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Impacts of Regional Productivity Growth, Decoupling and Pollution Leakage



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Making a difference to policy outcomes locally, nationally and globally

OCCASIONAL PAPER

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Abstract

This IPPI Occasional Paper examines the issues of decoupling regional economic growth and pollution and the extent to which pollution effects spill-over regional and national borders. Specifically, a UK, regionally-disaggregated, computable general equilibrium (CGE) model is used to investigate the relationship between economic growth and the level of CO₂ emissions posited by the 'Environmental Kuznets Curve' (EKC) conjecture. The simulation results suggest that at the regional level the existence of an EKC relationship depends on the source of regional growth and how the EKC relationship is specified.

Keywords: regional CGE models; labour productivity; regional economic growth; Environmental Kuznets Curve; embedded pollution; carbon footprints

JEL codes: D57, O18, O44, Q56

1. Introduction

Labour productivity improvement is widely recognised as a key driver of economic growth (World Bank, 2011). Its contribution has been measured in numerous growth accounting studies, most recently by Jorgenson and Vu (2010), for the G7 and other major industrial economies and regions, and has been reflected in both international and national policy targets (see the Millennium Development Goals adopted by the United Nations in 2000 and HM Treasury, 2000, for the UK). Improving productivity has been a central concern for the European Union with the most recent policy initiative being to attempt to stimulate regional growth through Smart Specialisation (Davies *et al.*, 2013).

In the UK, many sustainable development responsibilities and environmental policy functions have been devolved to the regional governments. In this respect, the Scottish Government has adopted a particularly strong environmental stance, setting targets to reduce Greenhouse Gas (GHG) emissions by 42% by 2020 and 80% by 2050, relative to the 1990 level (Climate Change (Scotland) Act, 2009). However, a region's environmental targets might be compromised by its commitment to economic growth. Again, the Scottish Government has set a target to match the growth rate of the small independent EU countries and to improve

Scottish labour productivity so that it is in the top quartile of key trading partners in the OECD by 2017 (Scottish Government, 2011a). Nevertheless, these economic and environmental aims are seen as compatible through sustainable economic growth, with a focus on the transition to becoming a 'low carbon economy' (Scottish Government, 2011a).

In the literature, labour and capital productivity improvements have also been identified as important mechanisms for decoupling economic growth from increased pollution. This is one possible reason for suggesting the existence of an Environmental Kuznets Curve (EKC) (Jaffe *et al.*, 2003), the posited inverted-U-shaped relationship between total or *per capita* emissions and GDP.¹ However, even if the economy appears to follow an EKC, there is concern over potential pollution leakage. This is where environmental targets in one jurisdiction might be met not by reducing pollution in total but rather by shifting the pollution generation elsewhere (Babiker, 2005; Böhringer and Löschel, 2006; Löschel and Otto, 2009; Elliot *et al.*, 2010).

This paper investigates how economic growth driven by technological progress in one region, in this case Scotland, impacts on neighbouring regions (the rest of the UK). The spread and backwash effects identified in the regional economics literature will generate both economic and environmental interactions (Brakman *et al.* 2009; Myrdal, 1957). We proceed by introducing a step Harrod-neutral (labour-augmenting) technological improvement across all Scottish production sectors. The subsequent economic and environmental effects are then simulated using a two-region (Scotland-rest of the UK) Computable General Equilibrium model. The simulation reports changes in a range of economic variables and also CO₂ emissions for both Scotland and the rest of the UK (RUK).² CO₂ emissions are measured in absolute and *per capita* terms using both production and consumption accounting principles, labelled as PAP and CAP respectively.³

Current international agreements, such as the Kyoto Protocol and Copenhagen Accord, along with the recent UNFCCC COP20/CMP10 meeting in Lima in advance of Paris 2015, use the

¹ Of course other factors are likely to play a part in any EKC relationship. For example, as incomes increase consumers' tastes might change so as to continuously substitute away from emissions-intensive goods or services. Similarly, the determinants of consumers' willingness to pay for green products differ by demographic composition. This paper does not take these sorts of effects into account but focuses purely on the impact of labour productivity improvement and interregional migration on the regional economy and emissions.

² We focus on both domestic carbon dioxide (CO₂) emissions and emissions embodied in imports to support domestic consumption for the environmental impact. CO₂ emissions account for up to around 77 per cent of Scotland Green House Gas (GHG) emissions in 2011. Scotland has targets and reporting responsibilities that cover emissions from both production and consumption.

³ The term Production Accounting Principle (PAP) is something of a misnomer as it includes all emissions produced in the territorial area, including those generated in consumption. The territorial accounting principle would seem to be a better title.

production (or territorial) approach in accounting for domestic emissions. The PAP measure identifies all the CO₂ generated directly in production and consumption within a given territory. On the other hand, the CAP approach quantifies the CO₂ emissions embodied in the public and private consumption in a particular territory, independently of where these emissions occur. The consumption approach is the most rigorous way to capture the economy's carbon footprint and allows us to control for pollution leakage between the UK regions and from the UK regions to the rest of the world (ROW).

At the UK level, the Departments for Energy and Climate Change (DECC) and Environment, Food and Rural Affairs (DEFRA) have regularly engaged in, and provided advice on, carbon footprint accounting for individuals, businesses, local authorities, government departments and the UK as a whole (for a recent example, see DEFRA, 2012). In April 2012, the House of Commons Energy and Climate Change Committee (2012) reported on its consultation on 'Consumption-based Emissions Reporting', with the core recommendation that consumption-based measures should be incorporated into the policy process. Scottish Government (Scottish Government, 2011b) has explicitly identified the goal of lowering the Scottish greenhouse gas and carbon footprints in its emissions reduction strategy. Input-output accounting and modelling approaches are commonly applied in comparative CAP and PAP analyses (see Wiedmann 2009 for a recent review). One novel contribution of the present work is the use of a more flexible CGE modelling framework (which incorporates a set of Input-Output IO accounts as its core database) to calculate the changes in the carbon footprint of the Scottish and RUK economies.

The remainder of the paper is structured as follows. Section 2 briefly reviews the existing literature on economic growth and pollution leakage. Section 3 introduces the interregional CGE model of Scotland and RUK. This model is used for the 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 given 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 (Arrow *et al.*, 1995; Antweiler *et al.*, 2001). The main focus in the pollution leakage literature has been to examine how actions to reduce domestic pollution generation, particularly in industrialised economies, may lead to increased pollution leakage and global emissions. For example, measures such as pollution taxes in one particular country might result in increased emissions in other countries through changing

incentives for the location of dirty industries when products and factors of production are mobile across international borders (Sheldon, 2006).

There is a literature on the relationship between economic growth and pollution leakage. The most basic argument is that within a particular economy, growth involving structural change away from manufacturing might lead to a fall in domestic emissions. However, these structural changes might involve import substitution, so that the continued and increased consumption of pollution-intensive products could drive increased pollution in the countries from which they are imported (Bruvoll and Faehn, 2006). However, this depends on the source of growth and development.

A number of methods have been employed to produce empirical evidence of pollution leakage. Using both historical data and CGE modelling, Faehn and Bruvoll (2009) find that economic growth was not associated with leakage impacts in the form of net imports of “dirty” goods. On the other hand, in a study using a global CGE model, the same authors found that the impact of a domestic carbon tax has partly offsetting impacts on third country emissions (Bruvoll and Faehn 2006). Elliot *et al.* (2010) also adopt a CGE approach to examine various scenarios involving taxing carbon emissions and find that border tax adjustments are required to eliminate pollution leakage as a result of Annex B Kyoto countries substituting imports from developing countries for domestic emissions. Further, Babiker (2005) uses a CGE approach to analyse carbon caps rather than carbon taxes. This work considered 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.

CGE studies have mainly taken a production accounting approach to measuring pollution, with the above-mentioned works adopting varying treatments of the pollution content of imports. As reflected in the review by Wiedmann (2009), full consumption-based accounting of carbon emissions is a more common development in the input-output literature. For example, Peters and Hertwich (2006) use IO modelling to measure the pollution content of imports to Norway. They found that CO₂ embodied in imports equated to more than 50% of domestic PAP emissions, and that consumption of these imports had led to significant implied carbon emissions in developing countries. They conclude that national emissions inventories should be based on domestic consumption rather than production. A similar analysis for Italy was presented by Mongelli *et al.* (2006). Ghertner and Fripp (2007) use life-cycle analysis to calculate the “global warming potential” implicit in US consumption. They find that, once one allows for the carbon-equivalent emissions contained in imports, there is no turning point in the relationship between GDP *per capita* and absolute emissions levels. That is to say, they detect no evidence of an EKC once a consumption accounting principle is adopted. (It is not

clear whether there was evidence of one under PAP). Moreover, some recent studies explore the use of weights to develop a hybrid model comprising the both PAP and CAP emissions (Peters, 2008). Further, Andrew and Forgie (2008) attempted to split out the territorial GHG emissions into two parts; one the responsibility of consumers and the other the responsibility of producers.

Turner and Hanley (2011) questioned the definition of the EKC as a relationship between absolute pollution levels and per capita GDP. This issue is important where population change is a key element of the growth story; it is quite feasible for per capita GDP to rise whilst population falls. Therefore in this paper we express the EKC conjecture as an inverted U shaped relationship between *per capita* pollution and *per capita* GDP. That is to say, that at high levels of GDP per head the conjecture predicts a fall in pollution per head. In this paper, the territorial unit is the region and the target pollutant is CO₂ emissions, which we measure using both the PAP and CAP conventions.

Looking across the various modelling approaches, a number of conditions generally emerge as important for determining the degree of pollution leakage. These 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 treated regional economy and its regional trading partner. The modelling approach in this paper can also measure pollution leakage using a full consumption accounting measures of carbon emissions (or carbon footprints), CAP, which can then be compared with the more commonly considered production (or territorial) accounting measure, PAP. However, this paper is differentiated by focusing on the technological progress argument underlying the EKC hypothesis.

3. The AMOSRUK 2-region CGE modelling framework

AMOSRUK is a CGE model of the UK economy with two endogenous regions, Scotland and RUK, and one exogenous region (ROW). It is calibrated on a 6-sector interregional Social Accounting Matrix (SAM) for 2004, which provides a 'snapshot' of the Scottish and RUK economies and related CO₂ emissions generation for that year.⁴ The six sectors/commodities

⁴ 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?vlink=3026>). Interregional trade data, unpublished at the time, were provided by the Scottish Government as were Scottish environmental accounting data which are considered most reliable at the 6-sector level as used 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).

model are detailed in Table 1.⁵ A condensed listing of the AMOSRUK modelling framework used here is provided in a previous working paper.⁶ Harrigan *et al.* (1991) gives a full description of the initial AMOS framework, and Turner *et al.* (2012) provides an application of an early economic-environmental version of the AMOSRUK model. Greenway *et al.* (1993), Partridge and Rickman (2010) and Bergman (2005) reviewed general, regional and environmental CGE modelling frameworks respectively. This section summarises the main features of the interregional CGE model relevant to the scenarios reported in this paper.

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 supply	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

Table 1: The sectoral disaggregation with the corresponding UK IO (UK IOC) and Standard Industrial (SIC) classification codes

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.⁷ Both interregional and international exports are price sensitive. However, while non-price determinants of exports to ROW 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 the elements of intermediate and final demand in the other region.

⁵ The reliability of the available Scottish environmental accounting data limit the sectoral breakdown to six sectors. The problem is that the results from allocating emissions at a higher level across the 128 sectors of the Scottish input-output tables are inexplicably out of line with UK sectoral estimates. The Scottish Government is therefore concerned about their reliability, though these data have now released the data for public scrutiny (see <http://www.scotland.gov.uk/Topics/Statistics/Browse/Economy/SNAP/expstats/EnvironmentalAccounts>).

⁶ See pp.29-32 of the document at <http://www.management.stir.ac.uk/documents/SEDP-2011-13-Turner-Hanley-Cui.pdf>.

⁷ In the earlier working version of this paper we subject our results to sensitivity analyses where we relax this assumption – see pp. 20-22 of the document at <http://www.management.stir.ac.uk/documents/SEDP-2011-13-Turner-Hanley-Cui.pdf>.

In production, a local composite of intermediate inputs is combined with a composite of imports from the other region and ROW via an Armington link (Armington, 1969). This means that domestic products and imported goods are treated as imperfect substitutes, with the degree of substitutability determined exogenously. However, while the commodity composition of Scottish and RUK intermediates to each sector varies with local prices, the main assumption is that the commodity composition of ROW imports to each sector and to final consumption is fixed.⁸

In the current application, all Armington import elasticities are set 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 (constant elasticity of substitution), Cobb-Douglas or Leontief. The simulations in this paper use CES production functions at the value-added level, where the elasticity of substitution equals a mid-range value of 0.5. This figure is informed by literature review where substitutability between labour and capital takes a range of values less than 1. At the gross-output level, the elasticity takes the value of 0.3, informed by Harris (1989) with some sensitivity noted. Leontief productions functions are adopted at the intermediate-inputs level in each region.

The capital stock in each region is determined by sector-specific investment where in each period investment demand from each sector is a proportion of the difference between actual and desired capital stock. The desired capital stock is itself a function of commodity output, the nominal wage and the user cost of capital.⁹ Thus, in response to a shock investment acts over time to re-adjust capital stocks to their new optimal values.

The labour force also updates following an exogenous shock. In the current application we assume that there is no natural population increase and no international migration. However, the regional labour forces adjust through inter-regional migration between Scotland and RUK in response to changes in the regional real-wage and unemployment differentials. This flow equilibrium migration function is based on an extension of the Harris and Todaro (1970) model and is commonly used in US interregional migration studies. The parameterisation used here is based on regional work for the UK reported in Layard *et al.* (1991).

In each period, within each region and real wages are determined via a wage curve and labour can move freely between sectors. The wage curve reflects the workers' bargaining

⁸ Future research will introduce commodity level substitution between local and imported goods and services.

⁹ The speed of adjustment parameter is the proportion of the gap between a regional industry's actual and desired capital stock that is filled between any two periods. This takes the value 0.5 in this paper.

power in the form of a negative relationship with the regional unemployment rate (Blanchflower and Oswald, 1994) and is parameterised based on work by Layard *et al.* (1991).¹⁰

Direct CO₂ emissions generation in each production sector and in household consumption in the two endogenous regions are related to energy use where appropriate and otherwise to output or total final expenditure. For the CAP measure, emissions embodied in imports from ROW to each region are determined using a dataset provided by the OECD (see Turner *et al.*, 2011) and are adjusted to reflect total emissions (kilo-tonnes) per £1 million of imports to each production sector and household final consumption 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 (Turner *et al.*, 2012).

4. Simulation strategy

A Harrod-Neutral (labour augmenting) step increase in the efficiency of value added production is introduced in all Scottish production sectors. At the outset, both the Scotland and RUK regional economies are assumed to be in long-run equilibrium and the shock is introduced in period 1. Both economies adjust to a new long-run equilibrium through a series of temporary equilibria, each of which is interpreted as one year.¹¹ While period-by-period results are presented, the focus is primarily on two conceptual time periods. The first is the short run (SR), which is the period immediately after the introduction of the efficiency improvement. In this period capital stocks are fixed, both to the region and to the specific industry. The second is the long run (LR) where labour and capital stocks are fully adjusted, both across regions and sectors in response to the shock.

Given that we simulate the impact of a single exogenous shock, all changes reported are attributable entirely and solely to the direct, indirect and induced effects of that shock. That is to say, in the absence of an external shock the model continuously recreates the base year data, period by period. The results are reported either as percentage or absolute changes from the base year (2004) equilibrium values depending on pedagogic considerations. The CO₂ emissions are calculated under PAP and CAP conventions 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 (see Turner *et al.*, 2012).

¹⁰ The size of the coefficient in the wage curve has been confirmed in subsequent studies. See, for example, BLANCHFLOWER and OSWALD (2005) and GALVEZ (2014)

¹¹ This is because the data on which the model is based is annual and the adjustment rates are informed by econometric work on annual data.

5. Economic simulation results

5.1 Impacts in the host economy (Scotland)

A Harrod-neutral efficiency improvement increases the productivity of labour. This triggers a number of general equilibrium effects in the treated region, which in this case is Scotland. These changes are shown in Table 2 and Figures 1 and 2. Table 2 gives the short and long-run percentage changes in key aggregate economic variables for Scotland, the rest of the UK and the UK as a whole. Figure 1 shows the evolution of Scottish GDP, population, GDP *per capita* and the real take-home wage subsequent to the efficiency shock. Figure 2 gives a similar evolution of the percentage change in Scottish sectoral outputs.

Begin by considering the changes in employment and GDP. The direct efficiency impact, in itself, acts to reduce the demand for labour. That is to say, with no change in other inputs, a 5% increase in labour efficiency implies that 5% less labour is required to produce a given level of output. However, an increase in labour productivity simultaneously reduces the price of labour, measured in efficiency units. This has two important effects. First, it reduces the cost, and therefore increases competitiveness, of Scottish products, thereby stimulating exports and import substitution. Second, it leads to the substitution of labour, measured in efficiency units, for capital in the production of value added, and indirectly the substitution of value added for intermediate inputs in the production of output. Both of these effects stimulate the demand for labour.

Given the improvement in competitiveness, GDP is expected to increase. However, the impact on employment is less clear cut. Only if the increase in labour demand generated by the combined competitiveness and substitution effects is bigger than the decrease caused by the direct efficiency effect, will the demand for labour rise. Such an increase in the demand for labour would then generate a short-run increase in the real wage, and a fall in the unemployment rate, producing net in-migration, which further stimulates employment and economic activity through placing subsequent downward pressure on wage rates. As the economy expands, with the short-run supply constraints relaxed through in-migration of labour and investment in capital stock, the labour incomes received by households will rise. This further increases household consumption demand in all sectors of the economy.¹²

¹² A more detailed analytical treatment of an increase in labour efficiency in a single open-region context is given in Hermannsson et al. (2014).

	Base	SR	LR	Base	SR	LR	Base	SR	LR
GDP (£m)	88,351	3.18%	7.76%	967,744	0.02%	-0.20%	1,056,095	0.29%	0.47%
Household Consumption (£m)	54,923	0.88%	3.76%	621,187	0.01%	-0.27%	676,109	0.08%	0.06%
Aggregate consumption (Households and Government, £m)	79,630	0.61%	2.59%	846,395	0.01%	-0.19%	926,025	0.06%	0.04%
Investment (£m)	12,949	8.57%	6.11%	174,508	-0.05%	-0.17%	187,457	0.54%	0.27%
CPI	1.000	-1.43%	-3.21%	1.000	-0.13%	-0.22%			
Exports to other region (£m)	34,876	3.02%	7.85%	36,480	0.66%	0.07%			
Imports from other region (£m)	36,480	0.66%	0.07%	34,876	3.02%	7.85%			
Exports to ROW (£m)	15,706	2.96%	7.77%	249,595	0.20%	0.36%	265,301	0.36%	0.79%
Imports from ROW (£m)	18,329	0.31%	-0.37%	304,359	-0.19%	-0.61%	322,688	-0.16%	-0.60%
Real T-H consumption wage (£)	15.814	0.11%	0.19%	17.392	0.02%	0.17%			
Total employment (000s)	2,108	0.11%	3.71%	21,681	0.02%	-0.25%	23,789	0.03%	0.10%
Unemployment rate (%)	6.437	-1.63%	-1.63%	5.220	-0.35%	-1.53%			
Total population (000s)	5,078	0.00%	3.59%	54,756	0.00%	-0.33%	59,834	0.00%	0.00%
PAP CO ₂ emissions (absolute, tonnes)	52,790,125	54,089,453	56,463,815	578,294,304	578,645,275	578,153,272	631,084,429	632,734,728	634,617,087
PAP CO ₂ emissions (%change)	52,790,125	2.46%	6.96%	578,294,304	0.06%	-0.02%	631,084,429	0.26%	0.56%
CAP CO ₂ emissions (absolute, tonnes)	62,659,082	63,562,078	64,623,123	626,179,641	626,301,249	626,425,653	688,838,723	689,863,327	691,048,776
CAP CO ₂ emissions (%change)	62,659,082	1.44%	3.13%	626,179,641	0.019%	0.04%	688,838,723	0.15%	0.32%

Table 2: Impacts of a 5% increase in Scottish labour productivity on Scottish and rest of the UK (RUK) key economic and headline CO₂ variables (% change from base year values)

This complex pattern of effects underlies the results reported in the first three columns of Table 2. The first column shows the base year (2004) Scottish values, whilst columns 2 and 3 give the short- and long-run proportionate impacts on key economic variables in Scotland in response to the 5% step increase in Scottish labour efficiency. Recall that the short run is the first period after the shock is introduced. There is a very small, 0.11%, increase in employment, with the positive competitiveness, substitution, income and multiplier impacts entirely offsetting the drop in employment that would be generated by a pure efficiency effect.

Nonetheless, the economic expansion is limited in the short run by constraints on capital stock and labour supply. As these constraints are relaxed, through investment and migration, the economy expands with a further net increase in labour demand. The long-run increase in Scottish employment is 3.71%. The rise in the real wage and the fall in unemployment rate is the short-run trigger for immigration from RUK to Scotland. This continues until the initial differentials in the Scottish wage and unemployment rates, relative to their UK counterparts, are restored in long-run equilibrium. As shown in Figure 1, the real wage increases up to period 5 when it is 0.77% higher than its base-year value. However, it subsequently moves back towards its original value, with the long run increases of only 0.19%.

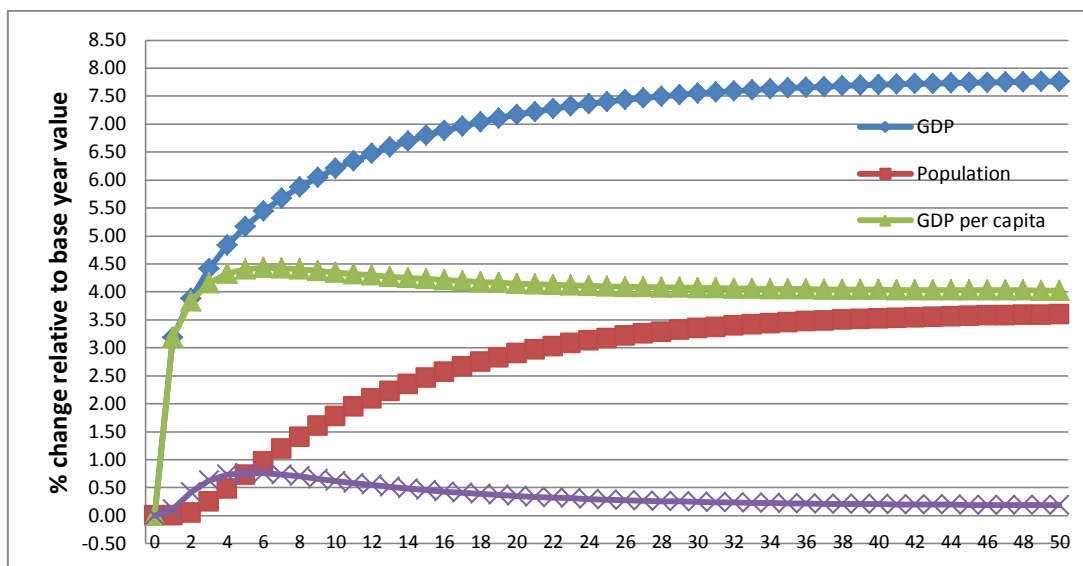


Figure 1. Impact of a 5% increase in Scottish labour productivity on key Scottish economic and demographic variables (time periods/ years 1-50).

As can be seen from Figure 1, Scottish GDP increases monotonically over time, as the economy adjusts to the efficiency increase, with a long-run rise of 7.76% over the base-year value. As a metric, this would correspond to between 3 and 4 year of average growth in the decade from 1997 (that is, before the onset of the financial crash). This growth in economic

activity is ultimately driven by the rise in competitiveness generated by the efficiency increase; the Scottish price level, reflected in the CPI, falls by 1.43% in the short run and by 3.21% over the long run.

This stimulates Scottish exports to both RUK and ROW which increase by around 3% in the short run and just below 8% in the long run. In the short run, imports from the RUK and ROW are both higher than their base year values by 0.66% and 0.31% respectively. This reflects the increase in Scottish GDP and the short-run capacity constraints. However, in the long run RUK imports to Scotland are only 0.07% above, and ROW imports have fallen below, their base year values as a result of import substitution. The stimulus to the Scottish exports generates subsequent positive impacts on consumption, investment and intermediate demand. However, note also from Figure 1 that the expansion in population through migration slows the growth in GDP *per capita* which peaks in period 5 at a value of 4.41%, but whose long-run increase is 4.17%.

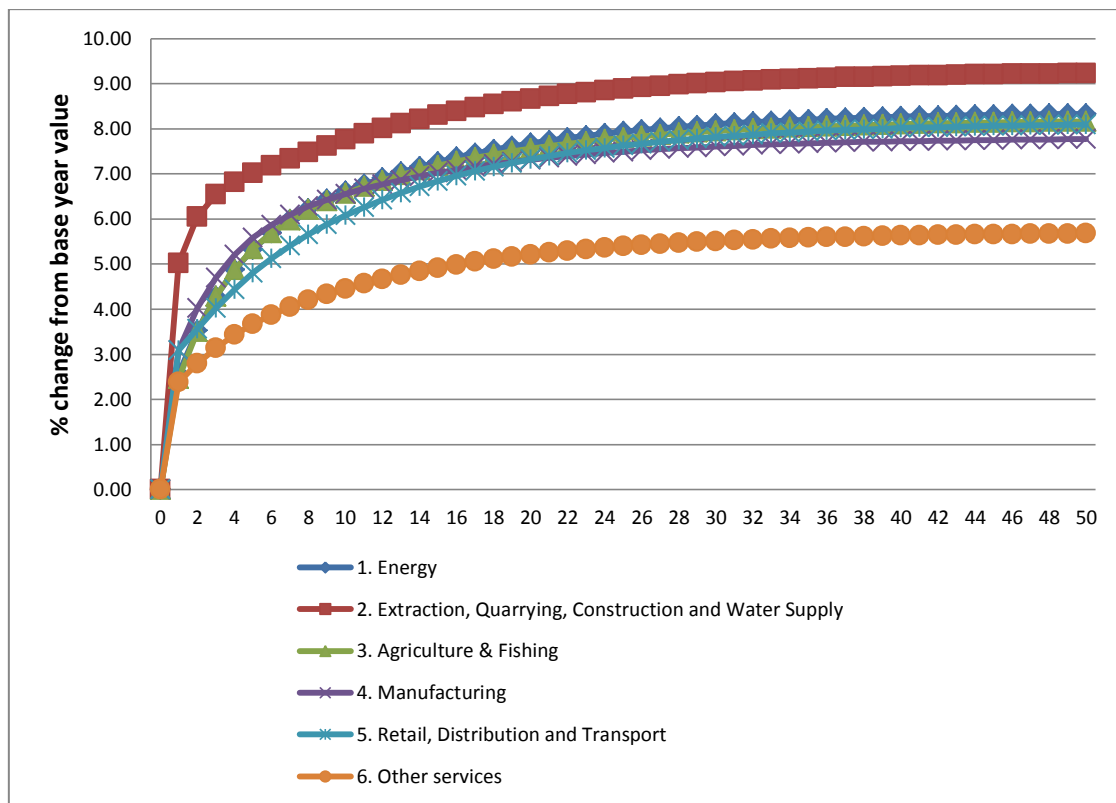


Figure 2. Impact of a 5% increase in Scottish labour productivity on Scottish output, disaggregated by sector (time periods/years 1-50).

Figure 2 shows that the stimulus to economic activity has a positive and continuing impact on the output in all production sectors. In the long run, the increase in output in individual

industries lies between 5.67% in “Other services” and 9.22% in “Quarrying, construction and water supply”. The long-run output change depends partly on the sector’s exposure to the efficiency improvement through their labour intensity, but is also strongly affected by the sector’s export intensity and the strength of local demand effects. “Other services” sells primarily to domestic consumption, which increases by a relatively small amount. However, “Quarrying, construction and water supply” are more closely linked to investment demand domestically and also include exports to the off shore oil sector.

5.2 Impacts in the neighbouring region (RUK)

The analysis in Section 5.1 focuses on the impacts of productivity growth on economic activity in the treated region (Scotland). However, neighbouring regions will be affected by spread and backwash effects resulting from the productivity shock in Scotland. In this paper, these economic spill-over effects are modelled in a second region, RUK, which is linked with Scotland not only through trade in goods and services but also through labour migration. The results are shown in Table 2 (above) and in Figures 3 and 4.

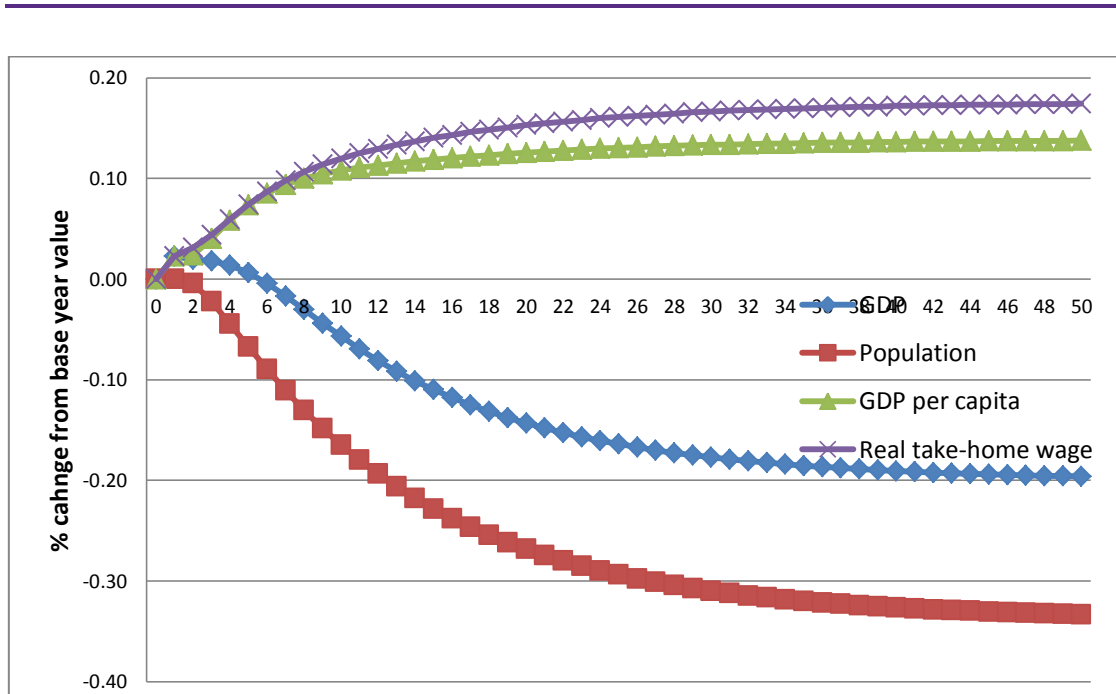


Figure 3. Impact of a 5% increase in Scottish labour productivity on key RUK economic and demographic variables (time periods/ years 1-50).

The impact on the RUK economy is a combination of four effects. The first is that aggregate output and income is rising in Scotland, an important export market for RUK products. The second is that the reduction in the price of Scottish imports increases the competitiveness of

RUK commodities in ROW markets by lowering the price of intermediate inputs and the nominal wage. The third is that, despite the reduction in RUK prices, RUK products lose competitiveness relative to Scottish commodities and this adversely affects exports to Scotland. Finally, the real wage will initially rise, and the unemployment rate fall, in Scotland relative to the RUK value. As was observed in Section 5.1, this leads to the emigration from the RUK to Scotland which increases the real wage, and therefore puts downward pressure on competitiveness in RUK. The overall impact in RUK depends on the relative strength of these effects which change as the economy adjusts to the efficiency shock.

Again, we start with aggregate RUK economic activity, as represented by total employment and GDP. Whilst in the short run both increase (by 0.02%), in the long run they both fall; GDP by 0.20% and employment by 0.25%. Figure 3 shows the evolution of GDP over the adjustment period. This indicates that GDP falls in all periods after period 1, with its value lower than the initial base-year level by period 6. Figure 3 shows that RUK population falls, through emigration, from the start. Moreover, population declines more rapid than GDP. This implies that even when RUK GDP is falling, RUK GDP per head is increasing here, monotonically. In the long run population falls by 0.33% so that GDP per head has risen by $(0.33 - 0.20)$, which is 0.13%.

Table 2 (above) reveals that there is an initial increase in RUK exports to, and a fall in imports from, ROW of 0.20% and 0.19% respectively. There is also a rise in exports to Scotland of 0.66%, but also a larger rise in imports from Scotland of 3.02%. As reported earlier, in the short run this generates an increase in RUK economic activity. In the long run, RUK CPI continues to fall, by 0.22%. However, the 3.21% CPI decline in Scotland is much greater. This means that whilst in the long run RUK gains competitiveness with ROW, it loses competitiveness with Scotland. In the long run, RUK exports to ROW are therefore further increased, by 0.36%, and imports from ROW are reduced, registering a 0.61% decline. However, these sorts of result are not replicated in RUK trade with Scotland where in the long run exports rise by only 0.07% whilst RUK imports from Scotland increase by 7.85%.

The long-run net negative trade stimulus produces the fall in RUK economic activity and is accompanied by a contraction in other macroeconomic variables: household consumption declines by 0.27%, investment by 0.17% and employment by 0.25%. However, the UK overall labour supply constraint is evident through an increased real wage rate and a reduced unemployment rate that reflects the 0.33% decrease in RUK population over the long run.

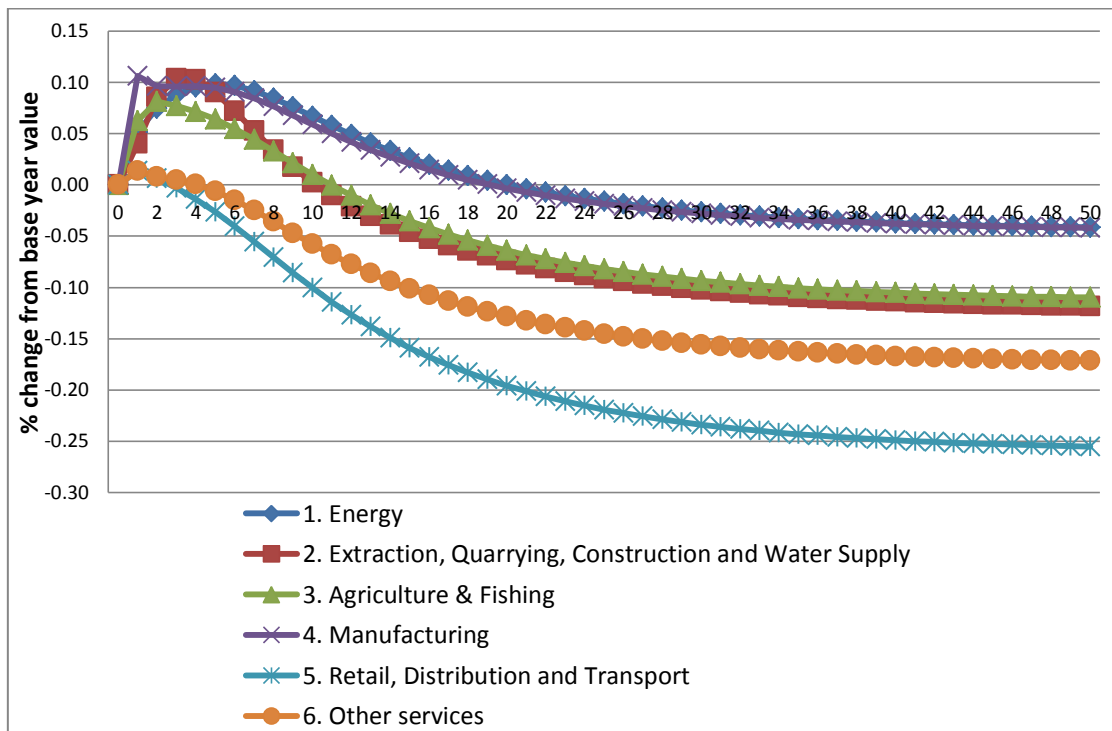


Figure 4. Impact of a 5% increase in Scottish labour productivity on RUK output, disaggregated by sector (time periods/years 1-50).

Figure 4 shows the evolution of output for all the RUK sectors. The output in all industries increases in the short run, but over time their outputs fall to below their initial levels. The production in those sectors most closely linked to domestic consumption, that is to say “Retail, distribution and transport” and “Other services”, begins to decline first and their long-run reduction is the greatest. This mirrors the long-run 0.27% decline in household consumption. The two intermediate sectors are “Agriculture and fishing” and “Extraction, quarrying and water supply”. In both these sectors, production falls below the initial value in period 11 and their long-run output reduction is just above 0.11%. In the final two sectors, “Energy” and “Manufacturing”, RUK output is above the initial value up until period 20 and their long run decline is less than 0.04%.

For the RUK economy, the impact of the stimulus to labour productivity in Scotland is ambivalent. In terms of the aggregate economic activity, there are negative backwash effects: total GDP and employment both fall. However, when measured by changes in productivity per head and real wage, the impact is positive. Further, the impact on different sectors of the economy is more varied. Those sectors directly or indirectly linked to ROW exports are affected in a quite different way to those linked more closely to domestic public or private consumption.

6. CO₂ simulation results

The economic impacts of the improvements in Scottish labour efficiency have associated environmental effects. This study is particularly interested in the changes in CO₂ production and use. As measured by GDP per head, there is economic growth in both Scotland and the RUK. This research is wishing to test the Environmental Kuznets Curve conjecture that such growth can be accompanied by reductions in per capita CO₂ levels.

6.1 The CO₂ simulation results for Scotland

Figure 5 shows the percentage change in Scottish CO₂ emissions using both production (territorial) and consumption, PAP and CAP, accounting methods. Under the PAP measure (emissions produced within the region in question) Scottish CO₂ emissions steadily increase from the outset: in the short run there is a 2.5% increase over the base period value and in the long run this rises to just less than 7%. The use of all inputs increases, as does the associated CO₂ generation, in each of the Scottish production sectors (largely driven by increased energy use). Direct emissions in the household sector, where consumption increases by 0.88% in the short run and 3.76% in the long run, also rise. However, the growth in PAP emissions in Figure 5 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.

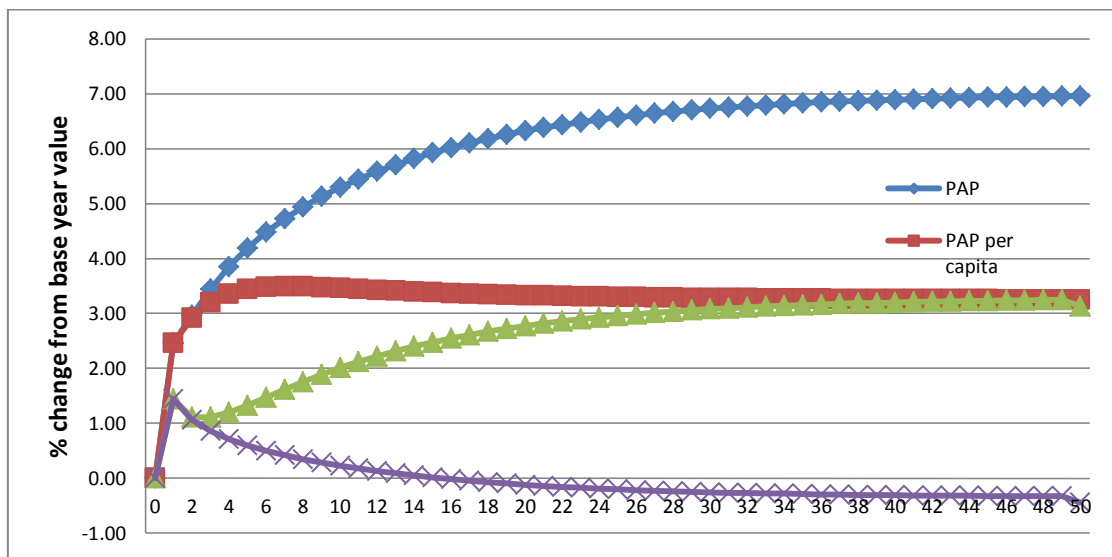


Figure 5. Impact of a 5% increase in Scottish labour productivity on Scottish CO₂ emissions levels (time periods/years 1-50).

Compare the Scottish GDP and PAP CO₂ figures given in Figures 1 and 5 respectively. Such a comparison shows that from the initiation of the productivity shock, Scottish GDP grows faster than CO₂ generation. This means that the CO₂ intensity of Scottish GDP falls. However, as is indicated in Figure 5, the generation of CO₂ within Scottish territorial boundaries, as given by the PAP measure, is growing more rapidly than the Scottish population. Therefore CO₂ emissions per head, using the PAP approach, increase.

On the other hand, Scottish CAP emissions (which include some emissions produced in RUK and ROW) are driven by Scottish consumption rather than production. Figure 5 shows that whilst total CAP emissions still rise by 1.44% in the short run and 3.13% in the long run, these are significantly smaller than the increases in the PAP emissions. Moreover, the proportionate increase in population begins to outstrip the proportionate growth in CAP emissions around period 14 or 15 so that CAP emissions *per capita* begin to fall below their base year value.

Note that the short-run increase in Scottish CAP CO₂ emissions is greater than the increase in aggregate Scottish household and government consumption, as reported in Table 2. It is pulled up by the larger rise 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 (measured here using the OECD data described in Turner *et al.*, 2011). 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 results in Table 3.

	Scotland	RUK	UK
CO ₂ embodied in imports from ROW (tonnes)	144,715	-1,041,055	-896,340
CO ₂ embodied in imports of commodities			
1. Energy	205,485	-504,848	-299,362
2. Extraction, quarrying, construction and water supply	11,333	-42,763	-31,430
3. Agriculture & fishing	4,231	-30,749	-26,517
4. Manufacturing	-21,799	-250,721	-272,520
5. Retail, distribution and transport	-50,035	-192,139	-242,174
6. Other services	-7,894	-19,835	-27,729

Table 3. Long-run change (tonnes) in CO₂ embodied in imports from ROW to the UK regional and national economies in response to the increase in Scottish labour productivity.

As noted earlier in Section 5, the easing of the short-run supply constraints leads to a fall in ROW and a very small rise in RUK imports to Scotland, compared to their base year levels. Nevertheless, as shown in Table 3, there is a net increase of 0.8% or 144.7 kilo-tonnes tonnes in CO₂ embodied in ROW imports to Scotland over the long run caused by the change in their sectoral composition. Whilst long-run Scottish imports from ROW are falling for “Manufacturing”, “Retail distribution and transport” and “Other service”, they are rising in the other three sectors and in particular in the CO₂ intensive “Energy” sector. According to the data supplied by OECD, non-EU countries such as Russia and Canada are important in terms of Scottish “Energy” imports.

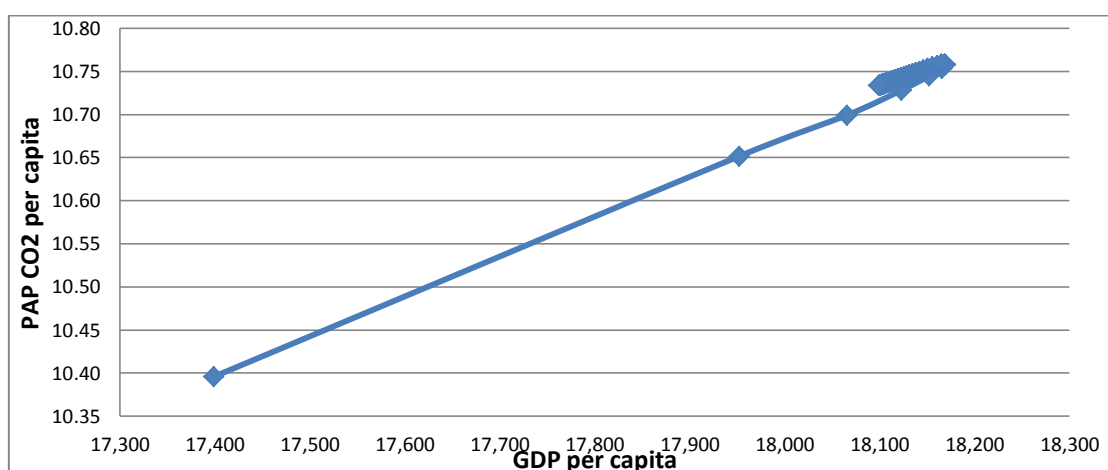


Figure 6. Scotland PAP CO₂ per capita plotted against GDP per capita (time periods/years 1-50).

There is a degree of ambiguity about the specification of the Environmental Kuznets Curve (Turner and Hanley, 2011). In this case it seems most appropriate to express it as a relationship between GDP per head and CO₂ per head. This is shown for Scotland in Figures 6 and 7 (next page). These differ in that in Figure 6 the CO₂ values are measured under the PAP method, whereas in Figure 7 the CAP approach is used. It is clear that using PAP, the relationship does not fit the EKC conjecture. GDP per head and CO₂ per head both rise. There is no effective decoupling of environmental harm from economic growth. However, under the CAP CO₂ measure, Figure 7 gives weak evidence of an Environmental Kuznets Curve relationship. Here there is a range of observations where GDP per head is rising as CO₂ per head falls. Perhaps more importantly, with a complete long-run adjustment, Scottish GDP per head is above its initial value, whereas CO₂ per head is below that value.

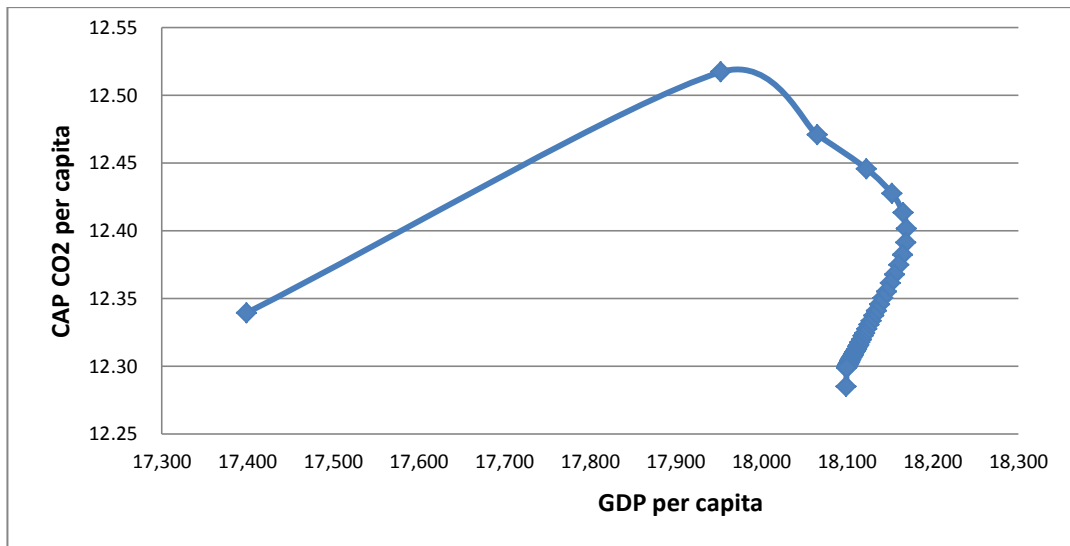


Figure 7: Scotland CAP CO2 per capita plotted against GDP per capita (time periods/years 1-50).

6.2 The CO₂ simulation results for RUK

Figure 8 shows the percentage change in total CO₂ emissions and emissions *per capita* for the economy of the Rest of the UK. In this case, for both PAP and CAP CO₂ measures, after an initial rise in total emissions there is a subsequent fall after period 5. But long-run total CO₂ emissions fall below the original base year value only for the PAP measure, by 0.02%. Using the CAP method, total long-run RUK CO₂ emissions actually rise by 0.04%.

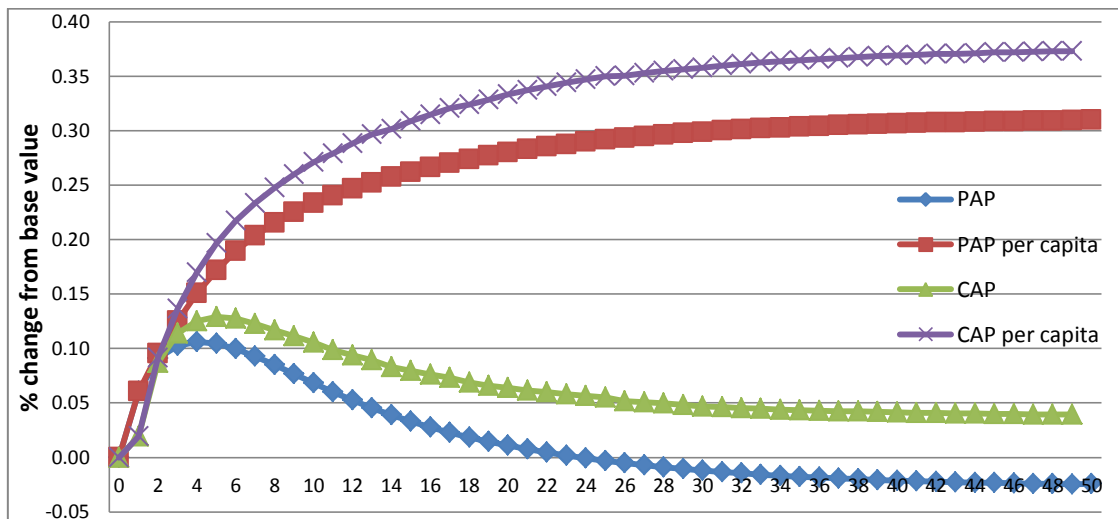


Figure 8: Impact of a 5% increase in Scottish labour productivity on RUK CO2 emissions levels (time periods/years 1-50).

From the discussion in Section 5.2, illustrated in Figure 3, we know that long-run RUK GDP and population fall. These decreases are more rapid than the changes in either the CAP or PAP emissions measures. This implies that RUK emissions per head rise over time, and in fact rise more rapidly than GDP per head. Therefore the EKC conjecture fails to emerge in the RUK simulation results. This is illustrated in Figures 9 and 10. For both the PAP and CAP measures there is a positive relationship between CO₂ emissions per head and GDP per head.

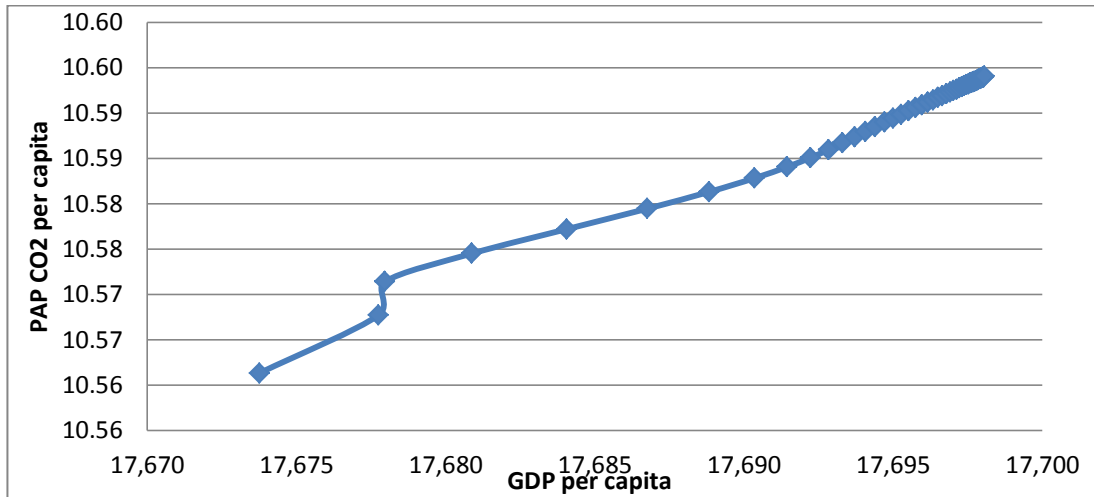


Figure 9: RUK PAP CO₂ per capita plotted against GDP per capita (time periods/years 1-50).

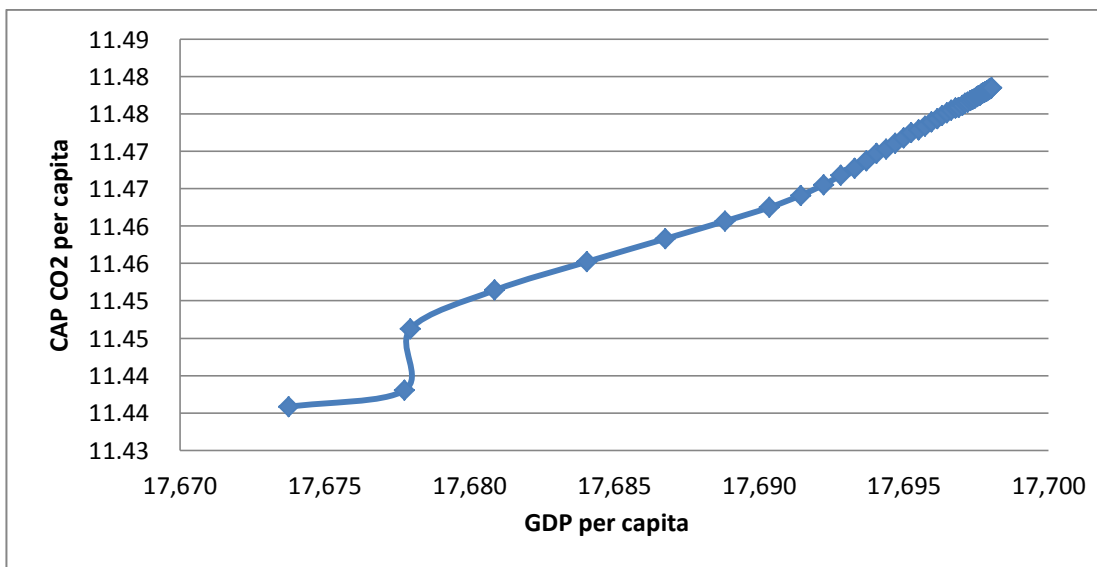


Figure 10: RUK CAP CO₂ per capita plotted against GDP per capita (time periods/years 1-50).

It is important to remember that the growth in measured productivity and the real wage in RUK is driven by a combination of demand and supply effects but that there is no change in underlying RUK efficiency. The demand and supply effects are the increased demand for RUK exports, generated by changes in income and output in Scotland and relative competitiveness with the ROW, together with higher wages produced by a labour supply restricted by inter-regional emigration. Because there is no underlying efficiency change driving growth in RUK, the aggregate macro-economic variables would be expected to move more closely in line with one another and the changes in the PAP and CAP measures of emissions are expected to be more similar than in the case of Scotland. This proves to be the case. Also one of the reasons for the higher emissions measured using the CAP method is that public expenditure is held constant in these simulations, so that although the simulated RUK population, private consumption and GDP are falling, public consumption remains unchanged.

Finally in this section we consider the change in the relationship between the rest of the UK economy and the rest of the World. Note from Table 3 that the 0.61% drop in imports from ROW reported in Table 2 is accompanied by reductions in CO₂ embodied in imports from ROW to RUK. This applies to commodities from each ROW sector. Therefore, despite the slight positive effect on total RUK CAP CO₂ emissions, underlying carbon leakage falls. Moreover, the reduction in carbon embodied in RUK imports from ROW is sufficiently large to offset the increases associated with Scottish imports from ROW in sectors 1-3.

This means that there is a net reduction of 896.3 kilo-tonnes across all commodities imported to the UK economy as a whole, as reported in the third column of Table 3. Thus, the increase in labour efficiency in the Scottish regional economy leads to negative carbon leakage at the UK level, but an increase in PAP emissions of just over 3.5million tonnes. This is largely driven by increased export demand from the rest of the world in both regions (particularly Scotland) as competitiveness improves. Therefore rather than there being carbon leakage associated with economic growth, there is something of a 'carbon blow-back'.

7. Discussion and conclusions

This paper considers the economic and environmental interaction between two regions generated by efficiency-driven growth in one. The specific application examines the impact of labour productivity-induced growth in one region on its own economic performance and pollution generation and also on the economic growth and pollution generated in a neighbouring region. This neighbour is linked to the host region through inter-regional trade and labour mobility.

In the simulation results for the Scotland-RUK case, the increased labour productivity in one region, Scotland, provides the basis for a supply-driven, export-led expansion in that region but also provides an indirect demand boost to the neighbouring region (RUK). This initially stimulates aggregate economic activity in RUK. However, there is a continuing negative supply shock to the neighbouring region as the treated region (Scotland) draws labour away from RUK. However, note that although the inter-regional outmigration eventually leads to a fall in RUK GDP and employment, the subsequent reduced labour supply results in higher RUK real wages and GDP per head.

In the region where productivity improves (Scotland), there is also growth in absolute pollution levels from both a production and a consumption accounting perspective. In the neighbouring region (RUK) there is a slight fall the long-run absolute level of PAP emissions, but an increase in CAP emissions. While international agreements on greenhouse gasses are currently set in terms of emissions generated within a nation's borders and therefore measured by the territorial or 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. That is, to use 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.

Given the fall in economic activity in the RUK economy, the most straightforward way to operationalize the environmental Kuznets Curve is to look at the relationship between emissions and GDP both measured per head. In the case of Scotland, there is evidence for the EKC conjecture where CO₂ emissions are measured using the CAP method. Essentially, consumption per head is rising by much less than GDP per head, plus there is substitution of imports from ROW by Scottish produced goods and services. These are typically less energy intensive than their ROW counterparts. However, for the RUK economy proportionate GDP and consumption change are much closer and there is a lower proportionate substitution away from ROW imports because the competitiveness effects are less strong.

The simulations have pointed to key differences between regional economic and environmental change powered primarily by direct efficiency improvements and those determined by secondary adjustments to price, output and income changes occurring elsewhere. As such, it highlights the inter-relationships between regional economies. However, there are a number of issues that need to be borne in mind when interpreting these results and which will serve as useful guides for future research.

The first point is that for the type of growth simulated here we found no strong evidence for the EKC conjecture. But note that there were assumed to be no changes in tastes as incomes change, no policies implemented specifically to limit climate change, and the efficiency improvement was directed towards greater efficiency in the use of labour, not intermediate inputs in general or energy in particular. 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).

Second, we only focus here specifically on economic and environmental spill-overs between two regions of the UK. We have not explicitly modelled the rest of the World economy. However, we have some evidence from the CO₂ embedded in ROW imports to the UK that the Scottish efficiency improvement might have a benign effect on CO₂ generation in ROW. Also we have assumed in the current application that the UK national population is fixed. However, international, and especially intra-EU, migration is an increasingly important phenomenon that should be examined.

Finally, although the inter-regional migration from RUK leads to the aggregate economic activity in that region ultimately falling, it has a positive effect on RUK real wages and GDP per head, as labour in RUK becomes scarcer. This is to impose an equilibrating view as to the operation of migration in multi-regional systems. Whilst there is empirical support for this approach, it is possible to take a much less benign viewpoint which stresses the selective nature of inter-regional migration. This could have potential adverse impacts on entrepreneurship, dependency levels and the skills base of the local economy losing population thereby reducing per capita GDP.

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