UNIVERSITY OF STIRLING

Stirling Management School

Productivity Growth, Decoupling and Pollution Leakage

Karen Turner
Nick Hanley
Cathy Xin Cui
Soo Jung Ha
Peter McGregor
Kim Swales
Ya Ping Yin

Stirling Economics Discussion Paper 2011-13
July 2011

Productivity Growth, Decoupling and Pollution Leakage

By

Karen Turner[a]*, Nick Hanley[a], Cathy Xin Cui[b], Soo Jung Ha[c], Peter McGregor[b], Kim Swales[b] and Ya Ping Yin[d]

a. Division of Economics, Stirling Management School, University of Stirling, UK
b. Fraser of Allander Institute, Department of Economics, University of Strathclyde, UK
c. Korean Research Institute for Human Settlements, South Korea
d. Department of Economics, Social Sciences and Tourism, Business School, University of Hertfordshire, UK

* Corresponding author: Division of Economics, Cottrell Building, University of Stirling, Scotland, FK9 4LA. Telephone: 00 44 (0) 1786 467474. E-mail: karen.turner@stir.ac.uk

Acknowledgements:

The research reported in this paper has been supported by the UK Economic and Social Research Council under the Climate Change Leadership Fellowship "Investigating the pollution content of trade flows and the importance of environmental trade balances" (ESRC ref. RES-066-27-0029), based at the Universities of Stirling and Strathclyde. It also draws on earlier research carried out under an ESRC 1st Grants project (ESRC ref. RES-061-25-0010) and the UK EPSRC SuperGen Marine Energy Research Consortium (Grant reference: EP/EO40136/1). We are grateful to participants at seminars at the University of Strathclyde in September 2010 and at University of Stirling in March 2011 for helpful comments on initial results. We also acknowledge the input and advice of the input-output team at the Office of the Chief Economic Advisor at Scottish Government and Tommy Wiedmann, formerly of the Stockholm Environment Institute, in constructing UK input-output and regional and national imports data, and to Nori Yamano at OECD, who worked with us to identify the pollution content of UK imports. Finally, we are grateful to Janine De Fence and Stuart McIntyre for research assistance.

Productivity Growth, Decoupling and Pollution Leakage

Abstract

This paper examines the issue of decoupling economic growth and pollution through growth driven by productivity improvements; and the extent to which pollution effects spill over national borders. Focus is widened from conventional production measures of pollution to a consumption accounting principle (carbon footprints). This adds a useful dimension to understanding pollution leakage effects. Using an interregional empirical general equilibrium framework, we consider the impacts of productivity growth in one region in that region and a neighbour linked through trade in goods and services and in the factor of production that is targeted with the productivity improvement (here through interregional migration of labour). The key finding is that while economic growth resulting from the productivity improvement in one region is accompanied by increased absolute pollution levels across both regions, positive competitiveness effects lead to a reduction in imports and pollution embodied therein to both regions from the rest of the world.

Keywords: CGE models; labour productivity; factor mobility; economic growth; pollution leakage; carbon footprints.

JEL codes: D57, D58, O18, O44, Q56

1. Introduction

Labour productivity improvements are widely recognised as a key driver of economic growth (World Bank, 2011). The contribution of labour productivity improvements has been measured in numerous growth accounting studies (most recently by Jorgenson and Vu, 2010, for the G7 and other major economies and regions), and it has provided a focus for both international (e.g. the Millennium Development Goals adopted by the United Nations in 2000[1]) and national policy targets (e.g. see HM Treasury, 2000, for the UK). Moreover, factor productivity improvements may also be important in decoupling economic growth from absolute pollution levels. This is one possible explanation for observations of an Environmental Kuznets Curve (Jaffe et al, 2003), where increased productivity in input use makes it possible to reduce the pollution intensity (generally defined as the amount of pollution emitted in a given time period relative to GDP) of an economy over time.

However, there has also been considerable debate in the literature relating to how actions to reduce domestic pollution generation, particularly in industrialised economies, may lead to increased global emissions through pollution leakage, or pollution embodied in trade. An important early contribution in this area was Arrow et al (1995). The pollution leakage literature is reviewed more comprehensively below. A key point is that the main focus in empirical analyses of pollution leakage to date (increasingly composed of computable general equilibrium, CGE, analyses) have focussed on the implementation of carbon caps (e.g. Babiker, 2005) or carbon taxes (e.g. Bruvoll and Faehn 2006; Elliot et al, 2010). The current paper adds to this literature by considering whether increased labour productivity in one economy (taking Scotland as an example) leads to a decoupling of economic growth and pollution in

[1] http://mdgs.un.org/unsd/mdg/Host.aspx?Content=Indicators%2fOfficialList.htm

terms of *both* direct CO2 emissions within Scotland *and* indirect emissions embodied in its imports.

We make a further contribution by considering the impacts of increased labour productivity in one region on a neighbour (here, the rest of the UK) linked with the target region not only through trade in goods and services but also through a mobile supply of labour, being the factor of production whose productivity improves in our simulations. This provides a link to the wider growth literature, where the available quantity of labour is a key determinant of growth (indeed Jorgenson and Vu, 2010, find this to be more important than productivity change). It also makes a new contribution to the pollution leakage literature, which has tended to focus on trade in goods and services with a fixed (domestic) labour supply.

A further, novel contribution of our paper is to consider pollution leakage in the context of measuring an economy's 'carbon footprint', a concept that is attracting increasing public and policy interest. Measuring carbon footprints and the pollution embodied in trade has been the focus of numerous input-output studies (see Wiedmann, 2009, for a review) since Munksgaard and Pedersen (2001) demonstrated that it is possible to account for pollution generation in a given economy in a given time period under both production and consumption accounting principles using this simple general equilibrium framework. The current paper extend this literature by employing a more flexible CGE modelling framework (which incorporates a set of input-output accounts as its core database) to consider the impact of changes in activity the carbon footprint of the target economy (Scotland) and its neighbour (the rest of the UK).

The remainder of the paper is structured as follows. In Section 2 we review the existing literature on economic growth and pollution leakage. In Section 3 we introduce the interregional CGE model of Scotland and the Rest of the UK (RUK) that is used for our empirical analysis of the economic and CO2 impacts of an increase in Scottish labour productivity in Sections 4, 5 and 6. Conclusions and considerations for future research are provided in Section 7.

2. Economic growth and pollution leakage

Pollution leakage has emerged as a potentially important factor in the relationship between economic growth and environmental quality (Antweiler et al, 2001). Critics of the Environmental Kuznets Curve hypothesis have suggested that whilst economic growth in country A may lead to lower domestic emissions due to structural changes in the domestic economy, continued consumption of pollution-intensive products imported from overseas may lead to increases in pollution in the exporting country (Bruvoll and Faehn, 2006). Moreover, measures to reduce emissions in country A – such as a pollution tax – may result in increased emissions in exporting countries, partly through changing incentives for the location of dirty industries when factors of production are mobile across international borders (Sheldon, 2006). Modelling studies of the effects of energy efficiency improvements on domestic pollution reveal a third channel for pollution levels in trading countries to be co-determined, due to competiveness effects on energy-intensive (and thus, typically, carbon-intensive) export sectors (Hanley et al, 2009).

Empirical evidence of pollution leakage has been developed using a number of approaches. Using both historical data and CGE modelling, Faehn and Bruvoll (2009) find little evidence of leakage in the context of economic growth impacts on net imports of “dirty” goods. The same authors (Bruvoll and Faehn 2006) also use a CGE model to study the effects on global pollution of a domestic carbon tax, and find partly offsetting impacts on third country emissions. Elliot et (2010) also adopt a CGE approach to examine various scenarios for taxing carbon emissions and find that border tax adjustments are required to eliminate pollution leakage as a result of Annex B Kyoto countries substituting domestic emissions for imports from developing countries. Babiker (2005) also uses CGE study to analyse carbon caps rather than carbon taxes, considering how, depending on market structure, energy-intensive industries may relocate away from developed countries with carbon control policies as a result of obligations under the Kyoto protocol. Again, the prediction is one of increased pollution leakage and global emissions.

The CGE studies noted above have mainly taken a production accounting approach to measuring domestic pollution. Consumption accounting of carbon emissions is a more common development in the input-output literature. For example, Peters and Hertwich (2006) use input-output modelling to measure the pollution content of imports to Norway, and find that CO2 embodied in imports equated to more than 50% of domestic emissions, and that consumption of these imports had led to significant implied carbon emissions in developing countries. They concluded that national emissions inventories should be based on domestic consumption rather than production. A similar analysis for Italy is presented by Mongelli et al (2006). Finally, Ghertner and Fripp (2007) use life-cycle analysis to calculate the "global warming potential" implicit in US consumption, and show that allowing for the carbon-equivalent emissions contained in imports resulted in no turning point being found for the relationship between GDP per capita and emissions – that is, no evidence of an EKC once a consumption accounting principle was adopted.

Looking across both modelling approaches, conditions which emerge as important from this literature for determining the degree of pollution leakage are compositional changes in the domestic economy, factor mobility, and the pollution content of imports which substitute for domestic production. These are all allowed for in the model described below, along with endogenous changes in the scale of economic activity in both the domestic economy and its trading partners induced by productivity-led growth. Our modelling approach also allows us to measure pollution leakage in the context of full consumption accounting measures of carbon emissions (or carbon footprints): these consumption-accounting measures of leakage can then be compared with more usual production-accounting leakage measures.

3. The AMOS UK 2-region CGE modelling framework

AMOSRUK is a computable general equilibrium (CGE) model of the UK economy with two endogenous regions, Scotland and the Rest of the UK (RUK), and one exogenous region, the Rest Of the World (ROW). It is calibrated on a 2-region, 6-sector interregional Social Accounting Matrix (SAM) for 2004, which provides a 'snapshot' of the Scottish and rest of the UK economies and related CO2 emissions generation for that year.[2] The six sectors/commodities modelled are detailed in Appendix 1.[3] A condensed model listing of the AMOSRUK modelling framework used here is provided in Appendix 2.[4] In this section we summarise the main features of the interregional CGE model in the context of the scenarios modelled here.

---

[2] The interregional SAM uses input-output data for Scotland in 2004 published by the Scottish Government (http://www.scotland.gov.uk/Topics/Statistics/Browse/Economy/Input-Output) and UK analytical IO tables (http://www.strath.ac.uk/fraser/research/2004ukindustry-byindustryanalyticalinput-outputtables/) derived from the UK Supply and Use tables, which may be accessed at the Office for National Statistics, ONS, web-site (http://www.statistics.gov.uk/STATBASE/Product.asp?vlnk=3026). Interregional trade data to derive the interregional framework were provided by the Scottish Government (not published) as were Scottish environmental accounting data (considered most reliable at the 6-sector level modelled here). The UK Environmental Accounts may also be accessed at the ONS web-site (http://www.statistics.gov.uk/about/methodology_by_theme/Environmental_Accounts/default.asp).

[3] The sectoral breakdown is limited to six sectors due to reliability issues regarding the Scottish environmental accounting data available (see previous footnote).

[4] Harrigan et al (1991) gives a full description of early versions of the AMOS framework, and Turner et al (2011a) provide an application of an earlier version of the AMOSRUK model. Greenaway et al (1993) provides a general appraisal of CGE models, Partridge and Rickman (1998, 2010) review regional CGEs, while Bergman (2005) provides an overview of environmental CGE modelling frameworks.

There are four main components of final demand: household consumption, investment, government expenditure and exports to the ROW. Household consumption is a linear homogenous function of income; investment is explained below, while government expenditure is exogenous (and unchanging) in the central case, though we relax this assumption, constraining to a fixed national expenditure/GDP ratio in sensitivity analysis. Both interregional and international exports are price sensitive – see equations (A.14)-(A.15). However, while non-price determinants of export demand from the rest of the world are taken to be exogenous, export demand to the other UK region is fully endogenous, depending not only on relative prices, but also on the structure of all elements of intermediate and final demand in the other region.

In production, a local composite of intermediate inputs is combined with composite imports from the other region and the rest of the world via an Armington link (Armington, 1969). This means that domestic products and imported goods are treated as imperfect substitutes, with the degree of substitutability set by the modeller.[5] However, while the commodity composition of Scottish and RUK intermediates to each sector varies with local prices, we assume that the commodity composition of ROW imports to each sector and for final consumers is fixed.[6]

In the current application we set all Armington import elasticities at 2.0 (Gibson, 1990). The composite intermediate input is then combined with labour and capital (value added) to determine each sector's gross output. Production functions at each level of the production hierarchy can be CES, Cobb-Douglas or Leontief. The simulations in this paper use CES production functions at the value-added and gross-

[5] We acknowledge issues raised by other authors (e.g. Copeland and Taylor, 2005; Babiker, 2005) regarding restrictions imposed by the use of the Armington assumption in most CGE studies. It may be a useful focus in future research to explore alternatives. However, at this time we follow Elliot et al (2010) in retaining the conventional Armington assumption in considering pollution leakage without a particular focus on issues such as production differentiation.

[6] It will be a focus of future research to introduce commodity level substitution between local and imported goods and services.

output level (with a value of 0.3, informed by Harris, 1989, with some sensitivity noted), and Leontief productions functions at the intermediate-inputs level in each region.

The capital stock in each region is determined by region-specific investment. Gross investment is determined by a capital-stock adjustment mechanism: in each period investment demand from each sector is a proportion of the difference between actual and desired capital stock, where desired capital stock is a function of commodity output, the nominal wage and the user cost of capital.[7] Thus in response to a shock, investment acts to optimally adjust capital stocks over time (equations (A.16)-(A.19)).

The labour force also updates following a shock. In the current application we assume that there is no natural population increase and no international migration, but regional labour forces adjust through inter-regional migration between Scotland and RUK in response to changes in real wage and unemployment differentials (equations A.20-A.24). This specification is based on the model of Harris and Todaro (1970), which is commonly used in US studies of interregional migration, and parameterised based on regional work for the UK carried out by Layard et al (1991). Real wages are determined using a regional wage bargaining function in each region and reflect workers' bargaining power through a negative relationship with unemployment (Blanchflower and Oswald, 1994). This function is also parameterised based on work by Layard et al (1991).

Direct CO2 emissions generation in each production sector and households in the two endogenous regions are related to energy use where appropriate and otherwise to output or total final expenditure (see equation A.25). For the CAP (Consumption Accounting Principle) measure, emissions embodied in imports from ROW to each

[7] The speed of adjustment of the capital stock – i.e. the proportion of gap between actual and desired capital stock filled between any two periods is an exogenously specified parameter. Here it is set at 0.5.

region are determined using a dataset provided by the OECD and are adjusted to reflect total emissions (kilo-tonnes) per £1 million of imports to each production sector and final consumer in the two endogenous regions. This involves weighting output-CO2 intensities for the six external commodities based on the commodity and country source composition of imports in each (see equation A.26 and Turner et al, 2011b for details).

4. Simulation strategy

We introduce an exogenous (and costless) step increase in Harrod Neutral (labour augmenting) technological progress in all Scottish production sectors. Both regional economies (Scotland and RUK) are assumed to be in long-run equilibrium at the outset and the shock is introduced in the first period/year. Both economies adjust to to a new long-run equilibrium through a series of temporary equilibria, each of which is interpreted as one year (due to the annual nature of the SAM data). While some period-by-period results are reported, we focus on two conceptual time periods. First, the short-run, the first period after the shock is introduced, where both labour and capital stocks and fixed. Second, the long-run, where labour and capital stocks are fully adjusted in response to the shock. Given that a single exogenous shock is simulated, all changes reported are attributable entirely and solely to the shock imposed. That is, if no shock were introduced, the model would recreate the base year data. Generally, we report in terms of percentage changes from the base year (2004) equilibrium (but with absolute physical changes reported for CO2 embodied in imports in Table 2). We calculate CO2 emissions under the consumption accounting principle by using CGE results on price and quantity changes to derive post-shock input-output accounts in value terms for each period after the shock is introduced, and then compute the CAP measure (and its components) using equation A.26 in Appendix 2.

5. Central case results

5.1 Impacts in the target economy (Scotland)

As stated above, a Harrod neutral efficiency improvement is one that increases the productivity of labour relative to capital and other inputs to production. The efficiency improvement increases the effective labour supply, thus reducing the price of labour measured in efficiency units. This will trigger a number of general equilibrium effects in the target economy (in this case, Scotland). The first is the pure efficiency effect, which acts to reduce demand for labour (i.e. as labour efficiency is increased by 5%, 5% less labour input is required to produce a given level of output). This may trigger an initial contraction in the Scottish labour supply (through out-migration) as the real wage rate falls and the unemployment rate rises. However, since the efficiency improvement reduces the effective price of labour, there will also be upward pressure on the labour demand as producers substitute in favour of labour and away from other inputs. Moreover, as both the effective and actual price of labour fall (the latter as a result of the efficiency effect), Scottish output prices will also fall, increasing competitiveness and stimulating export demand, which will in turn increase the (direct and derived) demand for labour and other inputs. Positive indirect demand (or multiplier) effects also occur. as Scottish firms require more intermediate inputs to meet increased demand, which puts opposing (upward) pressure on local output prices, partly or wholly offsetting positive competitiveness effects. Finally, as the economy expands (with short-run supply constraints relaxed through in-migration of labour and investment in capital stock), labour incomes to households will increase, further increasing demand in all sectors of the economy.

<Insert Table 1 around here>

This complex pattern of effects underlies the results reported in the first two numerical columns of Table 1. These summary results show the short- and long-run impacts on key economic and CO2 generation variables in Scotland in response to the 5% step increase in Scottish labour efficiency. In the first period after the shock is introduced the efficiency effect is reflected in a 0.8% drop in employment. This is significantly less than the proportionate increase in labour efficiency implying a large 'rebound' effect in employment driven by positive substitution, competitiveness, income and multiplier effects as the economy begins to expand. However, this expansion is limited in the short-run by constraints on capital and labour stocks. In the early periods (years) after shock in the scenario presented in Table 1, the labour supply constraint is actually exacerbated by the fact that the drop in the real wage rate and employment triggers out-migration of labour from Scotland to the rest of the UK.[8] However, this trend is quickly reversed as economy expands with a net increase in labour demand so that the real wage begins to rise and the unemployment rate falls, triggering migration in the other direction. Migration continues until the differential with RUK is restored in the long-run.

Economic growth in Scotland (GDP expands by 7.7% over the long-run) is ultimately driven by the rise in competitiveness facilitated by the efficiency increase. From the outset the Scottish price level, reflected in the CPI, falls (by 0.6% in the short-run and by 3.2% over the long-run). This stimulates export demand from both RUK and ROW. However, while output grows from the outset in all Scottish production sectors (see Figure 1) the underlying effects are more complex. Local intermediate demand pressures for the outputs of Sectors 1-3 (*Energy*; *Extraction, Quarrying, Construction*

[8] While it is not reported here, parametric sensitivity analyses show that the temporary out-migration effect is lost if the substitutability in favour of labour is increased in the nested production function (i.e. if a stronger substitution effect is facilitated).

and Water Supply; *Agriculture and Fishing*) initially cause an increase in the price of output in these sectors that is sufficient to reduce export demands for sectoral outputs (particularly from ROW). However, increased intermediate demands are sufficient to offset external demand reductions so that there is net growth in output in all sectors from the outset. As supply constraints ease, both local and export demands increase in all sectors with falling output prices.

<Insert Figure 1 around here>

In terms of CO2 generation, Table 1 shows that emissions generation within Scotland, the production accounting principle (PAP) measure, grows from the outset (a 2.5% increase over the baseline in the short-run rising to 6.9% over the long-run). Figure 1 shows that output grows in all production sectors by between 5.6% (*Other Services*) and 9.5% (*Quarrying, Construction and Water Supply*) over the long-run depending on (a) their exposure to the efficiency boost through their labour intensity, (b) to positive competitiveness effects, through their export intensity, and (c) the strength of local demand effects. Use of all inputs increases, as does associated CO2 generation in each sector (largely driven by increased energy use). Direct emissions in the household sector (where consumption rises by 2.8% in the short-run, rising to 3.6% in the long-run) also rise. However, the growth in emissions is dominated by the expansion in the highly carbon-intensive Energy sector, accounting here for almost half of the long-run increase in PAP emissions.

From the onset of the productivity shock GDP grows faster than CO2 generation so that the CO2 intensity of Scottish GDP falls (by 0.07% in the short-run and 0.8% in the long-run). This is due to the increase in competitiveness resulting from the labour efficiency improvement.

CAP emissions, on the other hand, are driven by what is consumed rather than what is produced in the Scottish economy. The results in Table 1 show that the increase in total CAP is greater in the short-run (3.2%) than in the long-run (3%). The short-run increase in CAP is also proportionately greater than the increase in aggregate (household and government) consumption (1.9%). It is pulled up by the larger increases in direct emissions by households and by the initial increase in imports from ROW, which tend to be more CO2-intensive than the average unit of consumption of UK (Scottish and RUK) goods and services. This is due to the commodity composition of imports and associated external polluting technologies. Moreover, there is a further net change in the composition of imports from ROW as different activities grow at different rates. This is reflected in the result that while imports from ROW rise by 2% in the short-run, the CO2 embodied therein rises more than proportionately (2.5%).

However, the initial net increase in imports from both RUK and ROW is partly driven by the presence of short-run supply constraints limiting the expansion of Scottish production. Over time, as supply constraints ease allowing Scottish prices to continue to fall, substitution effects in favour of locally produced commodities dominate so that there is a net reduction in total imports from ROW of 0.4% by period 50 and only a very small increase (0.09%) in imports from RUK (prices in the latter fall over time as activity levels contract – see below).

Nonetheless, there is a net *increase* (of 0.8%) in CO2 embodied in ROW imports to Scotland over the long run. This is because, despite a decrease in direct imports by Scottish households and service sectors (5 and 6 in Appendix 1), there is a strong enough income effect in Scottish production of outputs/commodities 1-4 to bring about an increase in the levels of both domestically produced and imported intermediates to these sectors. This leads to a net increase in emissions embodied in imports from ROW of commodities 1-3 (energy, agriculture and other primary production in ROW). This equates to around 218 kilo-tonnes of additional CO_2 generated outside the UK in these activities to support increased Scottish consumption demands (see the first numerical column of Table 2 – to be discussed in more detail below).

At the aggregate level this gross increase is partly offset by a 79 kilo-tonne reduction in CO_2 embodied in imports of commodities 4-6 (broadly manufacturing and service sectors). However, the net increase of 139 kilo-tonnes may have implications in terms of impacts in different countries that Scotland imports from. For example, according to the data supplied by OECD to estimate the pollution content of trade flows used here, around half of imports of commodity outputs 2 and 3 come from other EU countries; however, non-EU countries such as Russia and Canada are important in terms of energy imports (commodity output 1).

Over the long-run, the increase in CAP of 3% is small relative to the increase in GDP (7.7%) so that the CO_2 intensity of Scottish GDP under the CAP measure falls by 4.3%. This is significantly larger than the reduction in the CO_2 intensity of GDP under PAP, at only 0.8%. However, the discussion above shows that it is important to decompose the results to determine whether growth is accompanied by pollution leakage effects. Moreover, the productivity growth does lead to increases in absolute CO_2 levels in Scotland under both PAP and CAP measures, though this is to a greater degree in the case of the former led by growth in export demands (i.e. emissions that are attributable to the carbon footprints or CAP measures of other regions/nations). Thus, while the PAP measure captures the total change in emissions that accompanies economic growth in the target economy, the CAP measure allows us to focus on the change in emissions at both home and abroad that is driven by increased consumption possibilities in the target economy.

5.2 Impacts in the neighbouring region (the rest of the UK)

The analysis above focuses on the impacts of productivity growth on economic activity in the target region (Scotland) and pollution embodied in induced consumption. However, neighbouring regions may also be impacted by the productivity shock in Scotland, particularly if factors of production flow across regional borders. This is a focus of the pollution leakage literature. Here, we model a second region, the rest of the UK (RUK) which is linked with Scotland not only through trade in goods and services but also in terms of the supply of the factor of production, labour, that is targeted with the productivity improvement through migration.

The third and fourth numerical columns of Table 1 show the short- and long-run impacts on key economic and CO2 generation variables in RUK response to the 5% step increase in *Scottish* labour efficiency. Given the extent of inter-regional trade, the positive supply shock in Scotland translates to a positive demand shock in RUK. This is reflected in the immediate (short-run) increase in RUK exports to Scotland of 2.1%. In order to meet the increased demand from Scotland, RUK producers also increase their imports from Scotland and from ROW. However, the short-run increase in RUK imports from Scotland of 1.5% is significantly larger than the 0.04% increase in imports from ROW, reflecting the fact that Scottish prices have generally fallen (see above) due to the productivity improvement there. ROW prices, on the other hand, are exogenous (and therefore unchanging in the simulations reported here). Over time the reduction in Scottish prices relative to those in RUK leads to a net reduction in trade flows from RUK to Scotland but an increase in the other direction (i.e. RUK production sectors, and also final consumers, substitute in favour of Scottish commodity outputs and away from domestic production).

However, the long-run results in Table 1 also reflect the fact that, after the short-run, inter-regional migration occurs in response to real wage and unemployment rate differentials between Scotland and RUK. Where Scotland is drawing labour away from RUK, this translates to a negative supply shock in the latter.[9] The impact of migration on RUK production is reflected in Figure 2. As noted above (though not shown in Table 1), in the early periods (years) after shock, there is actually an out-migration of labour from Scotland to RUK as a result of the drop in the real wage rate and employment due to the efficiency effect in the former. [10] Figure 2 shows that all RUK production sectors benefit from the indirect demand shock as Scottish imports rise, particularly with the relaxation of the labour supply constraint in RUK workers migrate from Scotland to RUK. However, this effect is quickly reversed as the Scottish economy grows and after peaking around 5 periods/years in Figure 2, the growth in output in RUK production sectors declines and eventually becomes negative in all sectors.

The contraction in RUK production activity overall is reflected in a net decrease in all key macroeconomic indicators over the long run: GDP falls by 0.17%, household consumption by 0.24%, investment by 0.16% and employment by 0.21%. The lasting supply constraint is reflected in the increased real wage rate but lower unemployment

[9] While it is not reported in detail here, all scenarios were also simulated with no migration, so that impacts are only transmitted through goods and services trade flows. This causes a more limited expansion in the targeted region, because of the fixed labour supply without migration. Here we found that, despite a 0.17% increase in aggregate Scottish consumption over the long-run, there is a net decrease in CAP due to substitution in favour of Scottish outputs, and in associated emissions embodied in imports in ROW. RUK (as the neighbouring region) also enjoys a small expansion due to the indirect demand shock with no *additional* supply constraint from out-migration. However, the small increase in RUK consumption (0.01%) is also accompanied a net reduction in CAP due to a reduction in imports from ROW (with substitution in favour of Scottish outputs, the price of which still falls, though to a lesser extent than in the presence of migration) and associated pollution leakage in ROW.

[10] However, as noted above, this initial migration effect in favour of RUK is sensitive to the values assigned to parameters governing the substitution effect in favour of labour in Scotland. However, the long-run result of labour shifting from RUK to Scotland is not.

rate as there is a 0.29% decrease in RUK population over the long-run. However, substitution in favour of cheaper Scottish inputs to production means that there is a net decrease in RUK prices as activity contracts (CPI falls by 0.24% over the long-run). This leads to positive growth in exports to ROW (with an aggregate expansion of 0.38% over the long-run). The largest sectoral increase in export production (0.51%) is observed in the case of the CO2-intensive *Energy* sector.

Nonetheless, due to the net contraction in RUK production activity over time, after a small short-run increase in RUK PAP emissions, the net long-run effect is one of almost no change relative to the base year level. Underlying the zero change result in Table 1 is a very small positive increase (0.0005%), which equates to a 1.7% increase in the CO2-intensity of RUK GDP (i.e. proportionate to the drop in the latter). There also is a shift in the sectoral source composition of PAP emissions, which largely reflects positive competitiveness effects of the reduced price of imported intermediates from Scotland. In terms of emissions driven by RUK consumption demands, there is a very small rise in CAP emissions in the short-run (before migration effects kick in) of 0.02%. By the long-run RUK CAP falls by 0.1% so that there is a smaller increase in the CAP CO2-intensity of GDP (0.07%) than the corresponding PAP measure.

However, perhaps more importantly from the pollution leakage perspective that may underlie public and policy interest in CAP (or carbon footprint) measures, is the finding that the 0.61% drop in imports from ROW is accompanied by reductions in CO2 embodied in all imports to RUK. Moreover, these are sufficiently large to offset the increases in CO2 embodied in Scottish imports of commodities 1-3 so that there is a net reduction of 116 kilo-tonnes in these commodities and 885 kilo-tonnes across all commodities imported to the UK regions (see the second and third numerical columns of Table 2). We thus find some evidence of pollution leakage in ways which relate to trade linkages, but which also shows that linkages through factor movements across borders in response to relative factor returns are important (though this is driven by a contraction is the region suffering out-migration of labour).

6. Sensitivity analysis – endogenous government expenditure

So far in this paper, we have examined the impacts on pollution of export-led growth triggered entirely by the increase in labour productivity. In Table 3, we repeat the simulation but make government expenditure endogenous, so that increased government revenues from increased macro activity may be spent (i.e. allowing income effects in government expenditure as the economy expands). We apply two constraints. First, we assume a fixed ratio between the government balance (revenue minus expenditure) and GDP across the two regions (we assume that government revenue is collected and spending decisions are made at the national, UK, level). Second, we assume that the pattern of government expenditure across the two regions and the six sectors therein remains the same as in the base case. Endogenising government expenditure means that the labour productivity increase triggers a knock-on demand shock to the economy that is sufficient to do several things. First, it partly offsets the long-run contraction in RUK activity so that there is no net change in RUK GDP, although there is still a long-run contraction in household consumption and employment (of -0.21% and -0.01% respectively) due to the out-migration to Scotland. In both regions the short-run expansion is more limited in Table 3 relative to Table 1 because the net decrease in employment across the two regions reduces revenue earned and increases unemployment benefits required. However, over the long-run, Scottish GDP grows by slightly more (7.9% relative to 7.7% in Table 1), as does aggregate (combined household and government) consumption (3.01% relative to 2.5%).

However, the additional government demand reduces the positive competitiveness effects observed in the central case. The long-run decrease in Scottish CPI is smaller (-2.8% in Table 2 relative to -3.2% in Table 1) and there is a net increase (of 0.16%) in RUK. This is reflected in a crowding out of ROW export demands. In the case of Scotland these now only grow by 6.8% over the long-run relative to the 7.7% increase in Table 1. In the case of RUK, the long-run increase of 0.38% reported in Table 1 becomes a decrease of 0.42% in Table 3. This equates to a net increase of only 0.008% across the two regions.

Whilst GDP growth is higher across both regions with government expenditure endogenous, PAP emissions of CO2 increase by less. This is because government expenditure is concentrated in Sectors 5 and 6, which are less CO2-intensive (i.e. export demands for more CO2-intensive sectors are partly crowded out). This also leads to a net *decrease* in the PAP CO2-intensity of GDP in both regions over the long-run (-1.17% in Scotland and -0.07% in RUK, compared to the respective -0.78% drop and 0.07% increase in Table 1). However, the increased government demand drives up the CAP measures in both Scotland and RUK CAP measures (with a 0.18% increase replacing the -0.1% drop in the case of RUK). The long-run impact on the CAP CO2 intensity of GDP is not qualitatively affected.

However, in terms of pollution leakage, the key result is that the reduced strength of the positive competitiveness effects of the Scottish productivity increase means that income effects in import demands dominate, so that there is an increase in imports from ROW in both Scotland and RUK (of 0.45% and 0.14% respectively over the long-run). There is also a change in the composition of imports as different activities grow and their prices change at different rates with the result that CO2 embodied in imports rises more than proportionately in both Scotland and RUK (1.4% and 0.8%

respectively, though with a proportionate small short-run decrease in RUK accompanying the drop in imports). The net impact across both regions is a 0.16% increase in imports from ROW and a 0.21% rise in embodied CO2. This pollution leakage is reported in physical units in the last three columns of Table 2 where we see that, while there are some net reductions, e.g. in RUK imports of Energy (due to the different pattern of sectoral expansion) the net impact is that there is positive pollution leakage of 398 kilo-tonnes of CO2 to the rest of the world from the UK.

7. Discussion and conclusions

This paper considers the spill-over effects of productivity improvements in one country on a neighbour, in terms of both absolute CO2 emissions and emissions per pound of GDP. We find evidence of small spill-overs which move in opposite directions. The paper has also considered the implications of different ways of measuring regional or national emissions, between consumption- and production-based measures. While international agreements on greenhouse gas emissions are currently set in terms of emissions generated within a nation's borders (under a production accounting principle, PAP), there is increasing public and policy interest in and pressure to account for pollution embodied in trade flows using 'carbon footprint' type measures (a consumption accounting principle, CAP). The relevance of the CAP concept to our paper is in terms of the measurement of pollution leakage from one country's economic growth on others through the pollution embodied in its imports. In this respect, the paper makes a novel contribution by considering pollution leakage in the context of calculating CAP emissions in an empirical general equilibrium modelling framework (using input-output accounting techniques to process CGE model results).

In the specific application in this paper we examine the impact of productivity-induced growth in one region on its own economic performance and pollution generation and also in a neighbouring region that the target region trades with in terms of both goods and services and the factor targeted with the productivity improvement. We also examine the wider global pollution leakage effects of changes in imports. In our results for the UK two-region case, we find that increased labour productivity in one region, Scotland, provides the basis for an export-led expansion in that region but also provides an indirect demand boost to the neighbouring region (the rest of the UK). However, there is a negative supply shock in the neighbouring region as target region draws labour (the input targeted with productivity improvement) away. There is also growth in absolute pollution levels in both regions (under both PAP and CAP measures). While in the targeted region this is slower than GDP growth so that the CO2-intensity of aggregate activity falls, this will not necessarily be true in across both regions, particularly where labour migration equates to a negative supply shock in the neighbouring region. However, the export led nature of the growth means that CAP emissions rise less than PAP emissions. Moreover, positive competitiveness effects feeding through to both regions from the productivity improvement (through interregional trade in the case of the neighbour) mean that there is substitution away from imports from the rest of the world in favour of domestic production, which limits or negates pollution leakage effects.

However, sensitivity analyses demonstrates that if government decides to use revenues generated by the productivity-led expansion to fund increased expenditures, then this increased domestic demand will put upward pressure on local prices, reducing the strength of substitution effects away from imported commodities and making pollution leakage effects more likely.

In practice, economy-wide responses to productivity growth will be complicated by many factors. In this paper we do not consider specific ways in which a labour productivity improvement may be introduced, or the extent to which technological progress in the form of factor productivity improvements can also spill-over national borders. This will be a focus of future research. A positive cost of producing the labour productivity improvement may reduce the positive competitiveness effects of the productivity improvement, thereby making pollution leakage effects more likely. Another future research aim will be to extend to empirical analysis with greater sectoral and spatial disaggregation in terms of modelling both goods and services production and trade flows, but also factor markets. For example, in the current application we fix the UK national population. However, intra-EU migration is an increasingly important phenomenon that should be examined. More generally, it would be useful to consider more policy-orientated scenarios. An initial direction may be to consider different types of productivity improvement. For example, increases in energy efficiency are commonly regarded as central to climate change policy (European Commission, 2009, 2010; IPCC, 2007; Stern, 2007). However, the possibility of rebound and particularly backfire effects (Khazzoom 1980; Brookes 1990; Herring, 1999; Birol and Keppler, 2000; Saunders, 1992) makes the direction of pollution impacts more difficult to predict (Hanley et al, 2009; Fisher-Vanden and Ho, 2010).

References

Antweiler, W., Copeland, B., Taylor, M., Is free trade good for the environment? American Economic Review 91 (2001) 877-908.

Armington, P., A theory of demand for products distinguished by place of production, IMF Staff Papers 16 (1969) 157-178.

Arrow, K., et al., Economic growth, carrying capacity, and the environment, Science 268 (1995) 520-521.

Babiker, M.H., Climate change policy, market structure and carbon leakage, Journal of International Economics 65 (2) (2005) 421-445.

Bergman, L., CGE Modelling of Environmental Policy and Resource Management, in: K.G. Mäler and J. Vincent (Ed.) Handbook of Environmental Economics: Economy wide and International Environmental Issues, Elsevier North Holland (2005) 1273-1306.

Birol, F., Keppler, J. H., Prices, technology development and the rebound effect, Energy Policy 28 (2000) 457-479.

Blanchflower, D., Oswald, A., The Wage Curve, MIT Press Cambridge 1994.

Brookes, L., The greenhouse effect: the fallacies in the energy efficiency solution, Energy Policy 18 (1990) 199-201.

Bruvoll, A., Fæhn, T., Transboundary effects of environmental policy: Markets and emission leakages, Ecological Economics 59 (2006) 499-510.

Copeland, B.R., Taylor, M.S., Free trade and global warming: a trade theory view of the Kyoto Protocol, Journal of Environmental Economics and Management 49 (2) (2005) 205-234.

Elliot, J., et al., Trade and carbon taxes, American Economic Review: Papers and Proceedings 100 (2010) 465-469.

European Commission, EU action against climate change: leading global action to 2020 and beyond, http://ec.europa.eu/clima/ publications/docs/post_2012_en.pdf (2009).

European Commission, The European Strategic Energy Technology Plan - SET-Plan- towards a low carbon future, http://ec.europa.eu/energy/technology/set_plan/doc/ setplan_brochure.pdf (2010).

Fæhn, T., Bruvoll, A., Richer and cleaner - At others' expense? Resource and Energy Economics 31(2) (2009) 103–122.

Fisher-Vanden, K., Ho, M.S., Technology, development and the environment, Journal of Environmental Economics and Management 59 (2010) 94-108.

Ghertner, D. A., Fripp, M., Trading away damage: Quantifying environmental leakage through consumption-based, life-cycle analysis, Ecological Economics 63 (2007) 563-577.

Gibson, H., Export Competitiveness and UK sales of Scottish Manufacturers, Scottish Economists Conference, The Burn, Scotland, 1990.

Greenaway, D., et al., Applied General Equilibrium Modelling: Applications, Limitations and Future Developments. HMSO, London (1993).

Hanley, N., et al., Do increases in energy efficiency improve environmental quality and sustainability? Ecological Economics 68 (2009) 692-709.

Harrigan, F., et al., AMOS: A Macro-Micro Model of Scotland, Economic Modelling 10 (1991) 424-479.

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

Harris, J., Todaro, M., Migration, Unemployment and Development: A Two Sector Analysis, American Economic Review 60 (1) (1970) 126-142.

Herring, H., Does energy efficiency save energy? The debate and its consequences, Applied Energy 63(3) (1999) 209-226.

HM Treasury, Productivity in the UK: the evidence and the Government's approach, http://www.hm-treasury.gov.uk/media/D/C/ACF1FBA.pdf (2000).

IPPC, Intergovernmental Panel on Climate Change, IPCC Fourth Assessment Report: Climate Change 2007 – the physical science basis, Cambridge University Press, http://www.ipcc.ch/ipccreports/ar4-wg1.htm (2007).

Jaffe, A., Newell, R., Stavins, R., Technological change and the environment, Handbook of Environmental Economics, North-Holland (2003).

Jorgenson, D., Vu, K., Potential growth of the world economy, Journal of Policy Modelling 32 (5) (2010) 615-631.

Khazzoom, D.J., Economic implications of mandated efficiency in standards for household appliances, Energy Journal 1(4) (1980) 21-39.

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

Mongelli, I., Tassielli, G., Notarnicola, B., Global warming agreements, international trade and energy/carbon embodiments: an input–output approach to the Italian case. Energy Policy 34 (2006) 88–100.

Munksgaard, J., Pedersen, K., CO_2 accounts for open economies: producer or consumer responsibility? Energy Policy 29 (2001) 327-334.

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

Partridge, M., Rickman, D., CGE Modelling for Regional Economic Development Analysis, Regional Studies 44 (2010) 1311-1328.

Peters, G.P., Hertwich, E.G., Pollution embodied in trade: The Norwegian case, Global

Environmental Change 16 (2006) 379–387.

Saunders, H.D., The Khazzoom-Brookes postulate and neoclassical growth, Energy Journal 13 (4) (1992) 131-148.

Sheldon, I., Trade and environmental policy: a race to the bottom? Journal of Agricultural Economics 57 (3) (2006) 365-392.

Stern, N., Stern Review: The Economics of Climate Change, London: HM Treasury, http://webarchive.nationalarchives.gov.uk/+/http://www.hm-treasury.gov.uk/stern_review_report.htm (2007).

Turner, K., et al., An integrated IO and CGE approach to analysing changes in environmental trade balances, Regional Science, in press doi:10.1111/j.1435-5957.2011.00365.x (2011a).

Turner, K., et al., An input-output carbon accounting tool with carbon footprints estimates for the UK and Scotland, Fraser of Allander Institute Economic Commentary, Special edition (2011b) (06.01.2011).

Wiedmann, T., A review of recent multi-region input-output models used for consumption based emission and resource accounting, Ecological Economics 69 (2009) 211-222.

World Bank (2011) *The Changing Wealth of Nations.* Washington DC, The World Bank.

Appendices

Appendix 1. Sectors and commodity outputs identified in the general equilibrium modelling framework

Sector/commodity output	**UK IOC**	**SIC (2003)**
1. Energy	4, 85, 86, 35	10, 40.1, 40.2, 40.3, 23
2. Extraction, Quarrying, Construction and Water Suppy	5, 6, 7, 87, 88	11, 12, 13, 14, 41, 45
3. Agriculture & Fishing	1-3	01, 02 (Part), 05.01, 05.02
4. Manufacturing	8-84, except 35	15-37, except 23
5. Retail, Distribution and Transport	89-99	50-52, 55, 60.1-60.3, 61-63, 64.1-64.2
6. Other services	100-123	65-75, 80, 85.1-85.3, 90-93, 95

Appendix 2. AMOSRUK Condensed CGE Model Listing

Value-added prices	$pv_i^x = pv_i^x(w_n^x, w_k^x)$	(A.1)
Commodity prices	$p_i^x = p_i^x(pv_i^x, \underline{p}_{j-i}^x, \underline{p}^y, \overline{\underline{p}}^w)$	(A.2)
Consumer price index	$cpi^x = \sum_i \theta_i^{xx} p_i^x + \sum_i \theta_i^{xy} p_i^y + \sum_i \theta_i^{xw} \overline{p}_i^w$	(A.3)
Capital price index	$kpi^x = \sum_i \gamma_i^{xx} p_i^x + \sum_i \gamma_i^{xy} p_i^y + \sum_i \gamma_i^{xw} \overline{p}_i^w$	(A.4)
Labour demand	$N_i^x = N_i^x(Q_i^x, p_i^x, pv_i^x, w_n^x)$	(A.5)
Capital demand	$K_i^x = K_i^x(Q_i^x, p_i^x, pv_i^x, w_k^x)$	(A.6)
Capital rental rate	$K_i^x = K_i^{sx}$	(A.7)
Household income	$Y^x = \varphi_n^x N^x w_n^x + \varphi_k^x K^x w_k^x + L^x T^x u^x f$	(A.8)
Commodity demands	$Q_i^x = C_i^x + J_i^x + I_i^x + G_i^x + X_i^{xy} + X_i^{xw}$	(A.9)
Consumption demand	$C_i^x = C_i^x(\underline{p}^x, \underline{p}^y, \overline{\underline{p}}^w, Y^x)$	(A.10)
Intermediate demand	$J_i^x = J_i^x(\underline{Q}^x, \underline{pv}^x, \underline{p}^x, \underline{p}^y, \overline{\underline{p}}^w)$	(A.11)
Investment demand	$I_i^x = I_i^x(\underline{p}^x, \underline{p}^y, \overline{\underline{p}}^w, \sum_j b_{ij}^x \Delta K_j^x)$	(A.12)
Government demand	$G_i^x = \alpha_i^x \overline{G}^N$	(A.13)
Interregional export demand	$X_i^{xy} = X_i^{xy}(\underline{p}^x, \underline{p}^y, \overline{\underline{p}}^w, \overline{G}^N, \underline{J}^y, \underline{Q}^y, Y^y)$	(A.14)
International export demand	$X_i^{xw} = X_i^{xw}(\underline{p}^x, \overline{\underline{p}}^w, \overline{D}^w)$	(A.15)
Capital stock	$K_{i,t}^{sx} = (1-\delta_i^x)K_{i,t-1}^{sx} + \Delta K_{i,t-1}^x$	(A.16)
Desired capital stock	$K_{i,t}^{*sx} = K_{i,t}^{*sx}(Q_i^x, p_i^x, pv_i^x, ucc^x)$	(A.17)
User cost of capital	$ucc^x = ucc^x(kpi^x)$	(A.18)
Investment	$\Delta K_{i,t}^x = \lambda(K_{i,t}^{*sx} - K_{i,t}^{sx}) + \delta_i^x K_{i,t-1}^{sx}$	(A.19)

National population	$\overline{L}^{N} = L^{s} + L^{r}$	(A.20)
Regional population	$L_t^s = L_{t-1}^s + m_{t-1}^s$	(A.21)
Migration	$m_t^s = m^s\left[\frac{w_t^s}{cpi_t^s}, \frac{w_t^r}{cpi_t^r}, u_t^s, u_t^r, L_t^s\right]$	(A.22)
Unemployment rate	$u^x = \frac{L^x T^x - \sum_i N_i^x}{L^x T^x}$	(A.23)
Wage bargaining	$w_n^x = w_n^x(u^x, cpi^x)$	(A.24)
Direct CO2 generation	$P^x = \sum_i [\mu_i^x e_i^x + \rho_i^x Q_i] \quad + \mu_h^x e_h^x$	(A.25)
CO2 CAP measure	$F^x = \boldsymbol{\varepsilon}_{\boldsymbol{W}}^{\boldsymbol{p\omega}}[\boldsymbol{I} - \boldsymbol{A}^{\boldsymbol{x}}]^{-1}\boldsymbol{Z}^{\boldsymbol{x}} + \boldsymbol{\varepsilon}^{\boldsymbol{c}}\boldsymbol{C}^{\boldsymbol{x}}$	(A.26)

Endogenous variables:

cpi : consumer price index
kpi : capital price index
m : Scottish immigration
p : commodity price
pv : value-added price
u : unemployment rate
ucc : user cost of capital
w_n : nominal wage rate
w_k : capital rental rate
C : consumption
D : foreign demand
G : government expenditure
I : investment demand
J : intermediate demand
K : capital demand
K^s : capital supply
ΔK : capital stock adjustment
L : population
N : employment
Q : output
X : exports
Y : household income
Z: combined household and government expenditure on goods and services
e: energy/fuel use (energy purchases)
P: CO2 emissions directly generated
F: CO2 footprint

A: combined use (domestic and imported intermediate inputs) matrix
ε: output/expenditure emissions intensity (post-shock IO accounting)

Parameters and exogenous variables:
b: capital coefficient
f: benefit payment per registered unemployed
D: rest of the world demand
T: participation rate
α: government expenditure coefficient
β: real wage coefficient
δ: depreciation rate
φ: regional share of factor income
θ: consumption expenditure share
γ: capital expenditure share
λ: capital stock adjustment parameter
μ: emissions intensity of fuel use
ρ: non-fuel combustion emissions intensity of output production
I: identity matrix

Subscripts:
i, j: sectors, commodity outputs (there are six of each – see Appendix 1)
k: capital
n: labour
t: time
h: households

Superscripts:
r: rest of the UK
s: Scotland
w: rest of the world
x, y: generic regional identifiers
p: (pollution) generated in production
c: (pollution) generated in final (household) consumption
ω: weighting on pollution intensity to reflect use of commodities produced in other regions (and associated pollution intensities).

Functions:
$m(.)$: migration function
$p(.), pv(.)$: cost function
$ucc(.)$: user cost of capital function
$w(.)$: wage curve
$C(.)$: Armington consumption demand function
I(.): Armington investment demand function
$J(.)$: Armington intermediate demand function
$K(.), N(.)$: factor demand functions
$X(.)$: Armington export demand function

Notes:

- A bar above a variable indicates that this variable is exogenous for the purposes of the simulations) i.e. a bar over a variable denotes exogeneity.
- Underlined variables are vectors whose elements are the sectoral values of the corresponding variables. Where the subscript $j-i$ is used, this represents a vector of all sectoral values, excluding sector i.
- A starred variable indicates desired value.

Implicit time subscripts apply to all the variables; these are stated explicitly only for the relevant updating equations (A. 16, A.19, A.21, A.22).

Tables

Table 1. Impacts of a 5% increase in Scottish labour productivity in Scotland and the rest of the UK (RUK) (% change from base year values)

	Scotland			RUK		
	Base	**SR**	**LR**	**Base**	**SR**	**LR**
GDP (£m)	88,351	2.548%	7.703%	967,744	0.014%	-0.170%
Household Consumption (£m)	54,923	2.769%	3.557%	621,187	0.012%	-0.237%
Aggregate consumption (Households and Government, £m)	79,630	1.910%	2.453%	846,395	0.009%	-0.174%
Investment (£m)	12,949	8.348%	6.776%	174,508	-0.016%	-0.164%
CPI	1	-0.610%	-3.200%	1	-0.020%	-0.240%
Exports to other region (£m)	34,876	1.493%	7.814%	36,480	2.106%	0.094%
Imports from other region (£m)	36,480	2.106%	0.094%	34,876	1.493%	7.814%
Exports to ROW (£m)	15,706	1.675%	7.735%	249,595	-0.013%	0.380%
Imports from ROW (£m)	18,329	2.000%	-0.373%	304,359	0.040%	-0.611%
Real T-H consumption wage (£)	15.81	-0.730%	0.191%	17.39	0.020%	0.166%
Total employment (000s)	2,108	-0.786%	3.254%	21,681	0.017%	-0.211%
Unemployment rate (%)	6.44	11.419%	-1.664%	5.22	-0.301%	-1.462%
Total population (000s)	5,078	0.000%	3.136%	54,756	0.000%	-0.291%
PAP						
Total CO_2 generation (kilo-tonnes)	52,790	2.480%	6.865%	578,294	0.046%	0.000%
CO2/GDP (kilo-tonnes per £1million)	0.598	-0.066%	-0.778%	0.598	0.031%	0.170%
CAP (relaxed DTA)						
Total CO_2 generation (kilo-tonnes)	62,659	3.152%	3.061%	626,180	0.016%	-0.097%
CO2/GDP (kilo-tonnes per £1million)	0.709	0.589%	-4.309%	1	0.002%	0.073%
CO2 embodied in imports from ROW	18,236	2.489%	0.760%	172,164	-0.001%	-0.594%
CO2 embodied in imports of commodities						
1. Energy	10,044	2.609%	2.018%	63,366	-0.062%	-0.779%
2. Extraction, Quarrying, Construction and Water Supply	585	0.928%	1.850%	3,778	0.042%	-1.112%
3. Agriculture & Fishing	575	2.736%	0.727%	4,297	0.083%	-0.710%
4. Manufacturing	2,976	2.711%	-0.712%	62,794	0.049%	-0.394%
5. Retail, Distribution and Transport	3,781	2.397%	-1.323%	33,412	-0.003%	-0.569%
6. Other services	276	-0.271%	-2.862%	4,518	0.078%	-0.435%

Table 2. Increase (kilo-tonnes) in CO2 embodied in imports from ROW to the UK regional and national economies in response to the increase in Scottish labour productivity

	Central case			Government expenditure endogenous		
	Scotland	RUK	UK	Scotland	RUK	UK
CO2 embodied in imports from ROW (kilo-tonnes)	139	-1,024	-885	254	144	398
CO2 embodied in imports of commodities						
1. Energy	203	-494	-291	242	-154	88
2. Extraction, Quarrying, Construction and Water Suppy	11	-42	-31	14	-14	-1
3. Agriculture & Fishing	4	-31	-26	7	4	11
4. Manufacturing	-21	-248	-269	9	204	214
5. Retail, Distribution and Transport	-50	-190	-240	-13	80	68
6. Other services	-8	-20	-28	-5	23	18

Table 3. Impacts of a 5% increase in Scottish labour productivity in Scotland and the rest of the UK (RUK) with endogenous government expenditure (% change from base year values)

	Scotland			RUK		
	Base	**SR**	**LR**	**Base**	**SR**	**LR**
GDP (£m)	88,351	2.541%	7.901%	967,744	0.012%	0.000%
Household Consumption (£m)	54,923	2.774%	3.434%	621,187	0.005%	-0.210%
Government Expenditure (£m)	24,708	-0.124%	2.305%	225,208	-0.124%	2.305%
Aggregate consumption (Households and Government, £m)	79,630	1.875%	3.084%	846,395	-0.030%	0.459%
Investment (£m)	12,949	8.293%	7.026%	174,508	-0.067%	0.128%
CPI	1	-0.650%	-2.770%	1	-0.050%	0.160%
Exports to other region (£m)	34,876	1.495%	7.701%	36,480	2.091%	0.146%
Imports from other region (£m)	36,480	2.091%	0.146%	34,876	1.495%	7.701%
Exports to ROW (£m)	15,706	1.730%	6.787%	249,595	0.056%	-0.419%
Imports from ROW (£m)	18,329	1.919%	0.453%	304,359	-0.033%	0.141%
Real T-H consumption wage (£)	15.81	-0.739%	0.430%	17.39	0.013%	0.406%
Total employment (000s)	2,108	-0.795%	3.392%	21,681	0.011%	-0.097%
Unemployment rate (%)	6.44	11.553%	-3.714%	5.22	-0.203%	-3.525%
Total population (000s)	5,078	0.000%	3.128%	54,756	0.000%	-0.290%
PAP						
Total CO_2 generation (kilo-tonnes)	52,790	2.488%	6.641%	578,294	0.045%	-0.074%
CO2/GDP (kilo-tonnes per £1million)	0.598	-0.052%	-1.168%	0.598	0.033%	-0.074%
CAP (relaxed DTA)						
Total CO_2 generation (kilo-tonnes)	62,659	3.127%	3.236%	626,180	-0.015%	0.179%
CO2/GDP (kilo-tonnes per £1million)	0.709	0.571%	-4.323%	1	-0.027%	0.179%
CO2 embodied in imports from ROW	18,236	2.407%	1.395%	172,164	-0.082%	0.083%
CO2 embodied in imports of commodities						
1. Energy	10,044	2.543%	2.406%	63,366	-0.136%	-0.243%
2. Extraction, Quarrying, Construction and Water Supply	585	0.812%	2.324%	3,778	-0.035%	-0.382%
3. Agriculture & Fishing	575	2.669%	1.237%	4,297	0.006%	0.099%
4. Manufacturing	2,976	2.603%	0.313%	62,794	-0.038%	0.325%
5. Retail, Distribution and Transport	3,781	2.305%	-0.338%	33,412	-0.088%	0.240%
6. Other services	276	-0.441%	-1.642%	4,518	-0.029%	0.509%

FIGURES

Figure 1. Impacts of a 5% increase in Scottish labour productivity on Scottish production sector output levels (time periods/years 1-50)

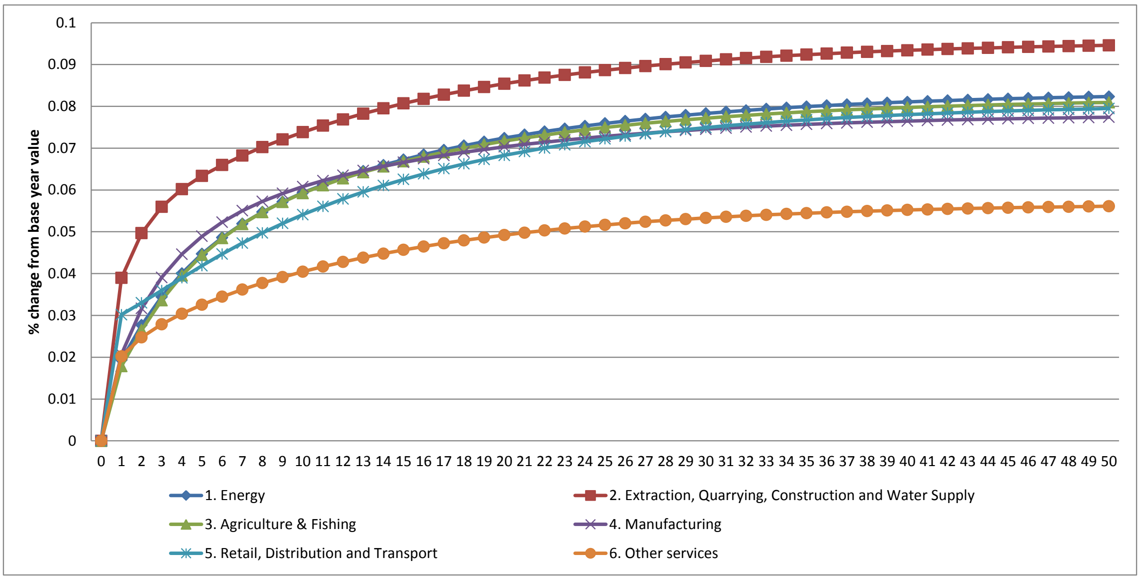

Figure 2. Impacts of a 5% increase in Scottish labour productivity on RUK production sector output levels (time periods/years 1-50)