ferguson **, Peter G McGregor +, J Kim Swales **, Karen R Turner ** and Ya Ping Yin •

June 2004

+ Department of Economics, University of Strathclyde
** Fraser of Allander Institute and Department of Economics, University of Strathclyde
• Department of Economics, Social Sciences and Tourism, Business School, University of Hertfordshire.

Abstract: In recent years, the notion of sustainable development has begun to figure prominently in the regional, as well as the national, policy concerns of many industrialised countries. Indicators have typically been used to monitor changes in economic, environmental and social variables to show whether economic development is on a sustainable path. In this paper we endogenise individual and composite environmental indicators within an appropriately specified computable general equilibrium modelling framework for Scotland. In principle, at least, this represents a very powerful modelling tool that can inform the policy making process by identifying the impact of any exogenous policy change on the key endogenous environmental and economic indicators. It can also identify the effects of any binding environmental targets on economic activity.

Key words: computable general equilibrium modelling, environmental indicators, sustainability policy.

[1] The research reported here has been funded by the ESRC under the grant (No. R000 22 3869) "Modelling the Impact of Sustainability Policies in Scotland". The authors are grateful to Rocky Harris, Head of the Environmental Accounts Branch, Office for National Statistics, for supplying the UK Trial NAMEA database used in this report. We would also like to thank: two anonymous referees for very detailed comments that significantly improved the paper; Michael Romeril, Environmental Adviser to the States of Jersey, for his encouragement and comments on related environmental research; participants in the conference on Input-Output held at Guadalajara, Mexico, 1999, for comments on early work in a similar vein and Nick Hanley, Glasgow University, for many discussions on related issues.

1. Introduction and background

Sustainable development is a key objective of UK government policies (Department of Environment, 1996) and is receiving increasing emphasis in a regional development context. The recently established Scottish Parliament has responsibility for protecting the environment in Scotland and sustainable development is one of the outcome objectives of the Scottish Executive's Framework for Economic Development (Scottish Executive, 2000). Furthermore, the National Assembly for Wales has a constitutional duty to promote sustainable development under section 121 of the Government of Wales Act 1998 (Department of Environment, Transport and the Regions, 2001a, Section III, Chapter 3). While the UK government could use its reserved powers to bind the devolved administrations of Scotland, Wales and Northern Ireland to the UK's international targets for greenhouse gas emissions, it has chosen not to do so. Rather, these administrations have agreed to join in a programme of action to deliver these targets and the domestic goal of a 20% cut in carbon dioxide emissions by 2010 (Department of Environment, Transport and the Regions, 2001a, Section I, Chapter 6). The region has therefore become the natural spatial focus for the UK evaluation of policies directed at sustainability.

Environmental issues figure large in the Scottish Parliament (see e.g. Advisory Group on Education for Sustainable Development, 1999). We therefore believe that there is now a compelling case for an empirical modelling framework for Scotland that will routinely track the economic and environmental effects of both environmental and economic policies and other disturbances. This model has to be empirical, rather than theoretical, since in general we require knowledge of the likely size of any induced change as well as its direction. Purely theoretical models can, at best, furnish information only on the latter. We propose to measure environmental impacts through the use of a number of "sustainability indicators", which are emphasised both by the Scottish Executive (2002, 2003) and by the UK's Department of Environment, Transport and the Regions (1999a,b,c, 2001b). In McGregor *et al* (2001) we construct and apply an environmental input-output (I-O) model for Scotland. In this paper we argue that there are substantial benefits to be gained by generalising our earlier approach through the development of a Scottish environmental computable general equilibrium (CGE) model.[2]

[2] This represents further development of earlier work reported in McGregor *et al* (2003).

This paper is organised as follows. In Section 2 we discuss key features of sustainability indicators and in Section 3 we present the rationale for our modelling approach. In Section 4 we briefly outline the structure of AMOSENVI, our environmental CGE model of Scotland. In Section 5 we use the model to examine the likely environmental impact of two economic policy changes that are feasible under devolution. Specifically, we consider the impact of a stimulus to government expenditures and then a rise in the basic rate of income tax within the range "plus or minus 3 p in the £1" given in the Scotland Act, 1998). Section 6 is a brief conclusion.

2. Sustainability indicators

Sustainable development is a prominent policy concern in many industrialised countries, typically operationalised through tracking sustainability indicators. This involves the systematic and regular reporting of movements in a number of economic, environmental and social variables that are thought to show whether economic development is on a sustainable path. However, the formulation of sustainability indicators has become an extremely controversial and hotly debated policy area. Uncertainty over sustainability objectives has contributed to a lack of consensus over how many and what type of sustainability indicators are required, and whether, for example, sets of individual indicators are preferable to composite indicators.

The purpose of this paper is not to debate further the choice of appropriate environmental indicators, but rather to consider their incorporation within a CGE model of the Scottish economy once this choice has been made (Conrad, 1999). We use the output of six pollutants as individual environmental indicators and construct two composite environmental indicators - the Index of Global Warming Potential (GWP) and the Sustainable Prosperity Indicator adopted by the Scottish Executive (2002). The choice of individual and composite environmental indicators is, at this stage, illustrative and pragmatic. for example, the Scottish Executive's sustainability policy focuses on a wider range of environmental, economic and social objectives (Scottish Executive, 2002; 2003). However, if environmental indicators can be built in as endogenous variables in the model, their changes can be tracked and analysed. Here we focus on such an extension to our existing AMOS economic modelling framework. We also explore the consequences of introducing environmental targets.

3. A Computable General Equilibrium (CGE) modelling approach to economy-environment interaction.

In recent years, there has been a huge increase in interest in the environment and its interaction with the economy (see Baumol and Oates (1988) and Perman *et al* (2003) for reviews). A key feature of this literature is its recognition of the interdependence between the economy and the environment. In general this interdependence operates in both directions. Clearly economic development can have a major impact on the environment and, in the very long run, environmental change may have substantial automatic feedback effects to the economy, although these effects are currently less well understood.[3] Given the small scale of the Scottish economy and its population, it is legitimate to abstract from any such feedback effects that may arise through induced global environmental change and associated sustainability issues. However, in Section 5 we explore the possible economic impacts of commitments to targets for environmental indicators: this is, of course, potentially a very important, though policy-induced, transmission mechanism from the environment to the economy.

There are a number of possible approaches to the empirical modelling of economy-environment interactions. However, because of the importance of the composition of economic activity in governing its environmental impact, such models must be multi-sectoral in nature. Industries are known to differ radically in the extent to which they generate pollution of various kinds, and any practical model of the environment-economy nexus must reflect this. In practice there are three main types of relevant models: econometric-environmental impact models (Barker, 1997); environmental input-output (I-O) models (Leontief, 1970) and environmental computable general equilibrium (CGE) models (Capros *et al*, 1996).

The econometric approach, while having much to commend it, could not currently be fully implemented on Scottish data. However, there is considerable potential for developing this method in the longer term, perhaps as a prelude to integrating the results with the other modelling frameworks. The application of I-O to environmental issues has a long pedigree with partial reviews given in Forssell (1998), Forssell and Polenske (1998) and Gale (1995). There also exists considerable I-O

[3] Potential transmission mechanisms are through the productivity of agriculture or through health (Espinosa and Smith, 1995, and Mayeres and van Regemotor, 2002)

research for Scotland, reflecting the regular availability of Scottish I-O tables. In McGregor *et al* (2001) we develop an environmental input-output model for Scotland, extending the earlier work of McNicoll and Blakemore (1993). Environmental I-O systems have many advantages, including their linearity and transparency, and their ability to identify all the direct, indirect and induced environmental impact of any change in final demands. However, their applicability is limited by their entirely passive supply side. This passivity might be a reasonable assumption under conditions of very substantial unemployment and excess capacity, which is why I-O models are often regarded as embodying a limiting Keynesian view of the macro-economy. But this rationale does not seem compelling given the recent experience of the Scottish economy. An alternative motivation in the context of a small, regional economy is that I-O models can accurately capture the long-run equilibrium impacts of demand disturbances in a wide range of neoclassical regional economic models, provided there is no regional-specific factor (McGregor *et al*, 1996). This condition typically requires perfect inter-regional factor mobility.

If supply conditions are non-passive, or if the focus of attention is on the impact of supply-side disturbances - such as changes in productivity or factor prices - we need a modelling approach that more fully identifies the supply side. We have already suggested that the stylised facts of the Scottish economy imply a non-passive supply side, at least in the short run. Furthermore, many economic, and virtually all environmental, policies are directed at the supply side. CGE models, which are capable of accommodating the supply side in a theory-consistent manner, are therefore proving increasingly popular in this context.

Overall, the case for a CGE approach seems compelling since, for any given aggregative structure, any environmental I-O system is a special case of the corresponding environmental CGE system. When the supply side is entirely passive and the disturbance under consideration operates purely as a demand shock, the CGE model emulates the behaviour of the corresponding I-O system.[4] CGE models are now being extensively used in studies of the economy-environment nexus, though typically at the level of the national economy. (See e.g. Beausejour *et al* (1995), Bergman (1990),

[4] For valuable general surveys of CGE models see Dervis *et al* (1982) and Shoven and Whalley (1984, 1992). Partridge and Rickman (1998) provide a critical review of regional CGE modelling.

Conrad and Schroder (1993), Goulder (1998) and Lee and Roland-Holst (1997). Conrad (1999, 2002) provide reviews.) There are, however, a limited but growing, number of regional applications of CGEs to environmental issues, including Despotakis and Fisher (1988), Kamat *et al* (1999), Li and Rose (1995) and Stevens and Rose (2001).

4. AMOSENVI: The ENVIronmental impact version of AMOS (A Macro-micro model Of Scotland)

Some general issues in the specification of environmental CGEs

Not surprisingly the spatial structure of environmental CGEs reflects the objectives of the particular modelling exercises. A focus on global environmental change requires a global modelling framework and an emphasis on the generation of the greenhouse gasses that are the major source of global warming. (See Dean and Hoeller (1992), which includes a discussion of results from three global CGE models: the GREEN model (Burniaux *et al*, 1992), the Carbon Rights Trade Model, or CRTM (Rutherford, 1992), and the Whalley-Wigle Model (Whalley and Wigle, 1992).) Since our focus is on a small open regional economy, global sustainability issues (including natural resource depletion) are beyond the scope of the present study. Instead we consider the more "local" ramifications of any commitments to global sustainability, for example, and on local quality-of-life issues. In this context it is natural to focus on a wider range of pollutants than the greenhouse gases that are the main concern of global models, although the latter, of course, remain important if, as is the case in Scotland, the region has responsibility for delivering on targets for limiting such emissions.

Regardless of the geographic coverage of environmental CGEs, two general specification issues have to be tackled, namely the appropriate modelling of energy inputs and of pollutant generation. The issues for energy are these. First, whether it should be treated as an intermediate or primary input; second, the substitutability between energy and non-energy inputs; and third, the substitutability among energy inputs (Bergman, 1988; Conrad, 1999). As will become clear below, in AMOSENVI we treat energy inputs as intermediates that are not separately identified. We assume a fairly typical hierarchical, multi-level production structure, characterised by various nested CES, Cobb-Douglas and Leontief functional forms. In this paper, within the intermediate nest of the production hierarchy we assume a Leontief production structure, so that no substitution is possible among different intermediate inputs, including energy. However, price-sensitive choices typically exist between imported and domestically produced intermediates. While this is a fairly common treatment of energy inputs in CGEs, it is clearly restrictive. For example, it allows no substitution among alternative energy sources and no differential specific substitutablity/complementarity between energy inputs and capital and labour services. We will relax these restrictions in future research.

A second key aspect of the specification relates to the treatment of pollution. In multi-sectoral modelling, pollution is most commonly assumed to be generated by means of fixed coefficients linking pollution production to each sector's output level. We also adopt this treatment of pollution here, though again we recognise that this imposes restrictions on our analysis. Where pollution is attributable to the combustion of fossil fuels, for example, it is more accurately modelled through emission coefficients that link pollutant generation directly to particular energy inputs. This would be essential, for example, in any system that seeks to allow for substitution among alternative energy inputs that are known to have quite different pollutant intensities. In fact, depending on the nature of the pollution, there may be a case for combined use of input and output-based pollutant modelling (Beauséjour *et al* 1995; Bergman, 1988, 1990).

In this particular exercise, the impact of these assumptions is limited by our focussing on the environmental impact of only those economic policies that have so far been devolved to the Scottish Parliament. The two key policies in the present context are variations in government expenditure (through an assigned budget of £20 billion) and the power to change the basic rate of income tax by 3p in the £1 in either direction. This tax-varying power allows incremental balanced-budget fiscal expansions or contractions. If our concern were to identify the impact of environmental policies that operate through inducing changes in the use of energy inputs in production (e.g. a carbon tax), then the limitations of the current structure would be more telling. However, such policies are not currently available to the Scottish Parliament and those that are are unlikely to influence significantly the incentives for the use of energy as against other inputs. They certainly are not aimed at doing so. The comparative rigidity of the present model's structure is therefore of less concern than it might otherwise be. In fact, there is considerable debate concerning the case for further fiscal autonomy in

Scotland and, as we shall show below, the attainment of its sustainability objectives is likely to prove difficult using the Parliament's current fiscal powers.

In line with our regional focus, we model the generation of six individual pollutants. These are sulphur dioxide, methane, nitrous oxide, carbon monoxide, carbon dioxide, and PM110. The choice of which pollutants are modelled here has been dictated by the availability of suitable direct emissions coefficients (production sector output-pollution and final demand sector expenditure-pollution coefficients). Due to the absence of appropriate Scotland-specific data, we have initially constructed a set of pollution coefficients that are based upon the relationships between the production of sectoral outputs and emissions generation at the UK level. However, this means imposing certain strong assumptions regarding the homogeneity of fuel use and polluting technology across space in the UK Therefore, we have attempted to estimate Scottish-specific pollution coefficients for the main greenhouse gas, CO_2, using Scottish based data for the estimated use of different types of fuels at the sectoral level and UK fuel-use emissions factors. Using UK emissions factors for CO_2 is less restrictive for than would be the case for the other 5 pollutants modelled here. This is because CO_2 is the pollutant for which there is the most direct relationship between fuel use and emission generation. We also take account of non-fuel-combustion emissions of CO_2 in the 'Manufactured metal and non-metal goods', 'Oil and gas extraction' and 'Refining and distribution of oil' sectors, using estimates of CO_2 emissions in 1999 from the relevant sources reported by Salway *et al* (2001).

Finally, we also use experimental IO data splitting the aggregate electricity supply sector into different generation sectors. This allows us also to relax the assumption of homogenous polluting technology and distinguish between electricity generated using renewable and non-renewable sources. This is a particularly important distinction since electricity generation using renewable sources is more prevalent in Scotland relative to the rest of the UK.

A fuller description of the pollution coefficients used here is provided in Appendix 3 and Turner (2003a) provides a detailed explanation of the estimation of the Scottish-specific CO_2 coefficients. In Section 5 below we report simulation results for CO_2 based on both the UK and Scottish-specific coefficients to identify the sensitivity of our results to the use of region-specific pollution data. The necessary use of UK coefficients for the other five pollutants in our model implies that the quantitative results should be regarded as illustrative. Our aim is primarily to demonstrate how this type of model can be used to track and analyse movements in the type of emissions that may be regarded as key environmental indicators, rather than to provide an accurate and conclusive assessment of the environmental impact of devolved fiscal policies. In fact, as discussed in Turner (2003b), the use of region-specific coefficients may lead to significant improvements in accuracy.

In addition to modelling these individual environmental indicators, we also employ an illustrative composite indicator at this stage. One is the Global Warming Potential (GWP) index. This is a composite indicator derived from three individual "greenhouse gasses" which enter with weights that reflect their carbon content. These are CO_2 (1), N_2O (310) and CH_4 (21). We also calculate the indicator of 'Sustainable Prosperity' intended to track the CO_2-intensity of Scottish GDP. This is simply carbon dioxide emissions per unit of Scottish GDP (Scottish Executive, 2002). The crucial point is that the selected indicators are based on variables that can be measured and built into the model. It is therefore a straightforward task to extend the type of analysis discussed here to the tracking of any policy change on any chosen indicator, or to the identification of the economic impact of adoption of binding targets for any environmental variable.

AMOSENVI

Because of its focus on environmental issues, AMOSENVI, our CGE modelling framework, is sectorally disaggregated. The model is parameterised on data from a UK region, Scotland.[5] The regional dimension is reflected in: the importance of interregional trade flows (in the SAM and through the Armington interlinks in the model) in goods markets; labour market linkages through migration (and, in general, wage bargaining); the assumed perfect mobility of financial capital, with interest rates set exogenously by the Bank of England's Monetary Policy Committee, and the permanently fixed nominal exchange rate that Scotland shares with the rest of the UK. A very brief description is presented in this section: more detail is available in Appendix 1 and a full listing of the basic version of the AMOS model is provided in Harrigan *et al* (1991). AMOSENVI has 3 transactor groups, namely

[5] AMOS is an acronym for *A M*acro-micro model *O*f *S*cotland. AMOSENVI is a variant with an appropriate sectoral disaggregation and set of linked pollution coefficients, developed specifically to investigate environmental impacts.

households, corporations, and government[6]; 25 commodities and activities (see Appendix 2 for details); and two exogenous external transactors (RUK and ROW). As stated earlier, there are six pollutants identified, the outputs of which are linked, through fixed coefficients, to each individual industry's outputs and household consumption. Throughout this paper commodity markets are taken to be competitive.

The AMOSENVI framework allows a high degree of flexibility in the choice of key parameter values and model closures. However, a crucial characteristic of the model is that, no matter how it is configured, we impose cost minimisation in production with multi-level production functions, generally of a CES form but with Leontief and Cobb-Douglas being available as special cases. For simplicity, all domestic intermediate transactions are assumed to be of the Leontief form in this paper. There are four major components of final demand: consumption, investment, government expenditure and exports. Of these, real government expenditure is taken to be exogenous. Consumption is a linear homogeneous function of real disposable income. Exports (and imports) are generally determined via an Armington link (Armington, 1969) and are therefore relative-price sensitive. Investment is a little more complex as we discuss below.

In all the simulations in this paper we impose a single Scottish labour market characterised by perfect sectoral mobility. Wages are subject to a regional bargained real wage function (BRW) in which the regional real consumption wage is directly related to workers bargaining power, and therefore inversely to the regional unemployment rate (Minford *et al*, 1994). This hypothesis has received considerable support in the recent past from a number of authors. Here, however, we take the bargaining function from the regional econometric work reported by Layard *et al* (1991):

[1] $$\mathbf{w_{s,t} = \alpha - 0.068\, u_s + 0.40\, w_{st-1}}$$

where: w_s and u_s are the natural logarithms of the Scottish real consumption wage and the unemployment rate respectively, t is the time subscript and α is a calibrated parameter.[7] Empirical

[6] In AMOSENVI, Scotland is treated as a self-governing economy, in the sense that there is only one consolidated government sector. Central government activity is partitioned to Scotland and combined with local government activity.

[7] Parameter α is calibrated so as to replicate the base period (as is β in equation [2]). These calibrated parameters play no

support for this "wage curve" specification is now widespread, even in a regional context (Blanchflower and Oswald, 1994).

Within each period of the multi-period simulations using AMOSENVI, both the total capital stock and its sectoral composition are fixed, and commodity markets clear continuously. Each sector's capital stock is updated between periods via a simple capital stock adjustment procedure, according to which investment equals depreciation plus some fraction of the gap between the desired level of the capital stock and its actual level. This process of capital accumulation is compatible with a simple theory of optimal firm behaviour given the assumption of quadratic adjustment costs. Desired capital stocks are determined on cost-minimisation criteria and actual stocks reflect last period's stocks, adjusted for depreciation and gross investment. The economy is assumed initially to be in long run equilibrium, where desired and actual capital stocks are equal.[8] Where migration is incorporated in the model, population is also updated "between" periods. We take net migration to be positively related to the real wage differential and negatively to the unemployment rate differential in accordance with the econometrically estimated model reported in Layard *et al* (1991). This model is based on that in Harris and Todaro (1970), and is commonly employed in studies of US migration (e.g. Greenwood *et al*, 1991; Treyz *et al*, 1993). The migration function we adopt is therefore of the form:

[2] $$\mathbf{m = \beta - 0.08(u_s - u_r) + 0.06(w_s - w_r)}$$

where: m is the net in-migration rate (as a proportion of the indigenous population); w_r and u_r are the natural logarithms of the real consumption wage and unemployment rates, respectively, in the rest-of-the-UK, and β is a calibrated parameter. In the multiperiod simulations the net migration flows in any period are used to update population stocks at the beginning of the next period, in a manner analogous

part in determining the sensitivity of the endogenous variables to exogenous disturbances but the assumption of initial equilibrium is important.

[8] Our treatment is wholly consistent with sectoral investment being determined by the relationship between the capital rental rate and the user cost of capital. The capital rental rate is the rental that would have to be paid in a competitive market for the (sector specific) physical capital: the user cost is the total cost to the firm of employing a unit of capital. Given that we take the interest, capital depreciation and tax rates to be exogenous, the capital price index is the only endogenous component of the user cost. If the rental rate exceeds the user cost, desired capital stock is greater than the actual capital stock and there is therefore an incentive to increase capital stock. The resultant capital accumulation puts downward pressure on rental rates and so tends to restore equilibrium. In the long run, the capital rental rate equals the user cost in each sector, and the risk-adjusted rate of return is equalised between sectors.

to the updating of the capital stocks. The regional economy is initially assumed to have zero net migration, and ultimately, net migration flows re-establish this population equilibrium. In the period-by-period simulations, each period is interpreted as a year. This is because the population and capital stock adjustment equations are parameterised using econometric results using annual data.

While domestic intermediate transactions are, for simplicity, here assumed to be characterised by Leontief technology, we otherwise assume CES technology (notably for the production of value-added from capital and labour services) with "best guess" elasticities of substitution of 0.3 (Harris, 1989) and Armington trade substitution elasticities of 2.0 (Gibson, 1990).

5. Simulation results

Our main purpose in this paper is to illustrate how the environmental impact of possible economic policies pursued by the Scottish Parliament could be tracked. These are examples of the very wide range of disturbances that could be investigated using AMOSENVI. We here tackle the impact of separate increases in Scottish government expenditures and the Scottish income tax rate. However, we do not attempt to provide a full analysis of the use of the "tartan tax" powers to vary public expenditure funded through changes in the standard rate of income tax by up to 3p in the £1. This simultaneous increase in taxes and expenditures would involve what are, for our current purposes, unnecessary complications.[9]

We begin by considering the impact of a 2.5% stimulus to general public expenditure that is *not* financed within Scotland. This is the kind of stimulus that might arise in the event of an increase in the Parliament's "assigned budget" (formerly the Scottish Office "block grant") of the type implied by the government's recent expenditure plans. However, here we assume for simplicity that the stimulus to government expenditure is equi-proportionately distributed in line with the initial sectoral distribution of such expenditure.

[9] We provide a detailed analysis of the tartan tax power in McGregor *et al* (2004b).

We then consider the likely impact of an increase in the basic rate of income tax, on the assumption that there is no corresponding stimulus to expenditures. The most plausible motivation for this simulation is to emulate one possible response to a contraction in Scotland's share of UK government expenditure generated by the strict application of the Barnett formula. This would be where the Scottish Parliament attempts to maintain public expenditure through the tartan tax. This would effectively produce an increase in taxation with no change in public expenditure (Ferguson *et al*, 2003a: Kay, 1998).

We do not give a formal analysis of the various impacts here, since the elements of this have been set out elsewhere. The theoretical basis of our approach is essentially a regional, general equilibrium variant of the Layard *et al* (1991) imperfectly competitive model. Our subsequent discussion seeks simply to provide an intuitive account of the results, although this inevitably draws on previous work to a degree.

For each policy simulation we consider briefly the economic and then the environmental impacts. These are considered over three conceptual intervals. In the short run regional population and capital stocks are fixed. In the medium run migration adjusts to generate an equilibrium regional distribution of population whilst capital stocks are kept fixed at the level of individual industries. In the long run, in addition, all sectoral capital stocks are fully adjusted to their desired levels. The multiperiod variant of the model can be used to trace out completely the adjustment paths between short-run and long-run equilibria. In this paper, however, we limit our reporting of multiperiod simulations to 10 periods (each period to be interpreted as a year). This is a standard time-frame for policy evaluation, and one which allows us to focus on the crucial movements in the environmental indicators modelled in response to the two policy changes described above.

The impact of a 2.5% stimulus to government expenditure

Table 1 summarises the aggregate results for the 2.5% stimulus to government expenditure. We report the results as percentage changes in each variable relative to its initial value. In the short run, with fixed capital stocks and population, the stimulus to demand generates a modest increase in GDP and employment, and a reduction in the unemployment rate. The tightened labour market conditions generate a higher real consumption wage and higher prices. In the medium run, in-migration continues until the higher real consumption wage, and lower unemployment rate, observed in the short run are completely eliminated. At this point, the stimulus to the real economy is significantly enhanced - with GDP increasing by 0.40% as against 0.30% in the short run - and the price increases are more limited. In the long run complete adjustment of capital stocks, given an exogenous national interest rate and the flow migration process, ensures that the model solution converges on the I-O solution. There are no price or wage changes, equi-proportionate changes in all inputs and a substantially greater impact on the real economy (McGregor *et al*, 1996).

Figure 1 illustrates the sectoral distribution of gross output effects in the short, medium, and long run. The differences among the three time intervals are striking, largely reflecting the different macroeconomic influences that predominate in each case. Thus the short run rise in the real wage and in capital rentals (given the fixity of capital stocks over this interval) push up prices and generate crowding out through reduced net exports for many sectors. Indeed, other than Public and Other Services (in which 84.2% of total government expenditure is concentrated), only R&D, Education, Gas, Construction and Distribution actually experience positive output effects in the short run. In all other sectors, the induced supply effects are such as to generate an increase in the real producer price of labour and a contraction in employment. In the longer-run, these negative effects are ultimately eliminated, as in-migration pushes down wages and prices, initially limiting the extent of crowding out, and ultimately eliminating it completely. In Figure 1 all long-run output effects are therefore non-negative, as they must be in response to a demand stimulus in a system that emulates an I-O model.

Figures 2 and 3 summarise the sectoral employment and value-added impacts in the short and long run respectively. Given the fixity of capital stocks, employment effects all exceed value-added impacts in the short run (regardless of the direction of change). The striking feature of the long-run results, however, is the equiproportionate changes in employment, value-added and output over this interval. This reflects the long-run I-O solution such that, within each industry, all inputs (and outputs) vary in the same proportion. Since there are no changes in relative prices over the long run, there are no substitution effects, and it is “as if” technology is Leontief in nature.

The factors governing the sectoral distribution of the demand stimulus in the long run are, of course, precisely those that operate in I-O systems augmented for endogenous consumption, investment, social security and migration effects (although here we present the results as percentage changes from base values, rather than as multipliers). The initial distribution of government expenditures is naturally important as is the structure of industries (in terms of their intermediate and labour intensities), and the composition of consumption and investment demands. In the shorter run, the relative openness of sectors is a key determinant of their sensitivity to induced price rises.

Figure 4 plots short-, medium- and long-run percentage changes in each of the 6 individual pollutants on a single graph so as to highlight the fundamentally different outcomes in each interval. Recall that in the present version of AMOSENVI pollutants are linked to sectoral outputs by means of fixed coefficients. Therefore the scale and sectoral composition of output changes drives the subsequent changes in pollutant generation. The differences between the figures again largely reflect both the distinct macroeconomic forces that operate in the short and long runs, and also the different sectoral impacts of these forces. Thus in the short run there is generally only a modest increase in the output of most of these pollutants, and even a reduction in one. These results reflect the contraction in economic activity in many industries over this period reported in Figure 1. In the medium run, the in-migration and subsequent reduction in the wage reverse, or limit, the short-run contractions in the relevant industries. All pollutants show a more significant increase over this time interval.

In the long run the outputs of all industries increase so that there is a much greater increase in all pollutants. The graphs illustrate the fact that there is generally a trade-off between environmental quality and economic activity: typically, increases in economic activity are associated with increased pollutants. Naturally, the pattern of pollution is closely related to the industrial composition of outputs. The most obvious example from Figure 4 is the change in the generation of nitrous oxide (N_2O): the sector that is the most intensive in the generation of N_2O is Agriculture, where the economic impact tends to be limited. Another example is CO_2 generation: the study by McGregor *et al* (2001) found that the electricity sector was particularly intensive in the production of CO_2 and this pollutant does indeed tend to move predominantly with changes in the Electricity (non-renewable) sector's output.

Note that in Figure 4 we report results for CO_2 based on both the UK and Scottish-specific pollution coefficients. This gives an indication of the sensitivity of our results to the inclusion of region-specific pollution data. The increase in CO_2 emissions is higher in all three conceptual time periods using the Scottish-specific coefficients. This is largely explained by the fact that in three sectors which receive the biggest stimulus to output - Public & Other Services, Education and Gas - the Scottish-specific CO_2 coefficients are greater than the corresponding UK coefficients.[10]

Figure 5 tracks the movement of one of the Indicators of Sustainable Development newly adopted by the Scottish Executive (2002). This is the indicator of Sustainable Prosperity, calculated as an index of Scottish CO_2 emissions divided by GDP, and devised to monitor the carbon intensity of the Scottish economy.[11] Figure 5 shows that because of the change in the *composition* of aggregate activity, the increase in total CO_2 generation is proportionately smaller than the increase in GDP. Thus the carbon intensity of Scottish GDP falls, and the value of the Sustainable Prosperity indicator decreases, over the 10-year period reported in Figure 5. The value of this indicator also declines over the conceptual medium and long run.[12]

The new set of Sustainability Indicators for Scotland also includes a Climate Change indicator, measured by millions of tonnes of greenhouse gases (in terms of carbon equivalent), with the aim of making a contribution to the UK Kyoto target. AMOSENVI reports on three greenhouse gases (carbon dioxide, methane and nitrous oxide) in physical units, which can easily be translated into carbon equivalent measures. In Figure 6 we track the movement of one illustrative composite indicator, an index of global warming potential (GWP), and the three individual indicators that enter this index, with weights as determined in the previous section. This tracking can be incorporated as part of the standard simulation results. Figure 6 shows that a step increase in externally-funded public expenditure leads to an immediate increase in the GWP index and an increase in all the individual pollutants by period 8. The sharp and sustained increase in methane in particular, combined with its high GWP weighting,

[10] Though this is partially offset by the fact that in most of the other sectors where there is a relatively large stimulus to output, such as the electricity sectors, Scotland is less CO_2 intensive than the UK average.
[11] The figures in Figure 5 are calculated using the Scottish-specific pollution coefficients.
[12] The short run in Table 1 corresponds to period 1 in this multiperiod simulations. Thereafter, migration and investment effects simultaneously influence corresponding stocks. The conceptual medium run of Table 1 therefore does not have a counterpart in the multiperiod solution. If the model is run forward for a sufficient number of periods, the long-run equilibrium is eventually achieved. However, this has not occurred by period 10.

pulls the index up from the start. The multi-period results reflect the feature of the conceptual short-run interval noted above, namely that emissions of one of the individual pollutants (N_2O) initially fall from the base levels because of the crowding out effect in early periods that results from the expansion in the public sector displacing other private sector activity.

The simulations reported in this section illustrate the ability of an environmental CGE model to estimate the environmental impacts of possible policies of the Scottish Parliament. For this particular pure-demand disturbance, the model replicates the behaviour of the corresponding environmental I-O system in the long run (McGregor *et al*, 1996). However, the environmental I-O system could not capture the short- and medium-run effects of the disturbance, nor the multiperiod effects, when supply conditions remain non-passive. Naturally, the I-O system could not deal either with circumstances in which there are any long-run regional-specific factors, whereas the CGE approach can accommodate this in a straightforward way. Even in the context of a demand-disturbance, therefore, moving from the I-O to a CGE approach yields considerable benefits. However, many regional disturbances - including virtually all current regional and environmental policies - impact on the supply side of the economy. I-O systems are simply incapable of analysing such disturbances, whereas this is not true of CGE systems, as we now illustrate.

The impact of an increase in the basic rate of income tax

Here we simulate the impact of a 7% increase in the average personal tax rate. This lies within the Parliament's power to raise the basic rate of income tax by up to 3p in the pound. Normally, this would be accompanied by a balanced budget expansion of government expenditures. However, here we consider the limiting case in which revenues are not "re-cycled" to increase expenditures or to cut other taxes. The Scottish Parliament would therefore never voluntarily pursue such a policy. Our motivation runs in terms of the Parliament reacting to adverse changes in its assigned budget. Here the policy has impacts that are unambiguously bad news for the Scottish economy. In these circumstances, under regional bargaining, households as wage bargainers would rationally seek to restore their real take-home pay at any given unemployment rate. Similarly, households as migrants would find Scotland a less attractive location than previously given the relatively lower take home pay implied by any gross wage. In medium run equilibrium under flow migration, the interaction of the zero-net-migration condition and the bargaining function would restore the net of tax real consumption wage and the unemployment rate. (See McGregor *et al*, 1995). Thus the real consumption wage in medium- and long-run equilibria is fully restored. This implies that in the medium run the incidence of the tax falls on the capital rental rate and the product price, and in the long run, solely on the product price.

Table 2 summarises the aggregate economic impact of the income tax increase for each conceptual time interval. The tax increase constitutes a simultaneous adverse demand and supply shock to the Scottish economy. The adverse demand shock impacts directly on consumption expenditures, which has further conventional indirect and induced demand-side effects. Under present assumptions of non-passive supply, this would in turn induce supply-side reactions. However, there is also a simultaneous adverse supply shock as workers seek to restore their net-of-tax bargained wage. The adverse demand impact is apparent in Table 2 from the contraction in consumption and the adverse supply effect is reflected in the rise in the nominal wage. The tax increase induces a significant contraction in the Scottish economy, the scale of which increases through time. In the short run, GDP contracts by 0.30%, but this in part reflects the "buffering" effect of the flexibility of the local real wage (in response to the 2.4% rise in the unemployment rate), which falls by 0.27% in the short run. However, in the medium run the real take-home consumption wage (and the unemployment rate) is restored to its original level, with nominal wages rising so as to compensate fully for the higher tax take. In the medium run, therefore, GDP contracts even further, by 0.41%, with employment falling by 0.65% (as compared to 0.49% in the short run). In the long run sectoral capital stocks react to the fall in capital rental rates, resulting in further contractions in economic activity. Ultimately, GDP falls by 1.77% and employment (and population) by 1.82%.

Figure 7 plots the percentage changes in sectoral outputs for each of the three time intervals. The news is bad in the short run, worse in the medium run and worst in the long run for all measures of economic activity, in all sectors. The long-run results do not now converge on I-O solutions, since we are dealing with both a supply- and demand-side shock. Supply-side disturbances permanently alter input prices, generating lasting substitution and competitiveness effects.

The short run effects of the tax increase on sectoral employment, output and value-added are shown in Figure 8, and the corresponding long run effects can be seen in Figure 9. In the short run the fixity of capital stocks ensures that the percentage contraction in employment exceeds that of value-added. However, the relative changes in output across sectors will vary depending on, for example, total intermediate- and import-intensity of production and the export- and consumption-intensity of demand for the commodity. In the long run, relative contractions in employment are still greater. The restoration of the take-home real-consumption wage necessitates a 1.48% increase in the nominal wage paid to labour. This generates a degree of substitution away from the now higher priced labour input and greater negative competitiveness effects. Changes in relative prices account for the absence of I-O results in Figure 8, although the changes in factor intensities are in fact much less marked than in the short run. This reflects the ability to adjust capital stocks in the long run, combined with the comparatively low elasticities of substitution between capital and labour in production.

Figure 10 summarises the percentage changes in pollutants associated with the tax increase for the three conceptual time intervals. Given that all industry outputs and final consumption contract over all intervals, all pollutants show a similar pattern of decline. Of course, the extent of relative environmental improvement (in terms of each pollutant) reflects the composition of the output change as well as its extent. Here the impact of reduced household consumption is particularly apparent: the two pollutants that show the largest negative effects – carbon monoxide and PM10 – are mainly generated directly during household consumption (private transport) activities. However, note that the tax change (Figure 10) has a more evenly dispersed impact on pollutants than the more sectorally concentrated government expenditure change (Figure 4).

Figure 11 tracks the movement of the Sustainable Prosperity indicator in response to the disturbance over the 10-year period immediately after the tax increase. As explained above, the decline in activity across the economy causes a decline in total pollution generation, including emissions of CO_2. The key point here is that the change in the composition of activity causes the decline in total CO_2 emissions to be proportionately greater than GDP, with the implication that CO_2 emissions per unit of GDP decline. The sustainable prosperity index improves with both an increase in government expenditure and a reduction in taxation, at least over the first ten years following the disturbance.

The potential impact of environmental targets on the Scottish economy[13]

In the preceding sections of the paper we have shown how a sample of the Scottish Executive's environmental indicators may be incorporated into a regional CGE, with the consequence that the impact of any policy initiative on these indicators can be monitored. To date, the Scottish Parliament has not published any targets for these indicators, beyond expressing a desire for a decline in the level of GHG emissions and the CO_2-intensity of the Scottish economy. So, for example, while it seems clear that the Executive will monitor Sustainable Prosperity, there is as yet no commitment to achieving any target level of this indicator. Presumably, the Parliament would take some action if its chosen environmental indicators deteriorated markedly, though this is never made explicit.

However, the Scottish Parliament has committed to make an "equitable contribution" (Scottish Executive 2003, p.19) to the UK government's target of a 20% reduction in CO_2 emissions by 2010, but it is not yet clear what the practical implications of this commitment are. For example, Scotland is a net exporter of electricity to the rest of the UK and Scottish electricity is less CO_2 intensive than that produced in the rest of the UK (RUK) (Appendix 3). Therefore, Scotland could claim to be contributing to the (post-Kyoto) targets even if its CO_2 emissions increased, provided that this reflected an increase in electricity production in Scotland at the expense of that in RUK.

Our own attribution analysis (Ferguson *et al*, 2003b) does indeed suggest that there are substantial CO_2 spillovers associated with interregional trade in the UK. We would expect these to play a role in any negotiations about appropriate regional contributions to national environmental commitments, since the Scottish Parliament is aware of the issue's existence, if not its scale.[14] However, given the differential average and marginal CO_2 intensities of production, and the potential for Scottish electricity exports, Scotland's target reduction for CO_2 emissions might be significantly less than the UK's. The target reductions for other regions would be correspondingly greater, but would be met, in part, through higher electricity imports from Scotland. For illustrative purposes only we assume that the Scottish Parliament negotiates a target of a 2.5% cut in its CO_2 emissions, relative to the base year.

---

[13] We are grateful to an anonymous referee whose comments led us to add this section.

[14] Of course, such considerations are relevant in any devolved system, not just in the UK.

Here we explore the implications of the Scottish Parliament seeking to meet this target solely through the use of the economic policy instruments that the Scottish Parliament has directly at its disposal, namely the ability to vary government expenditure and income taxation.[15] Table 3 summarises the impact on Scottish economic activity that result from effecting an ultimate contraction of 2.5% in CO_2 emissions through either a reduction in government expenditure or a rise in income taxation. Notice that these impacts would be substantial, since meeting the environmental target requires either a fall in government expenditure of 8.8% or a rise in the average tax rate of 9.73%. Meeting the target reduction in CO_2 emissions is slightly more painful via government expenditure contraction than through a rise in the basic rate of income tax; GDP falls 2.9% in the former case, as against 2.5% in the latter. Of course, while the basic characteristics of the simulations are as discussed above, tax rate variations are revealed here as being slightly more effective in influencing CO_2 emissions than changes in government expenditures, largely because of the more direct impact on household consumption.

Note that these effects accompany policies that only ensure an appropriate contraction in CO_2 emissions in the long run. In fact, the UK target lies only some 10 years away from the base year of 1999. It is therefore of interest to explore what the required tax and expenditure adjustments have to be in order to meet the CO_2 emissions target in year 10 of the simulations. In fact, because of lags in the population and capital stock responses to policies, this target requires much stronger action when it has to be met by period 10. This is evident from Table 4. Indeed in this case the required adjustment in the tax rate is strictly non-feasible since it would imply a rise in the basic rate of income tax that lies outside of the range of the tax-varying power permitted by the current devolution settlement. Nevertheless, for illustrative purposes we identify the consequences of the required changes, assuming they could in fact be implemented.

By the target period, year 10, the induced impact on GDP is just over 3% if government expenditure is reduced and 2.3% if the tax rate is increased. Furthermore, because population adjustments are incomplete, there are rises on the unemployment rate in both cases, of 4.4% and 4.3%

[15] We are also assuming that the RUK is not imposing similar sorts of targets at the same time.

respectively. Figure 12 illustrates the impact of the changes on CO_2 emissions if the policy adjustments are evenly distributed over each of the 10 periods. Note, however, that satisfying the target by year 10, by whichever route, implies that the policy stance will subsequently have to be relaxed to keep CO_2 emissions at a stable level. It would therefore be possible to raise government expenditure, or reduce tax rates, from period 11 onwards until adjustment to the new long-run equilibrium is achieved. The scale of the changes required ultimately is, of course, given in Table 3.

Our analysis shows that variations in general public expenditure and income tax rates are very blunt instruments indeed with which to meet emissions targets, and alternative instruments are likely to prove rather more attractive.[16] One possible longer-term strategy would involve the use of the tax system to induce, for example, substitution of less pollutant-intensive inputs. As already noted the Scottish Parliament does not possess the fiscal powers required to induce such substitution.[17] There is a continuing debate within Scotland about the attractions of a greater degree of fiscal autonomy in Scotland. But this has tended to focus exclusively on the potential economic benefits of such a change (McGregor and Swales, 2003), whereas there are also potential regional environmental gains to be obtained from increased decentralisation.

Of course, substitution away from energy and in favour of other inputs is not the only way of altering the output-pollution mix. An important assumption of our analysis so far is that of unchanged technology, even in the long-run. While our current model allows technical progress in the production of value added, introducing abatement technologies implies relaxing the fixed output-pollution assumption. For example, end-of-pipe abatement technologies exist for pollutants such as SO_2, and their adoption would reduce the amount of this particular pollutant emitted per unit of sectoral output. The primary objective of the Scottish Environmental Protection Agency (SEPA) is to contributing to sustainable development in Scotland. However, SEPA is essentially responsible for implementing UK-wide environmental policies and monitoring environmental changes in Scotland. It cannot unilaterally change behaviour other than through moral suasion.

[16] Our qualitative results do not depend on the chosen values of key parameters. Space constraints preclude a systematic sensitivity analysis, whether theory-based (Learmonth *et al*, 2002) or purely statistical (Gillespie *et al*, 2001; McGregor *et al*, 1996).

[17] The UK Parliament does, of course, have such powers and the UK Climate Change Levy represents a fiscally neutral combination of energy tax and labour subsidy.

To capture abatement activity, whether induced through energy-materials substitution (for example), or through explicit end-of-pipe or other direct abatement mechanisms, requires relaxing the fixed pollution-output coefficients assumption in favour of a more flexible method of modelling emissions. Two broad strategies have been pursued in an attempt to model "bad" ouput production and abatement activities. One approach involves modelling pollution abatement activities separately from "good" output production (Nugent and Sarma, 2002; Xie and Saltzman, 2000). The other strategy involves modelling the joint production of good and bad outputs (Komen and Peerlings, 2001; Willett, 1985). Clearly, such flexibility would reduce the scale of the contraction in output required to meet any given environmental improvement target, such as that illustrated above. Part of the adjustment can be borne by technology though this is unlikely to be costless. Indeed the results of our broad-brush fiscal policy simulations suggest that it may be essential for the Scottish Parliament to find means of inducing this flexibility in practice, if its commitments to environmental targets are, or become, genuinely binding.

Discussing our simulation results illustrates the ability of AMOSENVI to handle shocks which have both demand and supply implications. Input-Output systems are simply incapable of handling supply disturbances, and so are inapplicable in these circumstances. This is not a minor limitation since, for example, regional policy is now mainly supply-oriented. Furthermore, environmental policies typically also exert their impact predominantly through the supply side of the economy, although many of these policies are currently reserved to the UK Parliament. Accordingly, environmental CGEs are capable of addressing a much wider range of policy and non-policy disturbances than are their I-O counterparts.[18]

6. Conclusions

In the UK context at least, there is increasing concern with and, indeed, responsibility for, sustainable development at the regional level. We believe that for effective decision-making, policy-

[18] This is not to deny the usefulness of IO analysis, although, in our judgement, this is effective when used in descriptive "attribution" analysis. Examples include the decomposition analyses of Ang (1999), Ang and Zhang (2000) and Rose (1999). McGregor *et al.* (2004) devise an IO-based linear attribution system as an alternative to the "ecological footprint"

makers must be aware of the likely environmental impact of regional and national economic and environmental policies. While regional energy-economy-environment Input-Output analysis undoubtedly has an important role to play here, we believe that role should be primarily descriptive. Policy analysis is likely to be better served by the development of regional CGE models that are, like the illustrative model employed in this paper, augmented to accommodate relevant individual and composite environmental indicators. Such models, in principle at least, accommodate the essentially supply-oriented regional and environmental policies of the UK and EU.

However, in exploring the effects of meeting binding environmental targets we question the feasibility of using the rather blunt fiscal instruments that are currently devolved to the Scottish Parliament, even though Scotland is at present the most fiscally autonomous UK region. This in turn leads us to doubt either the seriousness of the commitment to devolved environmental targets or the validity of the current devolution settlement. We question whether the present responsibility for environmental objectives at the regional level is compatible with the degree of regional fiscal autonomy currently possessed by UK regions.

While our current analysis is instructive, especially in the present policy context, we anticipate, a number of extensions. In future research we intend to: focus on a wider range of disturbances; endeavour to generate more genuinely Scottish-specific economic-environmental data; extend the range of indicators to aggregate measures such as green net national product and genuine savings (Hanley, 2000); accommodate more flexible structures, especially for energy input substitutability and abatement technology; include distributional issues to allow monitoring of policy impacts on fuel poverty; extend the analysis to the multiregional context. All of these developments will improve the framework for economy-energy-environment policy analysis. Hopefully they will also allow more integrated economic and environmental policy making at both the regional and national levels than is currently apparent, at least in the UK.

approach (Wackernagel and Rees, 1996). Stutt and Anderson (2000) provide CGE-based decomposition.

REFERENCES

Advisory Group on Education for Sustainable Development (1999). *Scotland the Sustainable? The Learning Process: Action for the Scottish Parliament,* Scottish Office, Edinburgh.

Ang, B.W. (1999). "Decomposition Methodology in Energy Demand and Environmental Analysis", in J. C. J. M. van den Bergh, ed., *Handbook of Environmental and Resource Economics*, Edward Elgar, Northampton, MA.

Ang, B.W. and Zhang, F.Q. (2000). "A Survey of Index Decomposition Analysis in Energy and Environmental Studies", *Energy-The International Journal*, vol. 25, pp. 1149-1176.

Armington, P. (1969). "A Theory of Demand for Products Distinguished by Place of Production", *IMF Staff Papers*, vol. 16, pp. 157-178.

Barker, T. (1997). "Taxing Pollution Instead of Jobs", in T. O'Riordan, ed., *Ecotaxation,* Earthscan, London.

Baumol, W.J. and Oates, W.E. (1988). *The Theory of Environmental Policy,* 2nd ed., Cambridge University Press, Cambridge.

Beauséjour, L., Lenjosek, G. and Smart, M. (1995). 'A GCE Approach to Modelling Carbon Dioxide Emissions Control in Canada and the United States', *The World Economy***,** vol.18, pp. 457-489.

Bergman, L (1988). 'Energy Policy Modelling: a Survey of General Equilibrium Approaches', *Journal of Policy Modelling***,** vol.10, pp. 377-399.

Bergman, L. (1990). 'Energy and Environmental Constraints on Growth: a CGE Modelling Approach', *Journal of Policy Modelling***,** vol.12, pp. 671-691.

Burniaux, J.-M., Martin, J.P., Nicoletti, G. and Martins, J.M. (1992). 'GREEN. A Multi-Sector, Multi-Region General Equilibrium Model for Quantifying the Costs of Curbing CO2 Emissions: a Technical Manual', *OECD Economics Department Working Papers,* No.116, OECD, Paris.

Blanchflower, D.G. and Oswald, A.J. (1994). *The Wage Curve*, M.I.T. Press, Cambridge, MA.

Capros, P., Georgakopoulos, S., Zografakis, S., Proost, D., van Regemorter, D., Conrad, K., Schmidt, T., Smeers, Y. and Michiels, E. (1996). "Double Dividend Analysis: First Results of a General Equilibrium Model (GEM-E3) Linking the EU-12 Countries", in C. Carrero and D. Siniscalco, eds, *Environmental Fiscal Reform and Unemployment,* Kluwer, London.

Conrad, K. (1999). 'Computable General Equilibrium Models for Environmental Economics and Policy Analysis', in J.C.J.M. van den Bergh, ed., *Handbook of Environmental and Resource Economics,* Edward Elgar, Northampton, MA..

Conrad, K. (2002). "Computable General equilibrium Models in Environmental and Resource Economics", in M. Munasinghe, ed., *Macroeconomics and the Environment*, Edward Elgar, Northampton, MA.

Conrad, K. and Schröder M. (1993). 'Choosing Environmental Policy Instruments Using General Equilibrium Models', *Journal of Policy Modelling,* vol.15, pp. 521-543.

Dean, A. and Hoeller, P. (1992). 'Costs of Reducing CO2 Emissions: Evidence from Six Global Models', *OECD Economic Studies,* No.19, Winter.

Department of the Environment (1996). *Indicators of Sustainable Development for the United Kingdom,* HMSO, London.

Department of the Environment, Transport and the Regions (DETR) (1999a). *Quality of Life Counts*.

Department of the Environment, Transport and the Regions (DETR) (1999b). *Monitoring Progress*.

Department of the Environment, Transport and the Regions (DETR) (1999c). *A Better Quality of Life: a Strategy for Sustainable Development in the UK*.

Department of the Environment, Transport and the Regions (DETR) (2001a). *Climate Change: The UK Programme.* (www.environment.detr.gov.uk/climatechange/)

Department of the Environment, Transport and the Regions (DETR) (2001b). *Achieving a Better Quality of Life 2001: Review of Progress Towards Sustainable Development,* Government Annual Report, 2000.

Dervis, K., De Melo, J. and Robinson, S. (1982). *General Equilibrium Models for Development Policy*, Caambridge University Press, Cambridge.

Despotakis, K.A. and Fisher, A.C. (1988). 'Energy in a Regional Economy: A Computable General Equilibrium Model for California', *Journal of Environmental Economics and Management*, vol.15, pp. 313-330.

Espinosa, J. A. and Smith V. K. (1995). "Measuring the Environmental Consequences of Trade Policy: A Nonmarket CGE Analysis", *American Journal of Agricultural Economics,* vol. 77, pp 772-777.

European Commission, Statistical Office of the European Communities (2001). *NAMEAs for Air Emissions: Results of Pilot Studies*, Theme 2, Economy and Finance, Office for Official Publications of the European Communities, Luxembourg.

Ferguson, L., Learmonth, D., McGregor, P.G., Swales, J.K. and Turner, K. (2003a). "The Regional Distribution of Public Expenditure in the UK: An Exposition and Critique of the Barnett Formula", in J. Mønnesland, ed., *Regional Public Finance*, Pion, London.

Ferguson, L., McGregor, P.G., Swales, J.K. and Turner, K. (2003b). "An Interregional Environmental Social Accounting Matrix, Incorporating an Input-Output System for Scotland and the Rest of the UK (RUK): The Environmental Trade Balance between Scotland and RUK", Report to Scotecon.

Forssell, O. (1998). "Extending Economy-Wide Models with Environment-Related Parts", *Economic Systems Research,* vol. 10, pp. 183-199.

Forssell, O. and Polenske, K.R. (1998). "Introduction: Input-Output and the Environment", *Economic Systems Research,* vol. 10, pp. 91-97.

Gale, L.R. (1995). 'Trade Liberalization and Pollution: An Input-Output Study of Carbon Dioxide Emissions in Mexico', *Economic Systems Research,* vol.7, pp. 309-320.

Gibson, H. (1990). "Export Competitiveness and UK Sales of Scottish Manufactures", Paper delivered to the Scottish Economists' Conference, The Burn, 1990.

Gillespie, G., McGregor, P.G., Swales, J.K. and Yin, Y.P. (2001). "The Displacement and Multiplier Effects of Regional Selective Assistance: A Computable General Equilibrium Analysis", *Regional Studies,* vol 35, pp. 125-139.

Greenwood, M.J., Hunt, G., Rickman, D.S. and Treyz, G.I. (1991). "Migration, Regional Equilibrium, and the Estimation of Compensating Differentials", *American Economic Review*, vol. 81, pp. 1382-1390.

Goulder, L.H. (1998). "Environmental Policy Making in a Second-Best Setting", *Journal of Applied Economics*, vol.1, pp. 300-325.

Hanley N. (2000). "Macroeconomic Measures of Sustainability", *Journal of Economic Survey,* vol. 14, pp. 1-30.

Harrigan, F., McGregor, P.G., Dourmashkin, N., Perman, R., Swales, J.K. and Yin, Y.P. (1991). "AMOS: A Macro-Micro Model of Scotland", *Economic Modelling*, vol. 8, pp. 424-479.

Harris, R.I.D. (1989). *The Growth and Structure of the UK Regional Economy 1963-85*, Avebury, Aldershot.

Harris, J.R. and Todaro, M. (1970). "Migration, Unemployment and Development: A Two-Sector Analysis", *American Economic Review,* vol. 60, pp. 126-142.

Kamat, R., Rose, A. and Abler, D. (1999). "The Impact of a Carbon Tax on the Susquehanna River Basin Economy", *Energy Economics*, vol. 21, pp. 363-384.

Kay, N. (1998). 'The Scottish Parliament and the Barnett Formula', *Fraser of Allander Institute Quarterly Economic Commentary***,** vol. 24, no.1, pp.32-48.

Komen, M.H.C. and Peerlings J.H.M. (2001). "Endogenous Technological Switches in Dutch Dairy Farming under Environmental Restrictions", *European Review of Agricultural Economics*, vol 28, pp. 117-142.

Layard, R., Nickell, S. and Jackman, R. (1991). *Unemployment: Macroeconomic Performance and the Labour Market*, Oxford University Press, Oxford.

Learmonth, D., McGregor, P.G., Swales, J.K., Turner, K. and Yin Y.P. (2002). "The Importance of the Local and Regional Dimension of Sustainable Development: A Computable General Equilibrium Analysis", Strathclyde Papers in Economics, Department of Economics, University of Strathclyde, No. 2002/4.

Lee, H. and Roland-Holst, D.W. (1997). 'Trade and the Environment', in J.F. Francois and K.A. Reihert, eds., *Applied Methods for Trade Analysis: a Handbook***,** Cambridge University Press, Cambridge.

Leontief, W. (1970). 'Environmental Repercussions and the Economic Structure: An Input-Output Approach', *Review of Economic Statistics,* vol. 52, pp. 262-277.

Li, P. and Rose, A. (1995). 'Global Warming Policy and the Pennsylvania Economy: A Computable General Equilibrium Analysis', *Economic Systems Research,* vol.7, pp. 151-171.

McGregor, P.G., Swales, J.K., Yin, Y.P. (1995). "Migration Equilibria/ Disequilibria and the Natural rate of Unemployment in a Regional Context", *International Journal of Manpower*, vol. 16, No. 2, pp. 66-72.

McGregor, P.G., Swales, J.K., Yin, Y.P., (1996)."A Long-Run Interpretation of Regional Input-Output Analyses", *Journal of Regional Science*, vol. 36, pp. 479-501.

McGregor, P.G., McNicoll, I.H, Swales J.K. and Turner, K.R. (2001). "Who Pollutes in Scotland? A Prelude to an Analysis of Sustainability Policies in a Devolved Context", *Fraser of Allander Institute, Quarterly Economic Commentary,* vol.26, No.3, pp. 23-32.

McGregor, P.G., McNicoll, I.H., Swales J.K. and Yin, Y.P. (2003). "The Likely Environmental Impacts of the Scottish Parliament's Economic Policies: An Environmental Computable General Equilibrium Analysis" in J. C. Lopez, R. B. Galicia and A. M.Flores eds. *Insumo-Produto Regional Y Otras Aplicaciones,* Universidad Autonoma Metropolitana, Universidad Autonoma de Mexico and Universidad de Guadalajara,

McGregor, P.G. and Swales, J.K. (2003). "The Economics of Devolution/ Decentralisation in the UK: Some Questions and Answers", Strathclyde Papers in Economics, Department of Economics, University of Strathclyde, no. 03-13. (http://www.economics.strath.ac.uk/Dpapers/strath.econ.03-13.pdf)

McGregor, P.G., Swales, J.K. and Turner, K. (2004a). "An Input-Output-Based Alternative to "Ecological Footprints" for Tracking Pollution Generation in a Small Open Economy", *mimeo*, Department of Economics, University of Strathclyde.

McGregor, P.G., Swales, J.K., and Y.P. Yin, (2004b). “The Macroeconomic Consequences of Scottish Fiscal Autonomy: Inverted Haavelemo Effects in a General Equilibrium Analysis of the ‘Tartan Tax’”, paper presented at the British and Irish Regional Science Association, St Andrews, 2003, forthcoming Strathclyde Papers in Economics, Department of Economics, University of Strathclyde.

McNicoll, I.H. and Blakemore, D. (1993). “A Pilot Study on the Construction of a Scottish Environmental Input-Output System”, Report to Scottish Enterprise.

Mayeres, I. and van Regemotor, D. (2002). “Modelling the Health Related Benefits of Environmental Policies within a CGE Model for the EU-15 Countries”, Paper presented at the 5th Conference on Global Economic Analysis, Taipei, Taiwan.

Minford, P., Stoney, P., Riley, J. and Webb, B. (1994). "An Econometric Model of Merseyside: Validation and Policy Simulations", *Regional Studies*, vol. 28, pp. 563-575.

Nugent, J.B. and Sarma C.V.S.K. (2002). “The Three E’s – Efficiency, Equity, and Environmental Protection – in Search of “Win-Win-Win” Policies: A CGE Analysis of India”, *Journal of Policy Modeling*, vol. 24, pp. 19-50.

Partridge, M.D. and Rickman, D.S. (1998). ‘Regional Computable General Equilibrium Modelling: A Survey and Critical Appraisal’, *International Regional Science Review*, vol. 21, pp. 205-248.

Perman, R., Ma, Y, McGilvray, J. and Common, M. (2003). *Natural Resource and Environmental Economics,* 3rd edition, Longman Publishing, PLACE.

Prashant, V. (1999). “A NAMEA for the UK,” *Structural Change and Economic Dynamics*, vol 10, pp. 99-121.

Rose, A. (1999). “Input-Output Structural Analysis of Energy and the Environment” in J.C.J.M. van den Bergh, ed, *Handbook of Environmental and Resource Economics*, Edward Elgar, Northampton, MA.

Rutherford, T. (1992). ‘The Welfare Effects of Fossil Carbon Restrictions: Results from a Recursively Dynamic Trade Model’, *OECD Economics Department Working Papers,* No.112. OECD, Paris.

Salway, A.G., Murrells, T.P., Pye, S., Watterson, J. and Milne R. (2001). ‘Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland: 1990, 1995, 1998 and 1999’, report by AEA Technology.

Scottish Executive (2000). *The Way Forward: Framework for Economic Development in Scotland*.

Scottish Executive (2002). “Meeting the Needs: Priorities, Actions and Targets for Sustainable Development in Scotland”, Scottish Executive Environment Group, Paper 2002/14.

Scottish Executive (2003). *Indicators of Sustainable Development for Scotland*, Stationery Office Bookshop, Edinburgh.

Shoven, J.B. and Whalley, J. (1984). "Applying General Equilibrium Models of Taxation and Trade: An Introduction and Survey", *Journal of Economic Literature*, vol. 22, pp. 1007-1051.

Shoven, J.B. and Whalley, J. (1992). *Applying General Equilibrium*, Cambridge University Press, Cambridge.

Stevens, B. and Rose, A. (2001). “A Dynamic Analysis of the Marketable Permits Approach to Global Warming Policy: A Comparison of Spatial and Temporal Flexibility”, *Journal of Environmental Economics and Management*, vol. 44, pp. 45-69.

Stutt, A. and Anderson, K. (2000), “Will Trade Liberalisation Harm the Environment? The Case of Indonesia to 2020”, Environmental and Resource Economics, vol. 17, pp. 203-232.

Treyz, G.I., Rickman, D.S. and Greenwood, M.J. (1993). "The Dynamics of U.S. Internal Migration", *Review of Economic and Statistics*, vol. 75, pp. 209-214.

Turner, K. (2003a). "A Pilot Study on Constructing a Scottish Sectoral CO_2 Emissions Account", *Fraser of Allander Institute, Quarterly Economic Commentary,* vol. 28, No.3, pp. 43-51.

Turner, K. (2003b). "The Additional Precision Provided by Regional-Specific Data: The Identification of Fuel-Use and Pollution Generation Coefficients in the Jersey Economy", Strathclyde Discussion Papers, Department of Economics, University of Strathclyde No.03-09. (http://www.economics.strath.ac.uk/Dpapers/strath.econ.03-09.pdf).

Vaze, P. (1999). "A NAMEA for the UK", *Structural Change and Economic Dynamics*, vol. 10, pp. 99-121.

Wackernagel, M. and Rees, W. (1996). *Our Ecological Footprint: Reducing Human Impact on the Earth*, New Society Publishers, Canada.

Whalley, J. and Wigle, R. (1992). 'Results for the OECD Comparative Modelling Project from the Whalley-Wigle Model', *OECD Economics Department Working Papers*, No.121, OECD, Paris.

Willett, K. (1985). "Environmental Quality Standards: A General Equilibrium Analysis", *Managerial and Decision Analysis*, vol. 6, pp. 41-49.

Xie, J. and Saltzman, S. (2000). "Environmental Policy Analysis: An Environmental Computable General Equilibrium Approach for Developing Countries", *Journal of Policy Modelling*, vol. 22, pp. 453-489.

TABLES AND CHARTS

Table 1: The Aggregate Impact of a 2.5% Increase in Government Expenditure

	Short run	Medium run	Long run
GDP (expend. measure)	0.30	0.40	0.81
Consumption	0.45	0.55	0.78
Govt expend.	2.50	2.50	2.50
Investment	0.25	0.44	0.59
Nominal before-tax wage	0.47	0.21	0.00
Real T-H consumption wage	0.25	0.00	0.00
Consumer price index	0.22	0.21	0.00
Total employment (000's):	0.44	0.59	0.91
Unemployment rate (%)	-2.15	0.00	0.00
Total population (000's)	0.00	0.59	0.91

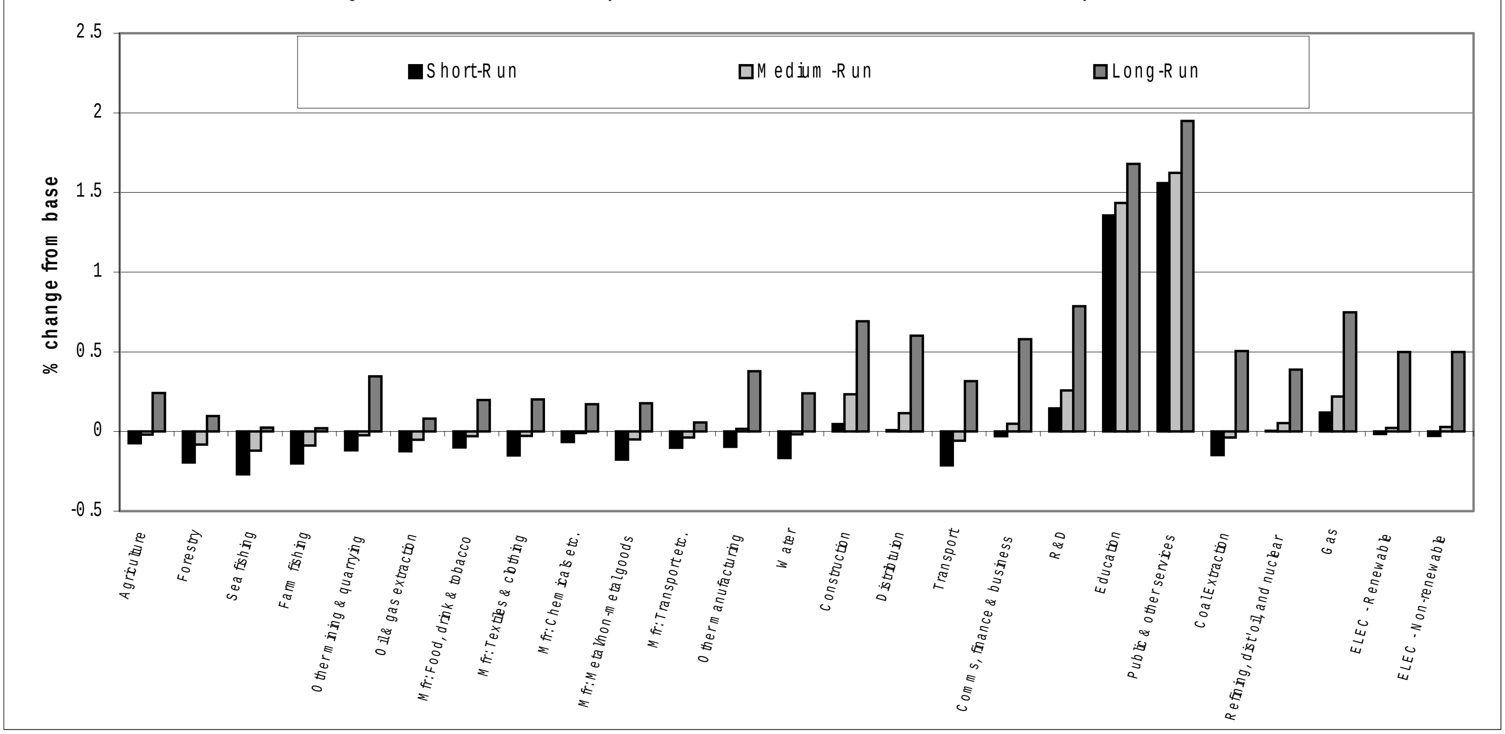


Figure 1: Sectoral Gross Output Effects of a 2.5% Increase in Government Expenditure

Figure 2: Short-Run Impacts on Sectoral Employment, Gross Output and Value-Added of a 2.5% Increase in Government Expenditure

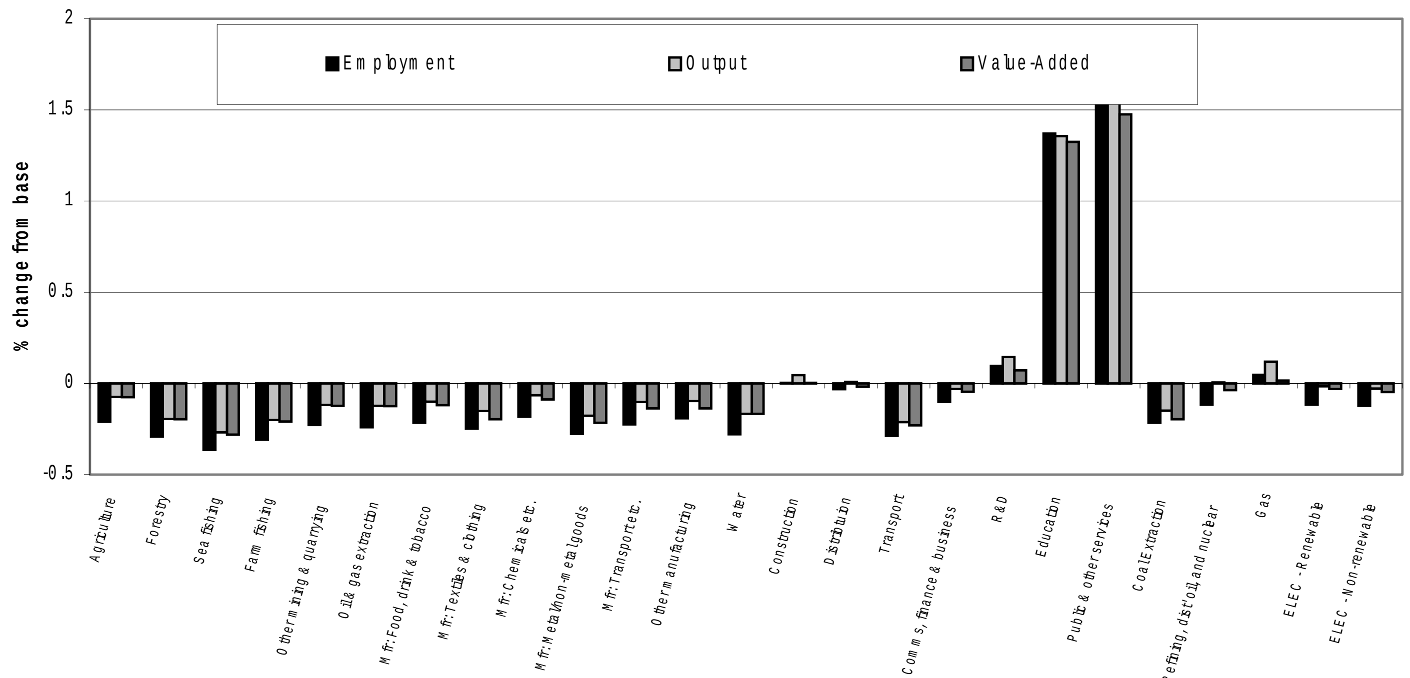


Figure 3: Long-run Impacts on Sectoral Employment, Gross Output and Value-Added of a 2.5% Increase in Government Expenditure

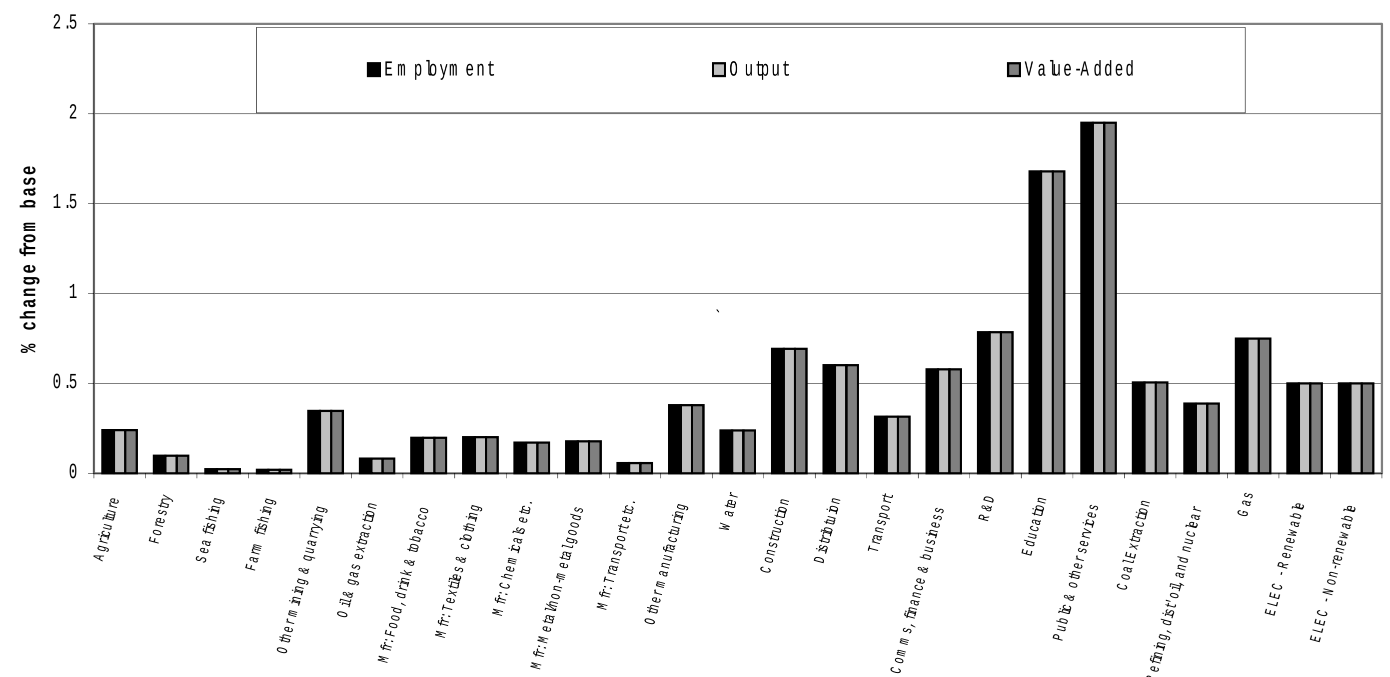


Figure 4. Impacts on Environmental Indicator Variables of a 2.5% Increase in Government Expenditure

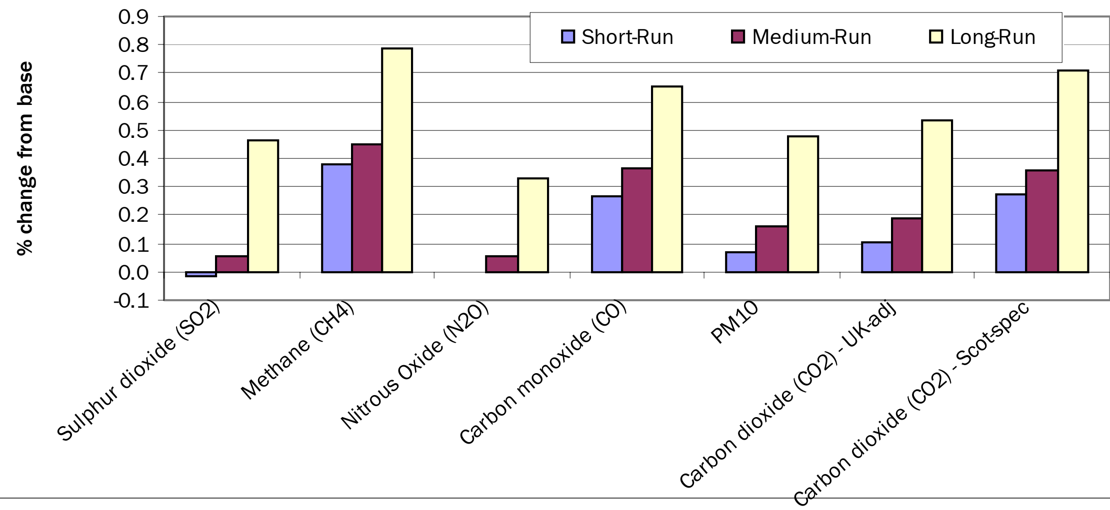
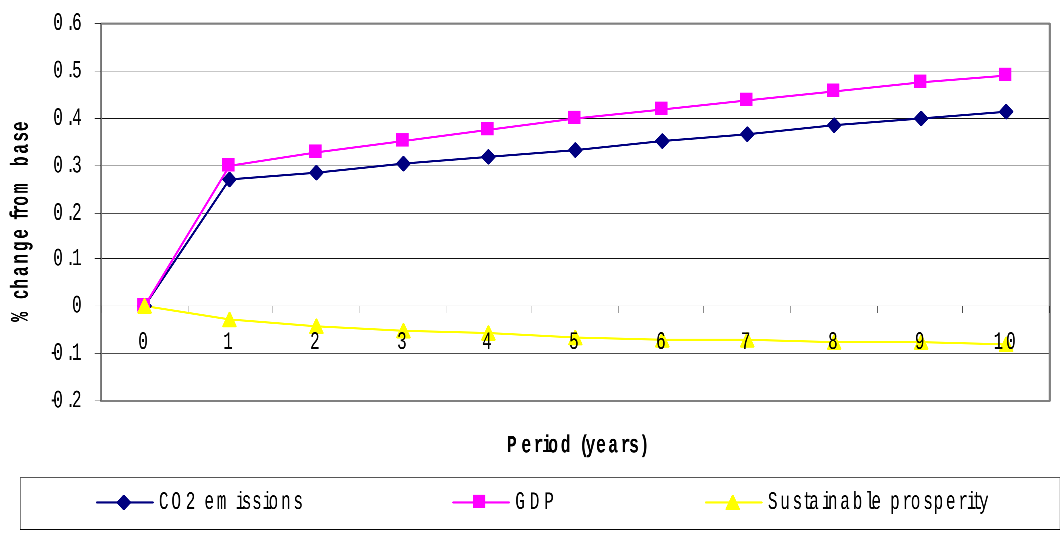


Figure 5: Impact on the Sustainable Prosperity Indicator of a 2.5% Increase in Government Expenditure



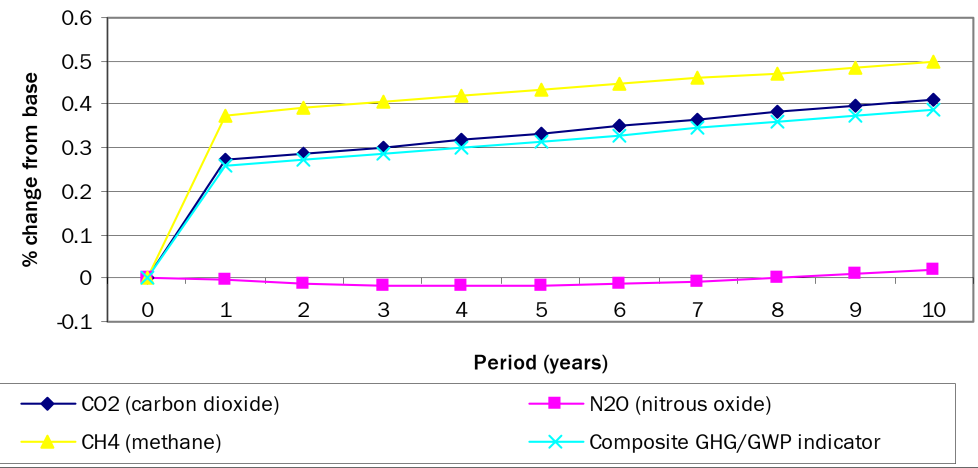


Figure 6: Percentage Changes in the Values of the Composite Greenhouse Gas (Global Warming Potential) Indicator and Component Individual Environmental Indicators from a 2.5% Increase in Government Expenditure

Table 2. The Aggregate Impact of a 7% Increase in the Basic Rate of Income Tax, equivalent to 3p in the Pound

	Short run	Medium run	Long run
GDP (expend. measure)	-0.30	-0.41	-1.77
Consumption	-0.88	-1.00	-1.97
Govt expend.	0.00	0.00	0.00
Investment	-0.67	-0.88	-1.80
Nominal before-tax wage	0.61	0.90	1.48
Real T-H consumption wage	-0.27	0.00	0.00
Consumer price index	-0.10	-0.08	0.49
Total employment (000's):	-0.49	-0.65	-1.82
Unemployment rate (%)	2.40	0.00	0.00
Total population (000's)	0.00	-0.65	-1.82

Figure 7: Sectoral Gross Output Effects of a 7% Increase in the Basic Rate of Income Tax

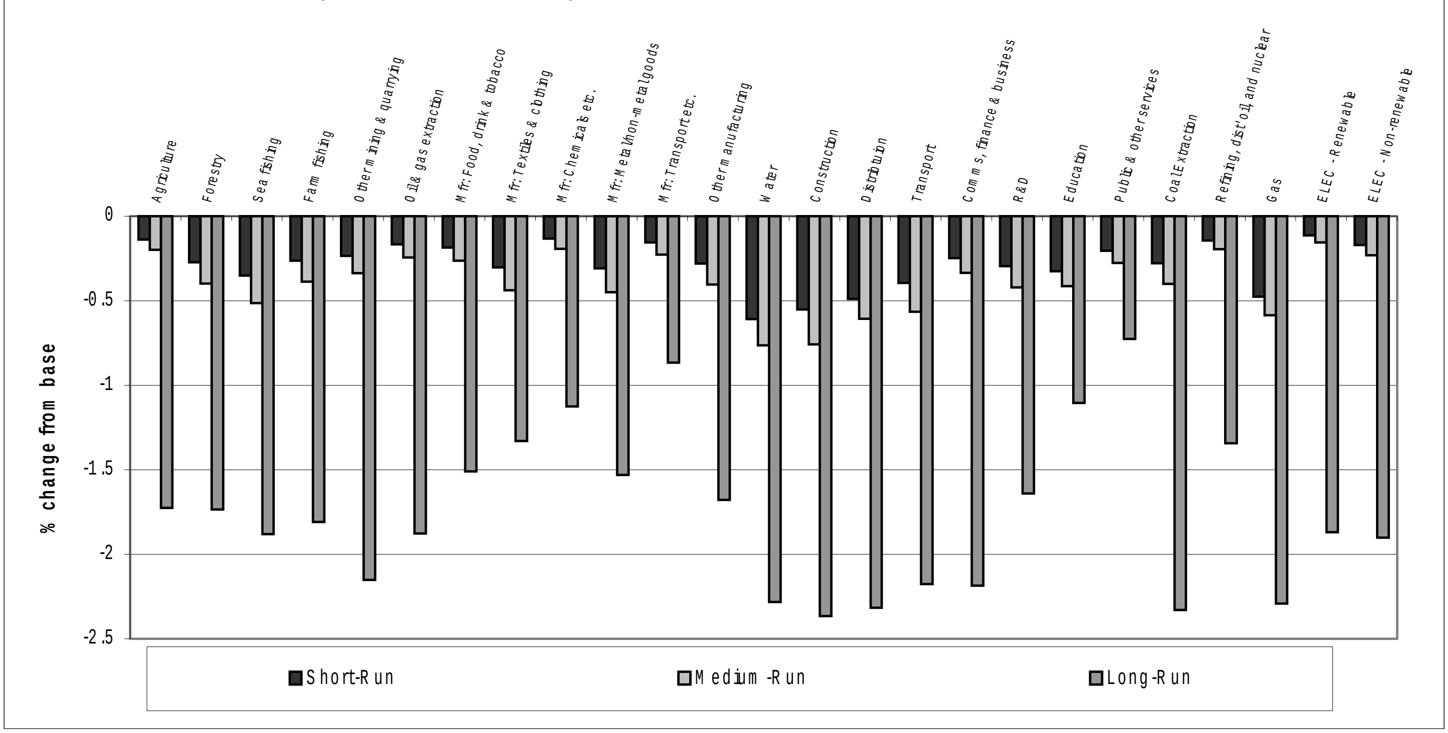


Figure 8: Short-Run Impacts on Sectoral Employment, Gross Output and Value-Added of a 7% Increase in the Basic Rate of Income Tax

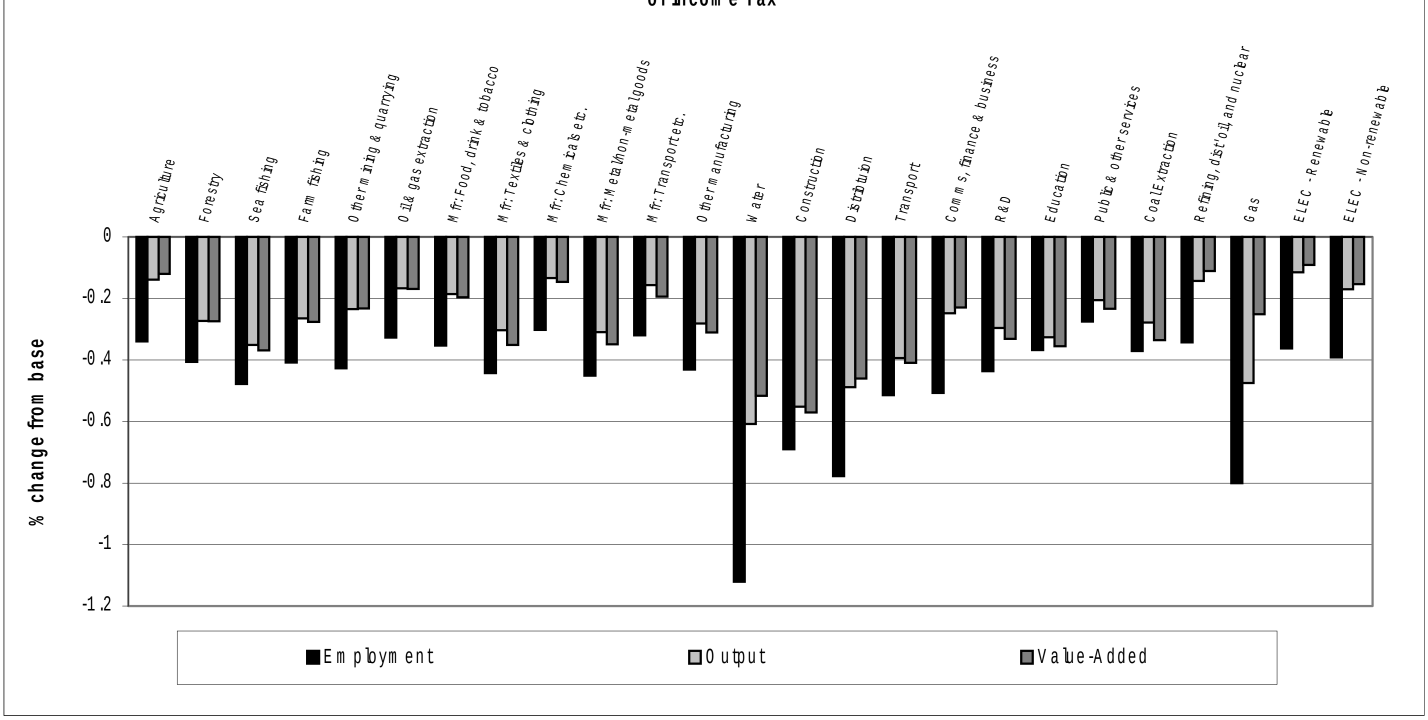


Figure 9: Long-run Impacts on Sectoral Employment, Gross Output and Value-Added of a 7% Increase in the Basic Rate of Income Tax

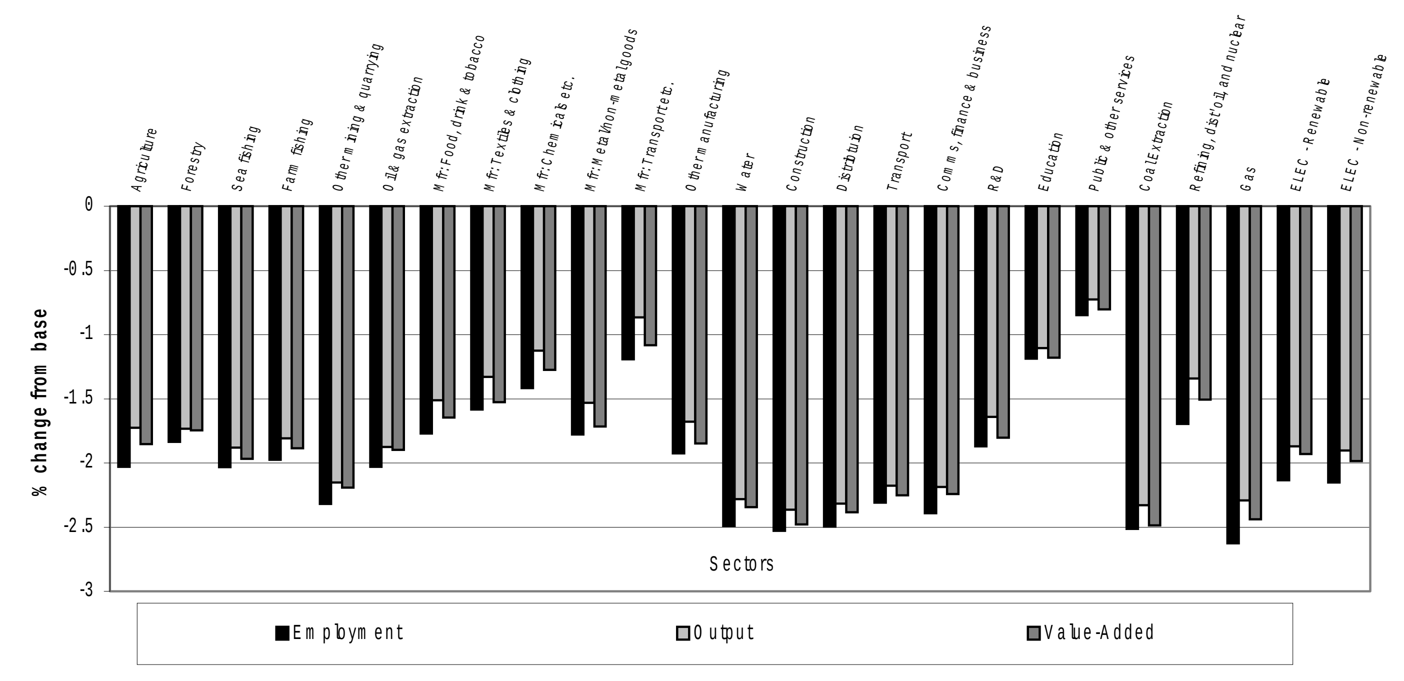
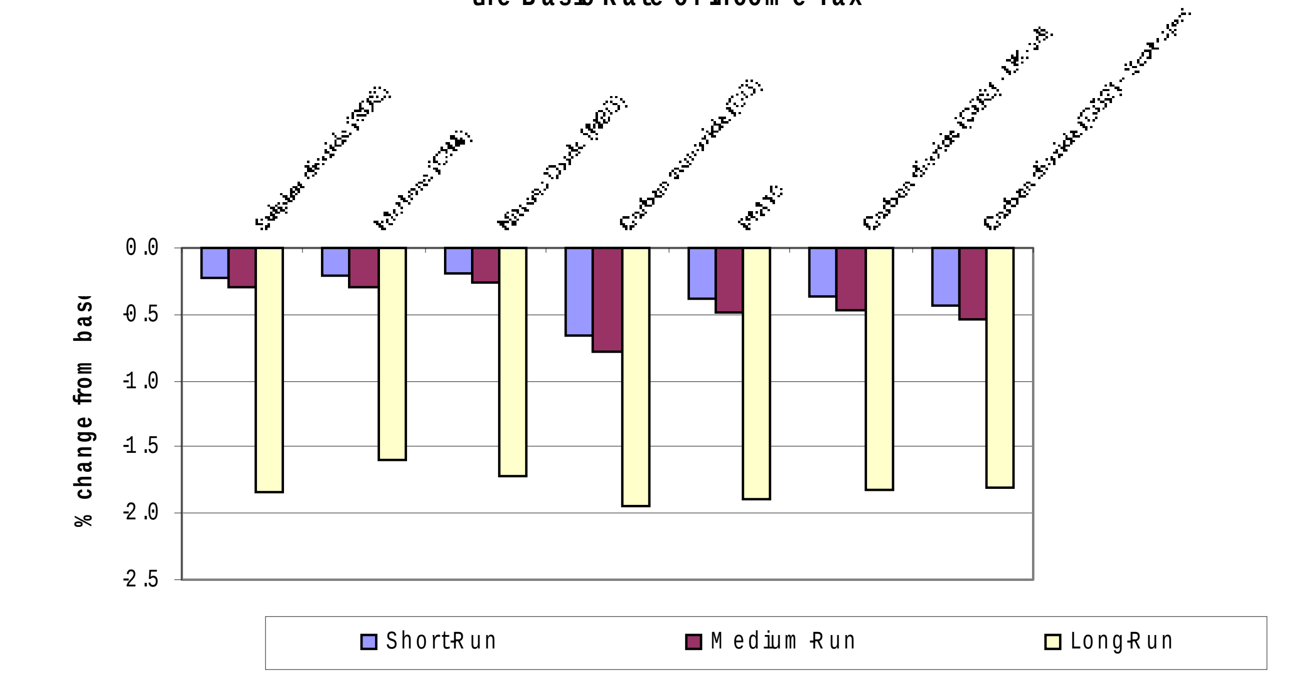


Figure 10: Impacts on Environmental Indicator Variables of a 7% Increase in the Basic Rate of Income Tax



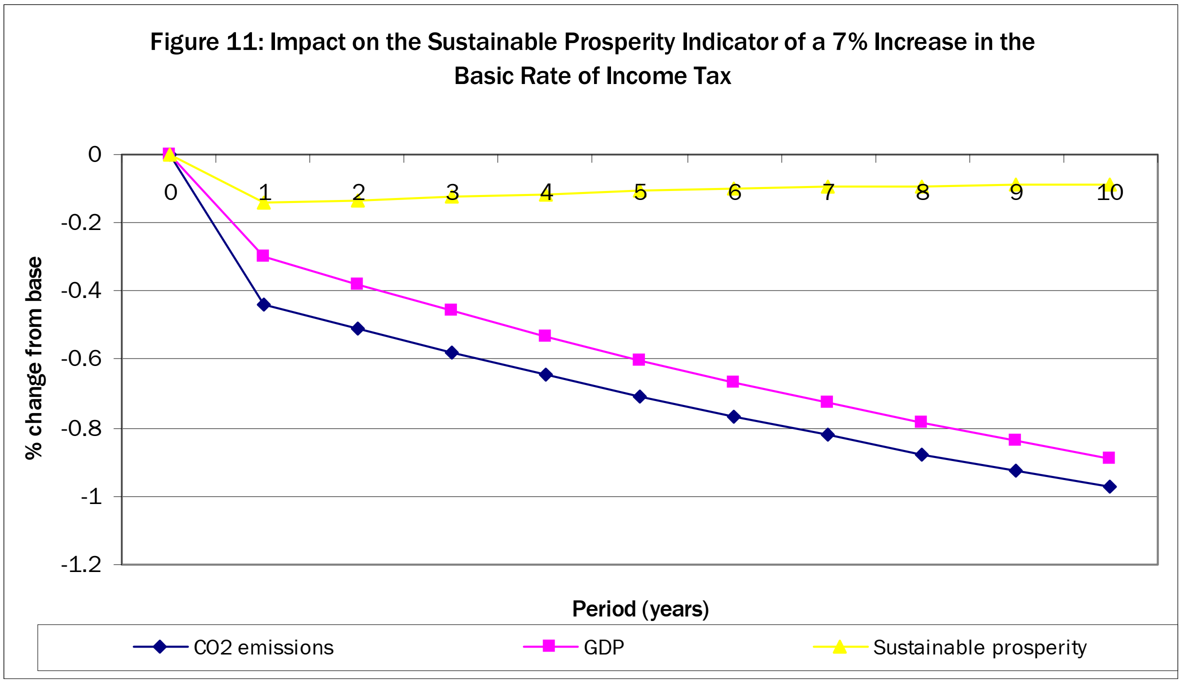


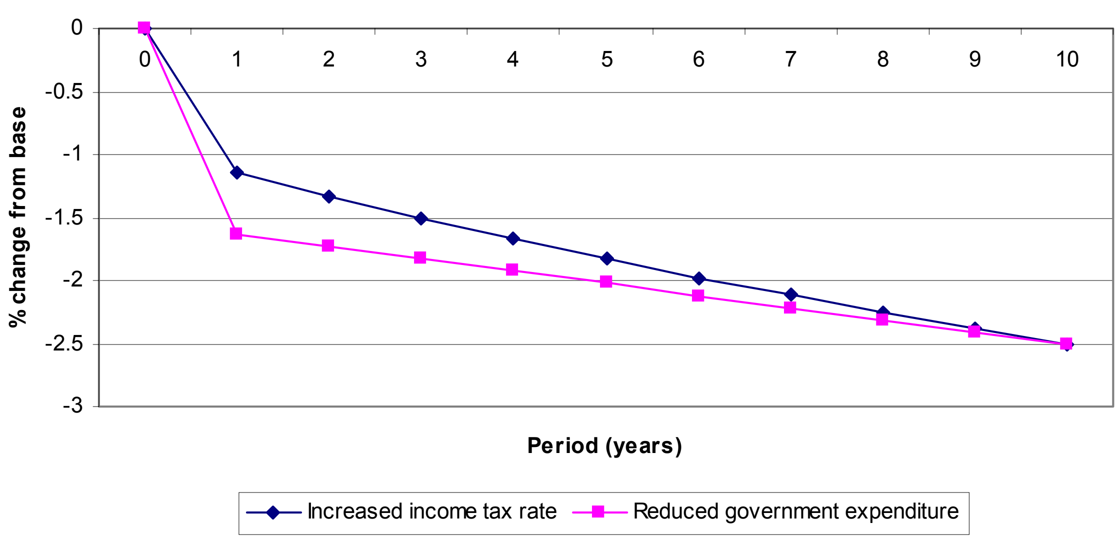
Table 3: The Aggregate Impacts of Alternative Policies to Achieve a 2.5% Reduction in CO2 Emissions in the Long Run

	8.8% decrease government exp.	9.73% increase avg. rate income tax
GDP (expend. measure)	-2.86	-2.45
Consumption	-2.75	-2.72
Govt expend.	-8.85	0.00
Investment	-2.10	-2.48
Nominal before-tax wage	0.00	2.05
Real T-H consumption wage	0.00	0.00
Consumer price index	0.00	0.68
Total employment (000's):	-3.21	-2.51
Unemployment rate (%)	0.00	0.00
Total population (000's)	-3.21	-2.51

Table 4: The Aggregate Impacts of Alternative Policies to Achieve a 2.5% Reduction in CO2 Emissions in 10 years (Year 10 results)

	15% decrease government exp.	18.15% increase avg. rate income tax
GDP (expend. measure)	-3.01	-2.29
Consumption	-3.32	-3.42
Govt expend.	-15.00	0.00
Investment	-2.10	-2.87
Nominal before-tax wage	-1.19	2.50
Real T-H consumption wage	-0.51	-0.48
Consumer price index	-0.68	0.44
Total employment (000's):	-3.74	-2.62
Unemployment rate (%)	4.38	4.33
Total population (000's)	-2.83	-1.76

Figure 12: Change in CO2 emissions in response to alternative policies to achieve target of 2.5% reduction in emissions by year 10



APPENDIX 1. A CONDENSED VERSION OF AMOSENVI

Equations	Short run
(1) Price Determination	$p_i = p_i(W_n, W_k)$
(2) Wage setting	$W_n = W(N/L, cpi, t_n)$
(3) Labour force	$L = \bar{L}$
(4) Consumer price index	$cpi = \sum_i \theta_i p_i + \sum_i \theta_i^{RUK} \bar{p}_i^{RUK} + \sum_i \theta_i^{ROW} \bar{P}_i^{ROW}$
(5) Capital supply	$K_i^S = \bar{K}_i^S$
(6) Capital price index	$kpi = \sum_i \gamma_i p_i + \sum_i \gamma_i^{RUK} \bar{p}_i^{RUK} + \sum_i \gamma_i^{ROW} \bar{P}_i^{ROW}$
(7) Labour demand	$N_i^d = N_i^d(Q_i, W_n, W_k)$
(8) Capital demand	$K_i^d = K_i^d(Q_i, W_n, W_k)$
(9) Labour market clearing	$N^S = \sum_i N_i^d = N$
(10) Capital market clearing	$K_i^S = K_i^d$
(11) Household income	$Y = \Psi_t N W_n(1-t_n) + \Psi_k \sum_i K_i W_{ki}(1-t_k) + \bar{T}$
(12) Commodity demand	$Q_i = C_i + I_i + G_i + X_i$
(13) Consumption Demand	$C_i = C_i(p_i, \bar{p}_i^{RUK}, \bar{p}_i^{ROW}, Y, cpi)$

App. 1. (cont.) Equations	Short run
(14) Investment Demand	$I_i = I_i(p_i, \overline{p}_i^{RUK}, \overline{p}_i^{ROW}, \sum_i b_{ij} I_j^d)$ $I_j^d = h_j(K_j^d - K_j)$
(15) Government Demand	$G_i = \overline{G}_I$
(16) Export Demand	$X_i = X_i(p_i, \overline{p}_i^{RUK}, \overline{p}_i^{ROW}, \overline{D}^{RUK}, \overline{D}^{ROW})$
(17) Pollutants	$POL_k = \sum_i b_{ik} Q_I$
Multi-period model	**Stock up-dating equations**
(18) Labour force	$L_t = L_{t-1} + nmg_{t-1}$
(19) Migration	$\frac{nmg}{L} = nmg\ (W/cpi, W^{RUK}/cpi^{RUK}, u, u^{RUK}$
(20) Capital Stock	$K_{it} = (1 - d_i)\, K_{it-1} + I_{i,t-1}^d$

NOTATION

Activity-Commodities

i, j are activity/commodity subscripts (There are twenty-five of each in AMOSENVI: see Appendix 2.)

Transactors

RUK = Rest of the UK, ROW = Rest of World

Functions

p (.) CES cost function

K^S(.), W(.) Factor supply or wage-setting equations

K^d(.), N^d(.) CES factor demand functions

C(.), I(.), X(.) Armington consumption, investment and export demand functions, homogenous of degree zero in prices and one in quantities

Variables and parameters

C	consumption
D	exogenous export demand
G	government demand for local goods
I	investment demand for local goods
$\mathbf{I^d}$	investment demand by activity
$\mathbf{K^d, K^S, K}$	capital demand, capital supply and capital employment
L	labour force
$\mathbf{N^d, N^S, N}$	labour demand, labour supply and labour employment
P	price of commodity/activity output
Q	commodity/activity output
T	nominal transfers from outwith the region
$\mathbf{W_n, W_k}$	price of labour to the firm, capital rental
X	exports
Y	household nominal income
$\mathbf{b_{ij}}$	elements of capital matrix
cpi, kpi	consumer and capital price indices
d	physical depreciation
s	labour subsidy rate
$\mathbf{t_n, t_k}$	average direct tax on labour and capital income
u	unemployment rate

Ψ	share of factor income retained in region
θ	consumption weights
γ	capital weights
h	capital stock adjustment parameter
$\mathbf{POL_k}$	quantity of pollutant k
$\mathbf{b_{ik}}$	output-pollution coefficients

APPENDIX 2. Sectors/commodities in AMOSENVI

	Sector name	99 Scot/UK IOC
1	AGRICULTURE	1
2	FORESTRY PLANTING AND LOGGING	2.1, 2.2
3	FISHING	3.1
4	FISH FARMING	3.2
5	Other mining and quarrying	6,7
6	Oil and gas extraction	5
7	Mfr food, drink and tobacco	8 to 20
8	Mfr textiles and clothing	21 to 30
9	Mfr chemicals etc	36 to 45
10	Mfr metal and non-metal goods	46 to 61
11	Mfr transport and other machinery, electrical and inst eng	62 to 80
12	Other manufacturing	31 to 34, 81 to 84
13	Water	87
14	Construction	88
15	Distribution	89 to 92
16	Transport	93 to 97
17	Communications, finance and business	98 to 107, 109 to 114
18	R&D	108
19	Education	116
20	Public and other services	115, 117 to 123
	ENERGY	
21	COAL (EXTRACTION)	4
22	OIL (REFINING & DISTR OIL AND NUCLEAR)	35
23	GAS	86
	ELECTRICITY	85
24	Renewable (hydro and wind)	
25	Non-renewable (coal, nuke and gas)	

APPENDIX 3: POLLUTION COEFFICIENTS IN AMOSENVI

The matrix of UK direct emissions coefficients is constructed using sectoral output and emissions data contained in a trial National Accounting Matrix including Environmental Accounts (NAMEA) database developed by the Environmental Accounts Branch of National Statistics as part of a project for Eurostat.[19] By dividing each sector's generation of each pollutant (in physical terms) by its gross output (in value terms) for a given time period (in this case one year, 1999), we obtain a measure of the direct emissions intensities of production. Where final demand sectors are responsible for direct pollution generation we can similarly estimate the emissions intensity of total final demand expenditure; here we limit this to one final demand sector, households, because the UK NAMEA database only includes measures of household pollution generation. The set of UK direct emissions coefficients was then applied to the Scottish case to construct output-pollution coefficients for each of the 25 production sectors that we identify in the Scottish economy (see Appendix 2) and for a single final demand sector, households. This involved weighting the UK coefficients to reflect the composition of total and sectoral outputs in the Scottish economy. The resulting set of UK-adjusted pollution coefficients used in AMOSENVI is shown in the first six columns of Table A.3.

However, applying UK output-pollution coefficients at the regional level means making certain assumptions regarding the homogeneity of fuel use and polluting technology in the production of outputs by equivalent sectors and in aggregate consumption by households across space in the UK:

(a) *Identical fuel use patterns* – i.e. we are assuming that the fuel used to produce £1 million output is the same in Scotland as in the UK.

(b) *Identical technology* – i.e. we are assuming that the emissions factors for how much pollution results from burning this fuel are the same in Scotland as in the UK, and that non-combustion related emissions (from production processes that do not involve burning fuel) are the same. (For any given technology this may not be an unreasonable assumption since this could be expected to be a technical relationship that does not vary across space.)

---

[19] For a discussion of NAMEA accounting see European Commission (2001) and Prashant (1999).

In the case of household emissions we also have to make the additional assumption that the pattern of consumer expenditure across all available consumption goods is the same in Scotland as it is in the UK (as well as those over fuel use and emissions factors). The UK household coefficients used here are also simply a ratio of total household emissions to total household consumption expenditures. Clearly it would be preferable to link emissions, where appropriate to specific types of commodity demand, particularly energy-use as reflected in the Scottish IO data used in the model.

Therefore, we have attempted to estimate Scottish-specific pollution coefficients for production and consumption activities for the main greenhouse gas CO_2. This involved using Scottish 1999 IO data on different types of fuel purchases to distribute estimated total physical fuel use in the Scottish economy in 1999 (estimated using the UK Environmental Accounts) across production sectors and households. We then apply UK emissions factors derived from the UK NAMEA database to estimate sectoral CO_2 generation from fuel use in each sector. Thus, we are able to relax the assumption regarding the homogeneity of fuel use in the Scottish economy in the case of CO_2 emissions.

However, we also take account of non-fuel-combustion emissions of CO_2 in the 'Mfr metal and non-metal goods', 'Oil and gas extraction' and 'Refining and distribution of oil' sectors, using estimates of CO_2 emissions in 1999 from the relevant sources reported by Salway *et al* (2001).

Finally we also use experimental IO data splitting the aggregate electricity supply sector into different generation sectors. This allows us to also relax the assumption of homogenous polluting technology and distinguish between electricity generated using renewable and non-renewable sources. This is a particularly important distinction since electricity generation using renewable sources is more prevalent in Scotland relative to the rest of the UK.

A more detailed explanation of the estimation of the Scottish-specific sectoral CO_2 accounts is given in Turner (2003a). Here, the resulting set of Scottish-specific pollution coefficients giving the CO_2-intensity of output in each production sector and final consumption expenditure by households are shown in the final column of Table A.3. In Figure A.3 we graph the UK-adjusted and Scottish-specific CO_2 coefficients together. Note that the biggest differences are observed in the energy extraction and supply sectors, particularly the electricity sectors, where technology in the Scottish sectors is known to differ radically from the rest of the UK.

Figure A.3: CO2 Intensity of Production and Final Consumption Activities - UK-adjusted and Scottish-Specific Output- and Final Demand Expenditure-CO2 coefficients

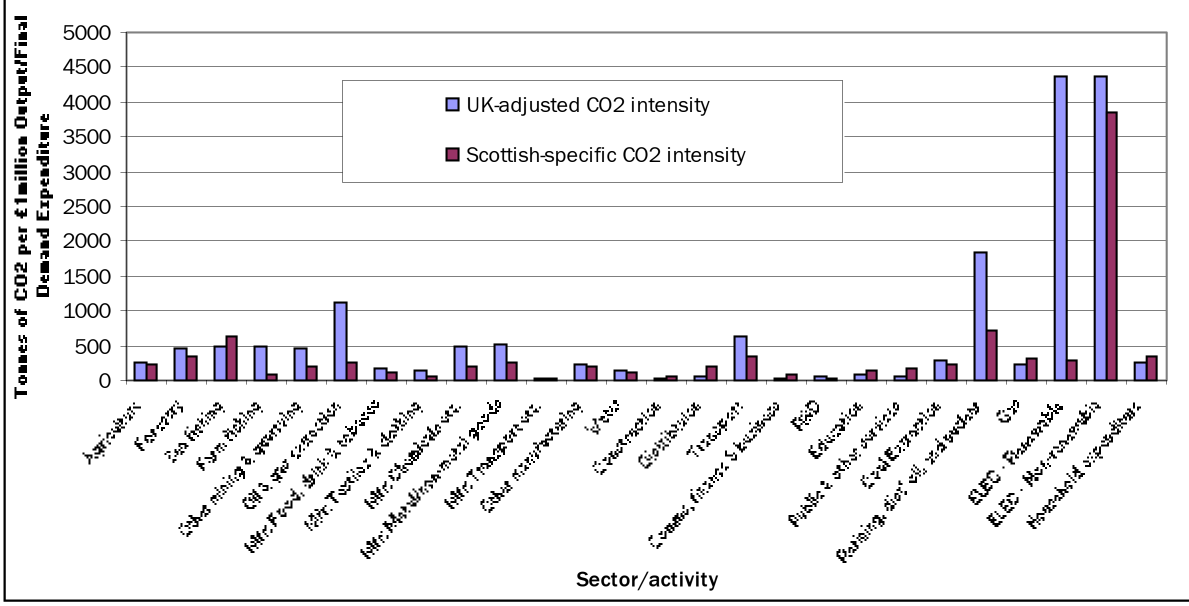


Table A.3: Output/Expenditure-Pollution Coefficients in AMOSENVI
(tonnes of emissions per £1million output in each sector i, and final consumption expenditure by households)

SECTOR/ACTIVITY	POLLUTANT Sulphur dioxide (SO2)	Methane (CH4)	Nitrous oxide (N2O)	Carbon monoxide (CO)	PM10	Carbon Dioxide (CO2) UK-adjusted coefficient	Scottish-specific coefficient
Agriculture	0.22651	50.29817	4.81928	3.50504	1.01155	267.34	225.80
Forestry	3.65180	0.01984	0.02908	0.44456	0.25395	466.22	343.01
Sea fishing	2.95249	0.04453	0.03079	1.15662	0.16684	484.64	643.24
Farm fishing	2.95249	0.04453	0.03079	1.15662	0.16684	484.64	81.66
Other mining & quarrying	0.40341	0.08958	0.15735	27.95864	5.76441	460.09	206.24
Oil & gas extraction	0.92224	3.47800	0.07088	1.84936	0.29933	1106.49	245.51
Mfr: Food, drink & tobacco	0.15742	0.01092	0.00353	0.15326	0.03162	168.42	127.45
Mfr: Textiles & clothing	0.12598	0.00836	0.00270	0.15480	0.02079	129.52	71.40
Mfr: Chemicals etc.	1.02437	0.08090	0.18570	2.52781	0.11853	478.87	194.37
Mfr: Metal/non-metal goods	1.09167	0.06268	0.00967	3.84565	0.19665	525.05	251.95
Mfr: Transport etc.	0.02480	0.00186	0.00072	0.08663	0.00476	27.95	26.44
Other manufacturing	0.22042	0.03044	0.00665	0.46465	0.05162	217.57	209.51
Water	0.05038	0.01163	0.01774	3.03860	0.05987	148.50	101.83
Construction	0.02264	0.00589	0.00952	1.67016	0.06796	39.82	71.00
Distribution	0.00299	0.00572	0.00322	0.73607	0.02155	58.89	187.66
Transport	2.08038	0.06597	0.03402	2.99489	0.17698	634.40	351.49
Comms, finance & business	0.00307	0.00329	0.00203	0.51424	0.01037	33.06	73.97
R&D	0.00351	0.00546	0.00260	0.40750	0.00624	47.79	36.61
Education	0.06054	0.00534	0.00185	0.37221	0.01775	88.89	147.58
Public & other services	0.08813	3.13683	0.01657	0.19198	0.01418	68.49	186.21
Coal Extraction	0.59748	213.05637	0.00822	3.44804	0.97414	278.00	221.31
Refining, dist' oil, and nuclear	8.37719	0.13301	0.03069	4.60247	0.37056	1841.37	719.26
Gas	0.02628	37.45164	0.00822	0.17796	0.00521	236.45	312.25
ELEC - Renewable	23.90580	0.74422	0.19172	2.05874	0.58812	4365.12	276.14
ELEC - Non-renewable	23.90580	0.74422	0.19172	2.05874	0.58812	4365.12	3857.42
Household final expenditure	0.10748	0.09346	0.01873	5.01978	0.08634	251.89	339.96

Strathclyde Discussion Paper Series: 2004

04-01 Julia Darby, V. Anton Muscatelli and Graeme Roy
Fiscal Consolidation and Decentralisation: A Tale of Two Tiers

04-02 Jacques Mélitz
Risk Sharing and EMU

04-03 Frank H Stephen and Stefan van Hemmen
Market Mobilised Capital, Legal Rules and Enforcement

04-04 Peter McGregor, J Kim Swales and Karen Turner
An Input-Output Based Alternative to “Ecological Footprints” for Tracking Pollution Generation in a Small Open Economy

04-05 G Allan, N D Hanley, P G McGregor, J K Swales and K R Turner
An Extension and Application of the Leontief Pollution Model for Waste Generation and Disposal in Scotland

04-06 Eric McVittie and J Kim Swales
‘Constrained Discretion’ in UK Monetary Regional Policy

04-07 Roy H Grieve
Price Flexibility and Full Employment: Losing the Plot?

04-08 Peter G. McGregor, Donald McLellan, Karen R. Turner and J. Kim Swales
Attribution of Pollution Generation to Local Private and Public Demands in a Small Open Economy: Results from a SAM-Based Neo-Classical Linear Attribution System for Scotland

04-09 Roy H Grieve
Roncaglia on Sraffa and Wittgenstein: Further Comment

04-10 Giorgio Fazio
Extreme Interdependence and Extreme Contagion between Emerging Markets

04-11 Ramesh Chandra
Saving, Investment and Growth: A Smithian Perspective

04-12 Roger Perman and Christophe Tavera
Testing for Convergence of the Okun’s Law Coefficient in Europe

04-13 Linda Ferguson, Peter G McGregor, J Kim Swales, Karen R Turner and Ya Ping Yin
Incorporating Sustainability Indicators into a Computable Equilibrium Model of the Scottish Economy