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HOW DO IMPROVEMENTS IN LABOUR PRODUCTIVITY IN THE SCOTTISH ECONOMY AFFECT THE UK POSITION ON THE ENVIRONMENTAL KUZNETS CURVE?

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How do improvements in labour productivity in the Scottish economy affect the UK position on the Environmental Kuznets Curve?

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Abstract

The Environmental Kuznets Curve (EKC) hypothesis focuses on the argument that rising prosperity will eventually be accompanied by falling pollution levels as a result of one or more of three factors: (1) structural change in the economy; (2) demand for environmental quality increasing at a more-than-proportional rate; (3) technological progress. Here, we focus on the third of these. In previous work we have used single region/nation models of the Scottish and UK economies to simulate the impacts of increased labour and energy efficiency on the domestic economy's position on the EKC, with a specific focus on CO2 emissions. There we find that, while the impacts of an increase in energy efficiency are difficult to predict, mainly due to the potential for 'rebound' effects, while increasing CO2 emissions, improved labour productivity is likely to move an economy along its EKC through more rapid GDP growth. However, recent developments in the EKC literature have raised the issue of whether this will still be the case if emissions are accounted for from a consumption rather than a production perspective (the 'pollution leakage' hypothesis) – i.e. taking account of indirect pollution generation embodied in trade flows rather than just domestic emissions generation. Here we extend our earlier single region analysis for Scotland by using an interregional CGE model of the UK economy to examine the likely impacts of an increase in Scottish labour productivity on the rest of the UK and on a national EKC through interregional labour migration and trade flows.

JEL codes: D58; F16; F18; O13

Keywords: computable general equilibrium; technological progress; environmental kuznets curve; pollution leakage

1. Introduction – modelling impacts of increased technological progress on an economy's position on the Environmental Kuznets Curve

The Environmental Kuznets Curve (EKC) hypothesis is based in the empirical observation that as economic growth occurs, pollution (which may be measure in absolute or per capita terms) first rises but then falls, once the economy moves past a "turning point". Thus the EKC takes an inverse U-shape. However, the EKC hypothesis is much disputed empirically, having generated a very large literature. Panel, time series and cross section studies have been carried out and the broad conclusion is that the EKC seems to exist for some pollutants / environmental impacts, but not for others, for some groupings of countries and not others and the turning point is also highly variable.

However, if the EKC hypothesis holds, there are significant policy implications. It would imply that we can grow without worrying about continually-increasing pollution; that there is less of a trade-off between economic growth and environmental sustainability than commonly thought; and, perhaps most significantly, that countries can "grow their way" out of environmental problems.

There are three main theoretical stories underlying the EKC hypothesis and these potential outcomes. The first two relate to structural change in an economy over time (Jaffe, 2003) and to the notion that increasing real incomes may translate into higher willingness to pay for environmental quality, leading to more voter pressure for stricter environmental legislation (Hokby and Soderquist, 2003). We focus on the third, which is that technological improvements, somehow correlated with economic growth, reduce the burden of each $/£ worth of economic activity on the environment (e.g. more fuel-efficient cars, more energy-efficient production systems) (Bretschger, 2005). For example, Johansson and Kristrom (2007) find technological progress to be key driver of the EKC in a time series analysis for SO2 in Sweden.

We consider the EKC debate and evidence more fully in Turner et al (2009). There we use single region/nation computable general equilibrium (CGE) models to consider the conditions under which increased efficiency in the use of energy and labour as inputs to production in different sectors of the UK and Scottish economies are likely to place each economy at different points on their domestic EKC. Our modeling strategy also allows us to quantify the impacts on aggregate CO_2 emissions of a policy to improve either labour or energy productivity. We find that, while the impacts of increased energy efficiency are somewhat ambiguous due to the potential for 'rebound' effect, in the case of both Scotland and the UK improved labour efficiency generally reduces the CO_2 intensity of GDP, but with increased CO_2 levels (due to positive output/competitiveness effects), so that the economy is moving *along* the EKC. In other words, the results presented in Turner et al (2009) suggest that boosting labour productivity will not, in its own, move the economy past a turning point. However, the higher the general equilibrium price elasticity of demand for labour, the greater the reduction in the CO_2 intensity of GDP and the faster we move along the EKC (due to positive substitution effects in favour of labour over energy).

However, in Turner (2009), we also argue that it would also be useful to examine the relationship between technological progress and the EKC in an interregional or international context, with specific focus on emissions under consumption rather than production accounting measures of emissions. This would allow us to address issues relating to the pollution leakage hypothesis in the context of EKC, identified by Arrow et al (1995) and others as a possible explanation as to why richer countries can become richer while reducing pollution levels. As a starting point, in this paper we use an interregional CGE model of the UK to examine the likely impacts of an increase in Scottish labour productivity on the rest of the UK and on a national EKC through interregional labour migration and trade flows.

2. General equilibrium responses to increased efficiency in an input to production

In Turner et al (2009) we explain that the net impact of an increase in the efficiency in use of an input to production on total input use is determined by a number of general equilibrium effects. These are as follows:

1. The pure efficiency effect – reduce demand for input targeted with efficiency improvement (here, labour) in proportion to the efficiency improvement (e.g. increase

labour efficiency by 5%, we require 5% less labour input to produce the same level of output.

2. The substitution effect – as we improve the efficiency with which an input is used, we lower its effective price (cost per unit of output). This will lead to shift in favour of the targeted input (here, labour) over others

3. Output/competitiveness effect – as effective and actual input prices fall, local output prices also fall, increasing competitiveness (e.g. export demand), in turn increasing labour and other input demand (direct and derived)

4. Composition effect – related to (3), there will be a shift in favour of more labour intensive activities

5. Income effect – as the economy expands, labour income will increase, which will in turn increase demand in all sectors of the economy, again increasing labour and other input demand

6. Turner (2009) also identified a ‘disinvestment effect’ in the case of energy efficiency – a contraction in supply of the input targeted with the efficiency improvement if the actual price of that input and returns on factor inputs fall. In case of labour, this will manifest as a reduction in labour supply through out-migration.

In our single region analyses (Turner et al, 2009), we find that improvements to energy efficiency *can* lead to falling CO2 emissions as GDP rises (moving *down* the EKC), but this depends on the general equilibrium price elasticity of demand for energy, which is governed by effects 2-5 above (but applying to energy rather than labour), and on the supply-side response, including effect (6) above and possibilities for labour migration. If the general equilibrium demand response is sufficiently strong, an extreme case of rebound effects, labelled ‘backfire’, where energy use actually rises may occur to the extent that the economy is shifted back on to the upward portion of the EKC.

The six effects outlined above also determine the impact of improvements in labour efficiency. However, our Turner et al (2009) single region (nation) CGE analysis for Scotland (and the UK) suggests that the qualitative impact will be more uniform. We find that increased labour efficiency tends to lead to total domestic generation of CO2 emissions increasing as GDP rises, but typically results in an improvement in the CO2/GDP ratio, as CO2 grows more slowly than GDP (moving *along* the EKC). However, the magnitude of own-region effects in our Turner et al (2009) analysis are sensitive to the degree of substitutability (direct and indirect) between labour and other inputs and to possibilities for migration of labour.

Therefore, in Turner et al (2009) we concluded that it vital to know the values of key parameters and to understand labour migration processes if we are to predict the effects of boosting factor productivity as part of climate change policy. However, one issue that the Turner et al (2009) single region/nation analysis does not address is the issue of pollution leakage effects (Arrow et al, 1995; Stern, 1998; Suri and Chapman, 1997; Cole, 2004) – i.e. the impacts on pollution generation in other regions and countries from growth and technological progress in the target region. One important issue in a UK policy context is that, while much responsibility for sustainability issues has been devolved to regional authorities, some important environmental goals, such as emissions reductions under the Kyoto Protocol, apply at the national level. Therefore, it would seem important to consider whether our generally positive conclusions with respect to the predictability of the impacts of labour productivity on the CO2 intensity of regional GDP in Turner et al (2009) also apply at the UK level, or whether there are negative GDP and/or CO2 spillover effects on other UK regions.[1]

3. AMOSUK – an interregional CGE model of Scotland and the rest of the UK (RUK)

[1] Of course it would also be of interest to examine the interregional spillover effects of improvements in energy efficiency at the regional level. However, the current interregional modelling framework is not specified to conduct such simulations. This will be a priority in future research.

Fuller details of the AMOSRUK modelling framework used here are given in Gilmartin et al (2008) [2]. Here we summarise the main features of the interregional CGE model as follows:

- There are 3 production sectors – Primary, Manufacturing and Construction, Electricity Gas and Water Supply, and Services – producing 3 commodities in each of two regions, Scotland and the Rest of the UK.
- A degree of substitutability (in response to changes in relative prices) is introduced between different inputs to production – labour, capital (which combine to give value-added), locally supplied intermediates, imports from the other region and the rest of the world (with imports and local intermediates combining through an Armington function, and total intermediates combining with value-added to give gross output) - and final consumption expenditure on goods and services (as production, excluding capital and labour). In the default, or base case, scenario elasticities of substitution in production are set at 0.3 and Armington import elasticities are set at 2.0 (see Turner et al, 2008)
- Both interregional and international exports are price sensitive. Non-price determinants of export demand from the rest of the world are exogenous; export demand from the other UK region is fully endogenous depending not only on relative prices, but also the structure of all elements of intermediate and final demand in the other region. The price elasticity of export demand for all UK outputs is set at 2.0 (see Turner et al, 2008).
- The model is dynamic with primary factor (labour and capital) stocks updating between periods. Given the annual data in the base year SAM[3], each period can be interpreted as one year. This allows us to consider the adjustment path of the economy and also to examine stages of the adjustment process (e.g. at present, policymakers in the UK consider a ten-year time horizon for the evaluation of regional policies – see HM Treasury, 1995). This is important as it may take a long time for the economy to adjust to a new equilibrium.
- Capital stocks are determined endogenously: in each period (year) investment demand in each sector is equal to depreciation plus a proportion of the difference between actual and

[2] Harrigan et al (1991) gives a full description of early versions of the AMOS framework, and Gillespie et al (2002) describes the interregional model AMOSRUK. Greenaway et al (1993) provides a general appraisal of CGE models and Partridge and Rickman (1998, 2008) review regional CGEs.
[3] Details on the SAM used here can be found in McGregor et al (2008).

desired capital stocks. In response to a shock, investment optimally adjusts capital stocks, gradually relaxing any capacity constraints.

- The labour force can also be updated following a shock. In the current application we assume that there is no natural population increase and no international migration (but these assumptions can be relaxed) but in the core ‘Migration’ scenario reported below, regional labour forces can be adjusted through interregional migration within the UK.
- Generation of CO2 emissions is a linear function of total intermediate input use, which includes energy, with the local intermediates composite a Leontief combination of the three commodities/sectoral outputs modelled.[4] In future research this will be developed in a KLEM production function of the type employed in the single region framework by Turner et al (2009).

4. Simulation strategy and results

4.1 Simulation strategy

As in the single region analysis for Scotland reported in Turner et al (2009), we introduce an exogenous (and costless) increase in labour augmenting technological progress in all Scottish production sectors. In selecting the size of the shock to introduce, we take the example of a potential policy to close Scotland’s labour productivity (GDP per FTE employee) gap with rest of UK in a period of 10 years. From the base year AMOSUK data (for 1999[5]), Scottish GDP per employee starts at the level of £33,137; while in RUK it is £34,755; with the weighted average across the UK at £34,618. Taking the default AMOSUK model parameterisation outlined above (particularly the value of 0.3 imposed on what are the key elasticities of substitution for these simulations – combining labour and capital to produce value-added, and value-added and total intermediates to produce gross output), and assuming that real wages are variable and interregional migration will occur in response to real wage and unemployment differentials, we

[4] The treatment of pollution linked to intermediate input use (including energy) develops on the simple Leontief treatment in Turner et al (2009b).
[5] There are issues with the quality of the 1999 interregional SAM database currently used to calibrate AMOSUK – see McGregor et al (2008) and Turner et al (2008). We are currently in the process of updating to 2004 and improving the quality of the dataset. Therefore, the precise simulation scenario and results reported in this paper should be taken as illustrative.

estimate that 5.8% step increase in labour augmenting technological progress in all Scottish production sectors is required to close the productivity gap in 10 years (after introduction).

In the next section, we report the results of introducing this shock to the model and, following the approach adopted in the Turner et al (2009) analysis, of running additional simulations to test the sensitivity of these results to the values assigned to the two key elasticities of substitution in all production sectors (Scotland and RUK). Then, in Section 4.3, we run additional simulations where we vary our assumptions regarding the functioning of the labour market: following Gilmartin et al (2007) and Turner et al (2008) we examine another two scenarios, one where we fix both the real wage and regional populations (Quasi IO) and a second where we allow real wages to vary in both regions but keep population fixed at the regional level.

4.2 Simulation results with flexible real wages and interregional migration

Figure 1. Impact of a 5.8% increase in labour augmenting technological progress on regional and national GDP per employee (default configuraiton: key paras 0.3; regional wage bargaining, interregional migration)

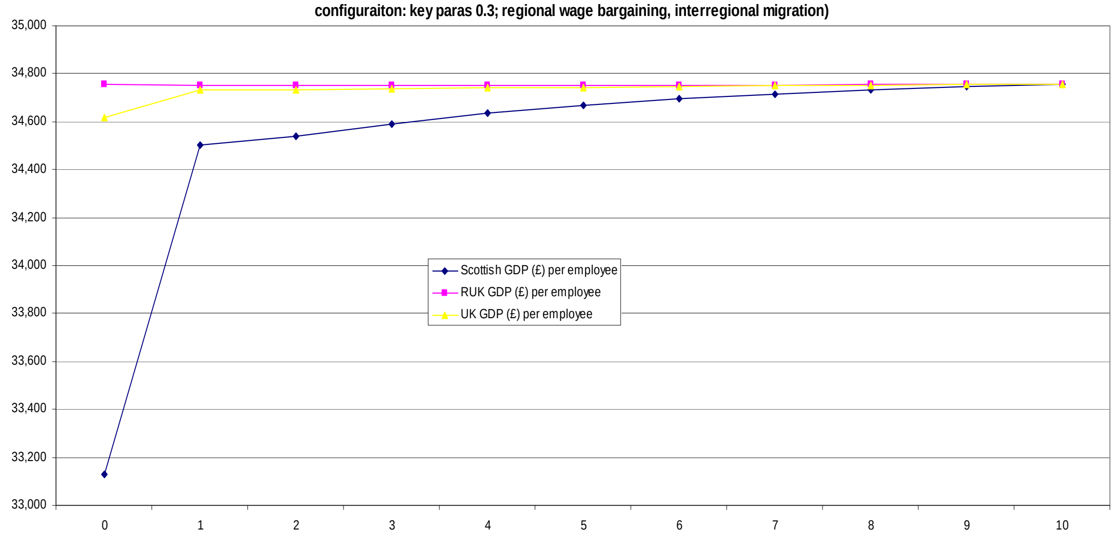


Figure 1 demonstrates that our base case scenario is set up to close the productivity gap between Scotland and RUK 10 years following the introduction of a 5.5% increase in labour efficiency in all Scottish production sectors. (Note that after 10 years the system is not fully adjusted to a new long-run equilibrium - after 10 years productivity gap grows again, but with Scotland over-taking the rest of the UK. However, Table 1 shows that if we vary the two key parameters governing the labour substitution effect to make them more elastic (in both regions) the gap is not closed. Note that the 0.3 case is actually the one where both GDP and employment growth in Scotland are at their lowest, but it is also the best outcome in terms of absolute GDP growth for UK and (the smallest contraction for) RUK – see Table 2.

Table 1. Impact of a 5.8% increase in labour efficiency in Scotland on regional and national GDP per employee (£)

	Scotland	RUK	UK
Base	33,127	34,755	34,618
10 years - 0.3	34,755	34,756	34,756
10 years - 0.8	34,445	34,769	34,741
10 years - 1.1	34,598	34,749	34,736

Table 2. Percentage change in regional and national GDP, employment and population over time from a 5.8% increase in labour efficiency in Scottish production (bargaining, interregional migration on)

KEY PARAS 0.3	1	2	3	4	5	10	15	20	30	50	75
Scotland											
GDP	2.774	3.266	3.625	3.927	4.198	5.254	5.974	6.474	7.069	7.511	7.633
Employment	-1.315	-0.960	-0.762	-0.597	-0.437	0.325	0.927	1.363	1.890	2.286	2.396
Population	0.000	-0.440	-0.624	-0.676	-0.652	-0.096	0.531	1.022	1.637	2.108	2.240
RUK											
GDP	0.013	0.026	0.039	0.048	0.054	0.058	0.039	0.014	-0.029	-0.069	-0.081
Employment	0.019	0.038	0.053	0.063	0.068	0.057	0.026	-0.003	-0.048	-0.086	-0.098
Population	0.000	0.041	0.059	0.064	0.061	0.009	-0.050	-0.096	-0.154	-0.198	-0.211
UK											
GDP	0.235	0.287	0.327	0.360	0.388	0.476	0.516	0.534	0.543	0.541	0.540
Employment	-0.093	-0.046	-0.015	0.007	0.025	0.079	0.102	0.111	0.115	0.113	0.112
Population	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
KEY PARAS 0.8	1	2	3	4	5	10	15	20	30	50	75
Scotland											
GDP	4.480	4.870	5.274	5.635	5.951	7.050	7.657	8.006	8.332	8.489	8.510
Employment	1.161	1.304	1.558	1.812	2.047	2.955	3.512	3.848	4.169	4.325	4.346
Population	0.000	0.414	0.726	1.013	1.283	2.373	3.078	3.513	3.934	4.139	4.167
RUK											
GDP	0.027	0.012	0.000	-0.012	-0.024	-0.083	-0.129	-0.161	-0.194	-0.211	-0.213
Employment	0.040	0.011	-0.010	-0.029	-0.047	-0.123	-0.176	-0.209	-0.242	-0.259	-0.261
Population	0.000	-0.039	-0.068	-0.095	-0.121	-0.223	-0.290	-0.331	-0.370	-0.390	-0.392
UK											
GDP	0.385	0.403	0.424	0.443	0.457	0.491	0.497	0.496	0.492	0.490	0.489
Employment	0.134	0.119	0.122	0.126	0.129	0.136	0.135	0.132	0.129	0.127	0.126
Population	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
KEY PARAS 1.1	1	2	3	4	5	10	15	20	30	50	75
Scotland											
GDP	4.946	5.267	5.679	6.054	6.383	7.526	8.156	8.516	8.851	9.008	9.029
Employment	1.822	1.922	2.240	2.557	2.847	3.929	4.574	4.956	5.316	5.487	5.509
Population	0.000	0.414	0.726	1.013	1.283	2.373	3.078	3.513	3.934	4.139	4.167
RUK											
GDP	0.030	0.000	-0.022	-0.041	-0.060	-0.140	-0.197	-0.232	-0.267	-0.284	-0.287
Employment	0.043	-0.009	-0.042	-0.071	-0.097	-0.199	-0.263	-0.302	-0.339	-0.357	-0.359
Population	0.000	-0.039	-0.068	-0.095	-0.121	-0.223	-0.290	-0.331	-0.370	-0.390	-0.392
UK											
GDP	0.425	0.424	0.437	0.449	0.459	0.477	0.476	0.472	0.466	0.464	0.463
Employment	0.193	0.154	0.150	0.150	0.151	0.148	0.144	0.140	0.136	0.134	0.134
Population	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

The key issue is that, with national population fixed, the increase in labour efficiency in Scotland (a positive supply side shock) actually draws labour away from the rest of the UK. Our particular interest here is how this impacts on EKC indicators in the Scottish and RUK economies. Figure 2 shows that in the case where the key elasticities of substitution are set at their most inelastic (0.3) – where we have the weakest sub effect in favour of labour - the efficiency effect (effect (1) in Section 2) means less labour is required to produce output, leading Scottish firms to shed labour and unemployment rises. This pushes down the real wage in Scotland and there is out-migration to RUK. However, within 10 years Figure 2 shows that there is a reversal of this negative wage effect and, as economy grows the increasing real wage in Scotland relative to that in RUK means that Scotland draws labour back in.

Note from Figure 2 that the unemployment effect doesn't correct. In the 0.3 case we get out migration then in migration; in the other cases (0.8 and 1.1), unemployment in Scotland actually falls from the outset (before in-migration kicks in producers have to draw from pool of unemployed labour in these scenarios).

Also, as demand for labour becomes more responsive to change in effective price of labour (as elasticity rises first to 0.8 then 1.1) we observe the opposite direction of effect with real wages in Scotland. First these are pushed up while Scottish labour is supply constrained, before they adjust back down with in migration (which, as noted above, occurs in response to higher relative wage in Scotland).

In the other region (not targeted with the labour efficiency improvement), RUK, in all 3 cases a drop in unemployment. Figure 2 shows that the RUK real wage is also bid up there – this is due to increased demand for RUK production as a result of growth in activity in Scotland. However, without benefit of direct supply side shock that occurs in Scotland, the net effect on RUK activity is actually negative.

Figure 2 Regional labour market impacts (% change) of a 5.8% increase in labour-augmenting technological progress in all Scottish production sectors

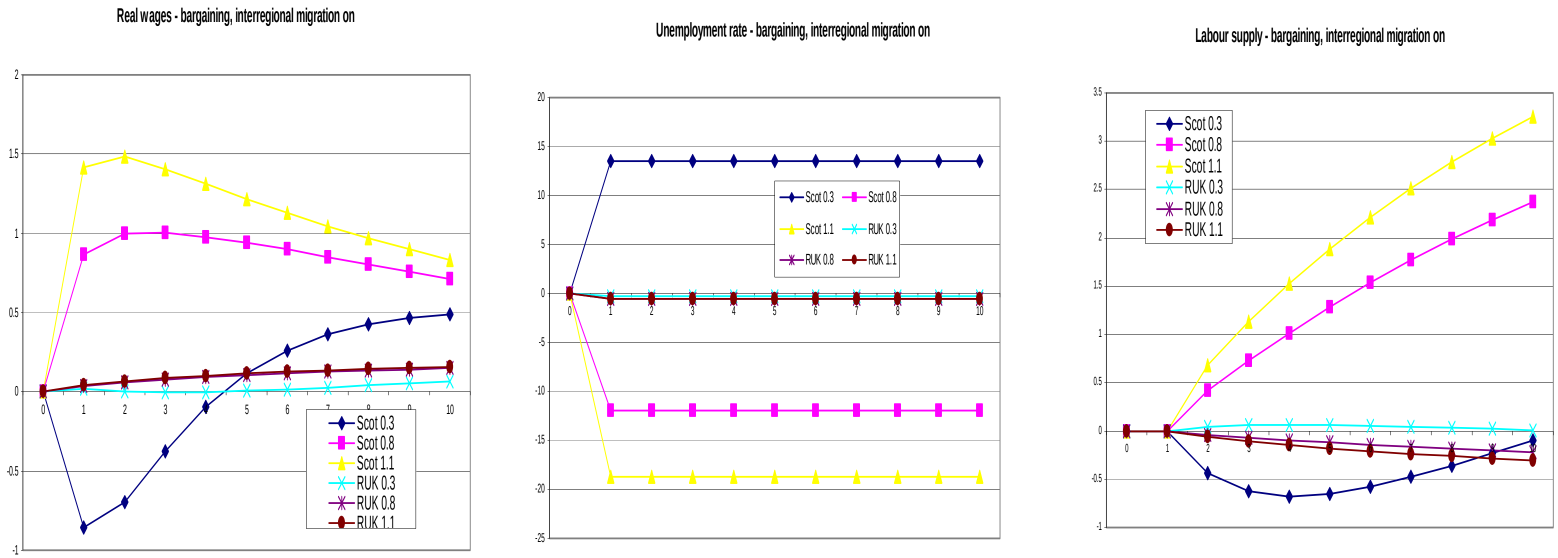


Figure 3 Regional EKC impacts (% change) of a 5.8% increase in labour-augmenting technological progress in all Scottish production sectors

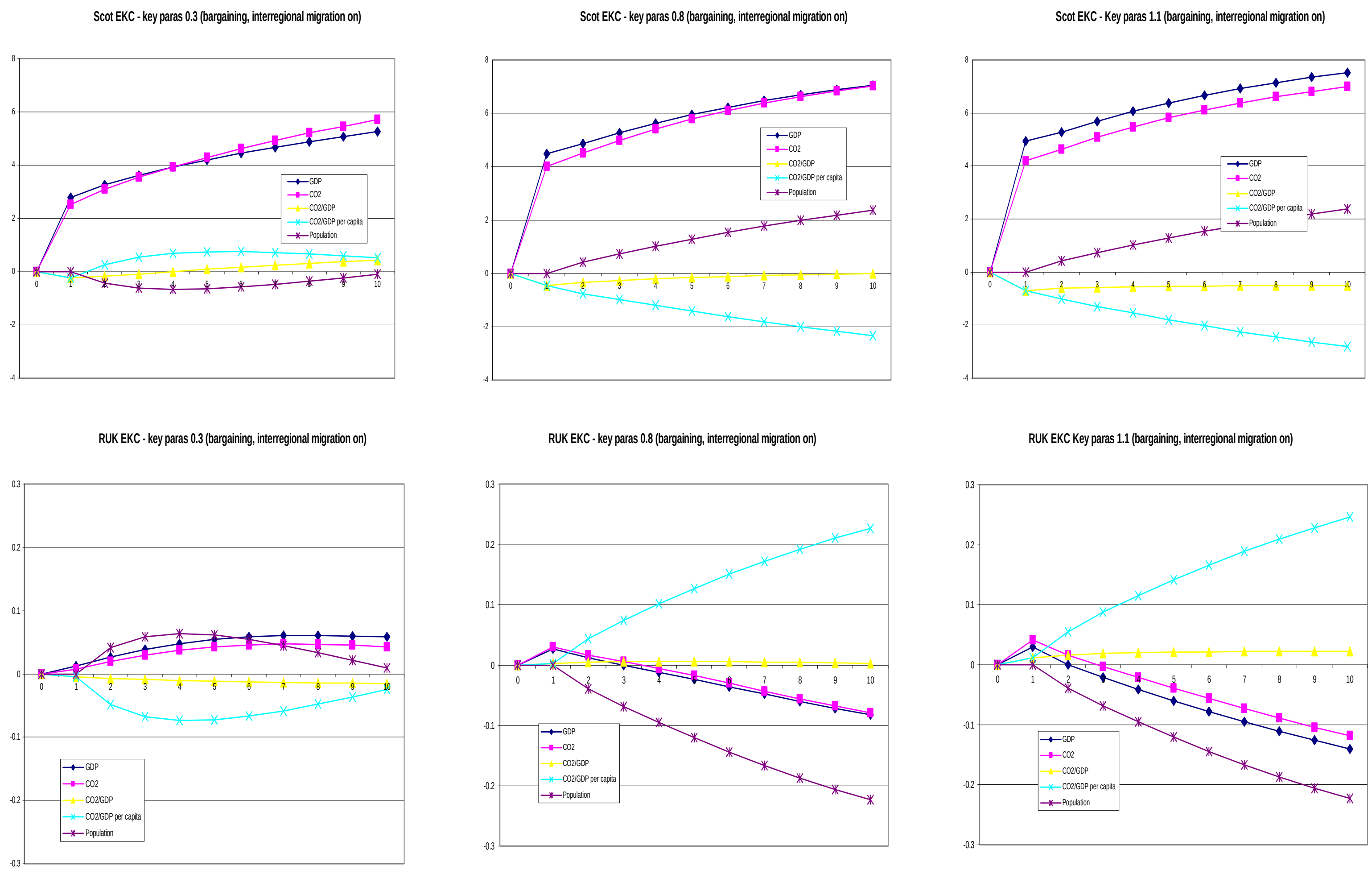


Figure 3 shows the impacts on regional EKC measures. In Turner et al (2009) we introduced an illustrative 5% increase in labour productivity at single region Scottish level and at UK national level (so all regions in latter) and found generally positive impact on CO2/GDP, with both rising but GDP rising faster. However, the lowest value for the key elasticities governing the labour substitution effect was 0.8. Here, with key elasticities of substitution set at O.3 in our base case, the results are not so uniform. At the 10 year point, domestic CO2 generation in Scotland is growing faster than GDP (and this continues into long run). The per capita measure (CO2 per capita divided by GDP) falls then rises before starting to fall again (with a decrease over the long run) – this happens because of initial out migration (see Figure 2) due to relatively low responsiveness of labour demand to falling effective price of labour (i.e. a weak substitution effect).

Moreover, in contrast to the Turner et al (2009) single region analysis, even when we raise the value of our key elasticities of substation to 0.8, CO2 growth actually outstrips GDP growth (and does so into long run) but the per capita EKC measure falls (so we are moving in right direction along the per capita curve) as Scottish population grows. Only when we go over 1, with an elastic response (1.1 case), do we observe the absolute CO2/GDP measure fall as well as per capita one: this is due to faster GDP growth as it becomes easer to substitute in favour of labour (the factor of production that has benefited from the efficiency improvement) and away from polluting intermediate inputs

If we look at the results for RUK, we see that what is positive for Scotland is negative for other region: CO2 does fall in all cases, but GDP falls faster (though this is not linear relationship with rising elasticities of substitution because of in migration to RUK in 0.3 case). With out-migration from RUK as the substitution effect becomes stronger in Scotland, RUK’s per capita EKC measure actually rises in all 3 cases, and by more the more elastic these key parameters are.

Figure 4 shows the net effect on the EKC position of the national economy, the UK. These diagrams show a much clearer picture at national level. However, it is not a positive in terms of the EKC relationship. In all cases we do see a large and positive GDP effect but, in contrast to the Scottish results, we see that GDP growth is greatest where the substitution effect in Scotland is weakest (0.3 case). However, this is also where we see the largest difference between CO2 and

GDP growth, with the former outstripping the latter so that CO2/GDP rises the most in this case. The gap closes the stronger the substitution effect in Scotland in favour of labour (there is no population change in UK so total and per capita measures are the same).

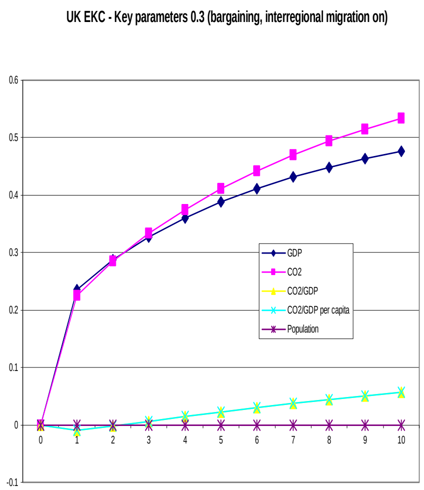
However, we should note that, particularly in the 1.1 case on the right on Figure 4, the long run increase in CO2/GDP is very small (0.032%) and always less than 1% - i.e. there is not much move on the UK's position on the EKC (if such a relationship exists). Moreover, as noted in Footnote 5, the analysis presented here is based on not a great data set. This is for 1999, and based on a UK analytical IO table that we have had to estimate ourselves, also highly aggregated to just 3 sectors. We are currently updating to 2004, where much more disaggregation will be possible, and with a much better quality UK analytical table.

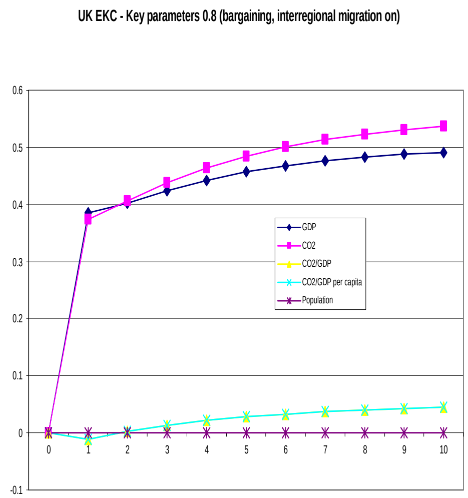
4.3 Simulation results with alternative labour market assumptions

However, the illustrative analyses presented here are still useful in allowing us to consider the issues that are important in determining the interregional effects of technological progress in one region on others. One thing that is clearly important from the results presented so far (and in Turner et al's 2009 analysis) is the impact of interregional migration, and also the real wage effects that drive it. Therefore, we have re-run the three simulations under different wage-setting and migration assumptions, each of which reflects a commonly-encountered view of how regional labour markets operate in the regional macroeconomic and labour market literature (see Gilmartin et al, 2008). We refer to these as:

1. Quasi IO - fixed real wages with population fixed at the regional level;
2. Bargaining - real wages are determined via a conventional 'wage curve' operating at the level of the region, with wages inversely related to the unemployment rate, and with population fixed at the regional level;
3. Flow Migration - regional wage bargaining as in (2) but with population fixed only at the national level. Interregional migration is determined by relative real wage and unemployment rates in Scotland and RUK.

Figure 4 National EKC impacts (% change) of a 5.8% increase in labour-augmenting technological progress in all Scottish production sectors





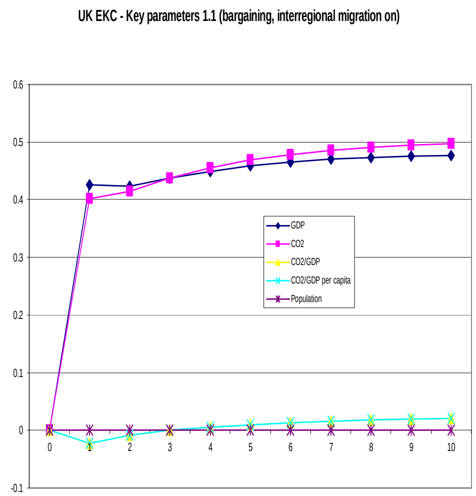


Figure 5. Labour Market Scenarios

	Population	Regional Wage Setting	
		Scotland	RUK
Quasi IO	Fixed at the regional level	Fixed real wage	Fixed real wage
Regional Bargaining	Fixed at the regional level	Bargaining	Bargaining
Flow Migration	Fixed at the national level	Bargaining	Bargaining

Table 3. Regional impacts (% change) of a 5.8% increase in labour efficiency in Scotland on regional and national EKC indicators

SCOTLAND

	Labour market scenario	Quasi IO		Bargaining		Migration	
Key parameters (el. sub VA and output)		10 years	75 years	10 years	75 years	10 years	75 years
0.3	GDP	5.530	7.947	5.406	6.201	5.254	7.633
	CO2	5.964	9.184	5.891	7.171	5.704	8.889
	CO2/GDP	0.411	1.146	0.460	0.913	0.428	1.167
	CO2/GDP per capita	0.411	1.146	0.460	0.913	0.525	**-1.049**
0.8	GDP	8.185	8.778	5.747	5.914	7.050	8.510
	CO2	8.106	8.794	5.700	5.914	7.036	8.652
	CO2/GDP	**-0.072**	0.015	-0.045	0.000	**-0.013**	**0.131**
	CO2/GDP per capita	**-0.072**	0.015	-0.045	0.000	**-2.331**	**-3.874**
1.1	GDP	8.975	9.273	5.681	5.771	7.526	9.029
	CO2	8.232	8.546	5.202	5.303	6.986	8.495
	CO2/GDP	**-0.681**	**-0.666**	**-0.453**	**-0.443**	**-0.502**	**-0.489**
	CO2/GDP per capita	**-0.681**	**-0.666**	**-0.453**	**-0.443**	**-2.808**	**-4.470**

RUK

	Labour market scenario	Quasi IO		Bargaining		Migration	
Key parameters (el. sub VA and output)		10 years	75 years	10 years	75 years	10 years	75 years
0.3	GDP	0.105	0.374	0.042	0.068	**0.058**	**-0.081**
	CO2	0.086	0.371	0.023	0.047	**0.043**	**-0.127**
	CO2/GDP	**-0.018**	**-0.003**	**-0.018**	**-0.021**	**-0.015**	**-0.046**
	CO2/GDP per capita	**-0.018**	**-0.003**	**-0.018**	**-0.021**	**-0.024**	**0.165**
0.8	GDP	0.250	0.342	0.046	0.052	**-0.083**	**-0.213**
	CO2	0.254	0.349	0.052	0.058	**-0.080**	**-0.220**
	CO2/GDP	0.004	0.007	0.006	0.005	**0.003**	**-0.007**
	CO2/GDP per capita	0.004	0.007	0.006	0.005	**0.227**	**0.387**
1.1	GDP	0.272	0.317	0.040	0.043	**-0.140**	**-0.287**
	CO2	0.285	0.329	0.057	0.060	**-0.118**	**-0.264**
	CO2/GDP	0.013	0.012	0.016	0.016	**0.022**	**0.023**
	CO2/GDP per capita	0.013	0.012	0.016	0.016	**0.246**	**0.417**

Let us begin by looking at the impacts of adopting different labour market assumption for Scotland first. In the first grid of Table 3, we start by looking at our base scenario of Migration (real wage and regional population variable), and move to Bargaining. In this latter scenario we allow the real wage to vary but don't allow migration of labour in response to this so the long-run positive GDP effects will be smaller (because of a more limited adjustment of the Scottish economy in response to the supply side shock).

In the 0.3 case, where we saw out migration (causes and) effects in Figs 2 and 3, the Bargaining scenario is better in the shorter run (even up to year 10). This is because not allowing migration stops labour leaving Scotland as real wages fall and unemployment rises (due to the net shedding of labour as the efficiency effect dominates). However, in the 0.8 and 1.1 cases, and over the longer run in the 0.3 case, the regional population constraint stops in-migration, limiting the size of the boost to the Scottish economy.

In terms of CO_2, the results reflect both the upward pressure from increased economic growth but also the ability to substitute in favour of labour (and away from the use of intermediates, including energy): despite increasing elasticities as in the Migration case, these are limited for Scotland where there is no migration, so the CO_2/GDP results are worse (0.8 case) or not so good (1.1 case) under Bargaining relative to Migration.

However, when we move to quasi IO, where we fix the real wage as well as regional population, it is better in terms of GDP growth in all scenarios because we lose the negative competitiveness effects from rising real wages. As elasticities rise (increasing the strength of the substitution effect in favour of labour) we again see the best results in terms of CO_2/GDP, and this is more so the higher the value of the key elasticities (production of value added and output).

In absolute terms, quasi IO may look best for Scotland from an EKC standpoint, but if we are interested in the per capita measure, Migration is clearly the best outcome, with rising GDP and CO_2 emissions spread across a larger regional population in Scotland.

However, here we are interested in the interregional spillover effects of increased labour productivity in Scotland on the rest of the UK. The right hand grid of Table 3 shows the impacts on our key EKC indicators in the RUK economy. If we look at the portion of this grid we see that the more we limit the substitution effect in favour of labour in Scotland (lower elasticities of substitution but also labour supply with no interregional migration), coupled with reducing negative competitiveness effects from rising real wages), the Quasi IO case with our most inelastic parameters gives the most favourable EKC outcome for RUK. Positive GDP growth outstrips CO2 growth. However, within Quasi IO (reading down the first two columns), the stronger the substitution effect without the exogenous increase in labour productivity, CO2 growth starts to outstrip GDP growth.

Nonetheless, Quasi IO is still the best scenario for RUK in economic terms. When we allow the real wage to vary (moving from Quasi IO to Bargaining), in the absence of a direct positive supply shock (as in Scotland), the positive indirect demand shock causes real wages to rise in the RUK economy, which has a negative impact on RUK competitiveness, limiting the positive GDP effect.

When we allow interregional migration (moving from Bargaining to Migration), this generally worsens the economic situation in RUK as it adds a labour supply constraint. Only in the 0.3 case, for the 10 year time frame (already examined in Figures 2 and 3) do we see an improvement for RUK under Migration relative to Bargaining, due to a temporary in-migration of labour from Scotland to RUK when the efficiency effect of the labour productivity improvement in the former dominates.

In terms of CO2, the results in the Migration columns may seem positive for RUK in that CO2/GDP falls at lower elasticities. However, this is simply due to CO2 falling faster than GDP and does not carry through to the per capita measure because RUK population is actually falling in this case. As elasticities grow, the proportionate decline in GDP overtakes the drop in CO2 so that the RUK economy is actually moving back down the EKC curve.

How does all this net out at the national level? The results in Table 4 show that there are less qualitative differences in the results. That is, in all scenarios simulated there is an increase in GDP and CO2, but with the latter outstripping the former so that the CO2 intensity of GDP increases (and, with population fixed at the national level in all cases, as noted in the discussion of Figure 4, the per capita and absolute measures are the same). Therefore, there is a uniform result in that the impact of an increase in Scottish labour productivity puts the UK on the upward portion of the EKC curve.

Table 4. National impacts (% change) of a 5.8% increase in labour efficiency in Scotland on regional and national EKC indicators

UK

	Labour market scenario	Quasi IO		Bargaining		Migration	
Key parameters (el. sub VA and output)		10 years	75 years	10 years	75 years	10 years	75 years
0.3	GDP	0.541	0.983	0.473	0.561	0.476	0.540
	CO2	0.596	1.135	0.532	0.664	0.533	0.654
	CO2/GDP	0.054	0.150	0.058	0.102	0.057	0.114
	CO2/GDP per capita	0.054	0.150	0.058	0.102	0.057	0.114
0.8	GDP	0.888	1.021	0.505	0.524	0.491	0.489
	CO2	0.935	1.081	0.541	0.565	0.537	0.549
	CO2/GDP	0.046	0.059	0.036	0.041	0.045	0.060
	CO2/GDP per capita	0.046	0.059	0.036	0.041	0.045	0.060
1.1	GDP	0.973	1.038	0.494	0.504	0.477	0.463
	CO2	0.974	1.041	0.503	0.514	0.497	0.495
	CO2/GDP	0.001	0.003	0.008	0.009	0.021	0.032
	CO2/GDP per capita	0.001	0.003	0.008	0.009	0.021	0.032

Reading down the columns of Table 4, we can see that this result weakens the stronger the substitution effect in favour of labour in response to the growth in Scottish labour productivity. However (according to the dataset that we are currently working with) the CO2 intensity of Scottish production at the aggregate level (most likely due to the larger energy supply sector) is higher to start out with than that in the UK and, while this drops in response to the shock (and more so the stronger the substitution effect in favour of labour) the gap does not entirely close in any of the scenarios.

Therefore, in future research with the AMOSUK framework, it will be interesting to see how the results are impacted (a) with a better dataset (we are currently updating to 2004 and now have access to better quality UK IO and interregional trade data); (b) with a greater degree of sectoral disaggregation (also possible with the new 2004 database; and (c) if we experiment in targetting the labour productivity shock at different production sectors in Scotland (e.g. in the single region analysis reported in our Turner et al (2009) paper we find more positive EKC results if we exclude the Scottish energy supply sectors from the labour productivity improvement.

However, remaining with the current model and analysis, a final question that we may want to ask in the contest of the potential policy scenario we have been simulating is how important is the model configuration in terms of how the labour market functions and the values attached to key parameters are in terms of being able to meet the target of closing the productivity gap between Scotland and RUK in 10 years.

Table 5. Difference in Scot/RUK productivity gap 10 years after shock (+ve overshoot; -ve undershoot)

Base case -4.68% (Scot gap relative to RUK)

	Labour market scenario		
	Quasi IO	Bargaining	Migration
Key parameters (el. sub VA and output)	10 years	10 years	10 years
0.3	-0.10%	0.01%	0.00%
0.8	-1.07%	-0.52%	-0.93%
1.1	-1.66%	-0.81%	-1.44%

Table 5 shows what happens to Scottish GDP per employee relative to that in RUK after 10 years (note from Table 1 that both change (improve) as a result of the labour productivity improvement in Scotland). Clearly labour market closure is not so important in determining whether the target is hit. In the initial scenario (where GDP per employee is reported in Table 1), the size of the shock is designed to ensure that the gap is closed in 10 years, so we have 0% difference. With bargaining but no migration, RUK GDP per employee increases by the same amount as with migration, but Scottish GDP per employee increases by slightly more (to £34,760 rather than

£34,756) so that there is a slight overshoot within the 10 years. Note also that the gap continues to grow in Scotland's favour as we run the model forward beyond 10 years.

In the Quasi IO case, the growth in GDP per employee is slightly less in both RUK (£34,750 instead of £34,755 in the Migration case and £1 more under Bargaining case) and Scotland (£34,715 instead of £34,755 in the Migration and Bargaining cases) so that there is a slight (-0.10%) undershoot. However, within just a few years after period 10, the gap is closed then continues to grow over time.

However, when we increase the value of the key elasticities of substitution (production of value added and output) in each labour market scenario, there is an undershoot and the gap doesn't close as we run the model forward.

5. Conclusions and priorities for current/future research

As in our single region analysis (Turner et al, 2009), the results presented here demonstrate that what we assume about how labour markets function and the values associated with key elasticities of substitution are crucial in determining the economic and environmental effects (and their relative strength) of increases in labour augmenting technological progress. What the analysis presented here adds is consideration of the importance of interregional spillover effects of increased technological progress in one region on others, particularly where this involves reallocation of the factor of production (labour) targeted with the efficiency improvement. However, even where there is no interregional migration of labour, we observe 'pollution leakage' effects in that a positive supply shock in one region will lead to an indirect positive demand shock in other regions and increased trade flows will engender increased pollution generation in all regions.

This latter point (pollution embodied in trade flows) is the general focus of the current project under the ESRC Climate Change Leadership Fellows programme on Investigating the Pollution Content of Trade Flows and the Importance of 'Environmental Trade Balances' in Addressing the Problem of Climate Change (ESRC Grant reference: RES-066-27-0029). This paper, focussing on technological progress and the EKC curve, is related to work on another ESRC project (under the 1st Grants initiative – ESRC Grant reference: RES-061-25-0010) on modelling the impacts of increased energy efficiency, but also constitutes a second experiment under the Fellowship project, using our existing interregional CGE model of the UK to examine the impacts of interregional trade on regional and national emissions generation. The first paper (Turner et al 2008) examined the interregional impacts of a demand side shock while this paper focuses on a supply-side shock.

Currently on the Fellowship project we are working on updating and improving our UK database to 2004, with better estimates for the UK and interregional components, and with greater sectoral disaggregation. Also we want to take account of the pollution content of international trade flows, and to look at non-UK examples – mainly US interstate cases – and are working with a number of collaborators to this end.

We are also currently working on econometric estimation of key elasticities of substitution in the production function. However, data are only currently available to do this at the UK national level. Nonetheless, this will allow significant improvement in the specification of the UK interregional modelling framework.

In terms of future research, we hope to better link the work on the energy efficiency and interregional strands of our work in order to examine the interregional impacts of increases in energy as well as labour efficiency. Given the prominence of energy efficiency enhancements in current UK climate change policy, this is likely to be a crucial development.

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