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Abstract

The application of multi-region environmental input-output (IO) analysis to the problem of accounting for emissions generation (and/or resource use) under different accounting principles has become increasingly common in the ecological and environmental economics literature in particular, with applications at the international and interregional subnational level. However, while environmental IO analysis is invaluable in accounting for pollution flows in the single time period that the accounts relate to, it is limited when the focus is on modelling the impacts of any *marginal change* in activity. This is because a conventional demand-driven IO model assumes an entirely passive supply-side in the economy (i.e. all supply is infinitely elastic) and is further restricted by the assumption of universal Leontief (fixed proportions) technology implied by the use of the A and multiplier matrices. Where analysis of marginal changes in activity is required, extension from an IO accounting framework to a more flexible interregional computable general equilibrium (CGE) approach, where behavioural relationships can be modelled in a more realistic and theory-consistent manner, is appropriate. Our argument is illustrated by comparing the results of introducing a positive demand stimulus in the UK economy using IO and CGE interregional models of Scotland and the rest of the UK. In the case of the latter, we demonstrate how more theory consistent modelling of both demand and supply side behaviour at the regional and national levels effect model results, including the impact on the interregional CO2 'trade balance'.

Keywords: CGE modelling, MRIO, CO2 trade balance, environmental responsibility

JEL Classifications: D57, D58, R15, Q56

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1. Introduction

Input-output (IO) analysis is a powerful accounting tool for examining the structure of economic activity and associated issues such as the pollution and/or resource use engendered or embodied, directly or indirectly, in production, consumption and trade flows under different accounting principles (Munksgaard and Pedersen, 2001). Particularly in the ecological footprint literature, where focus is on accounting for emissions under the consumption accounting principle, IO analysis has become an increasingly commonly used technique to measure and allocate responsibility for emissions generation (see Wiedmann et al., 2007, for a review). As explained by Turner et al. (2007) this would seem a natural development, given that the focus of ecological or carbon footprints is to capture the *total* (direct plus indirect) resource use or emissions embodied in final consumption in an economy. IO analysis is based around a set of sectorally disaggregated economic accounts, where inputs to each industrial sector, and the subsequent uses of the output of those sectors, are separately identified. Therefore, by the use of straightforward mathematical routines, the interdependence of different activities can be quantified, and all direct, indirect and, where appropriate, induced, resource use embodied within consumption can be tracked (Leontief, 1970, Miller and Blair, 1985). Turner et al. (2007) go on to derive a multi-region IO method that is appropriate for accounting for emissions under the production and consumption accounting principles and determining environmental trade balances. Most applications to date have had an international focus. However, pollution accounting is also important at a sub-national regional analysis where there is devolution of responsibility for setting and achieving environmental or sustainability objectives. For example, in McGregor et al (2008) we apply the interregional IO accounting method, as derived in Turner et al (2007) to the case of Scotland and the rest of the UK.

However, where concern lies in analysing the impacts of *changes* in policy, or other disturbances, on variables of interest, such as environmental trade balances, a more flexible framework is required. Such a framework should allow us to model both supply and demand side behaviour, and prices and quantities simultaneously and endogenously. An approach that incorporates the main strengths of IO for the treatment of environmental problems – i.e. the multi-sectoral, system wide features of IO tables – but builds a more flexible analytical framework around this is computable general equilibrium (CGE) modelling. CGE modelling is now firmly established in the academic literature as the dominant approach for analysing global, national and regional environmental issues (see, for example, Bergman, 1988, Beausejour et al., 1995, Conrad, 1999, Welsch, 1996, Wissema and Dellink 2007). Single region/nation nvironmental CGE modelling frameworks based on the AMOS framework developed by Harrigan et al (1991) have been developed for Scotland and the UK - see, respectively, Hanley et al (2006, 2009), and Allan et al (2007a) - primarily (to date) to examine the system-wide impacts of improvements in energy efficiency. However, in order to analyse issues relating to environmental trade balances between the regions of the UK, and between the UK and the rest of the world, an interregional CGE modelling framework is required. While interregional CGE models are fairly commonly applied at the international level, commonly through the application of the GTAP framework (Hertel, 1997)[1], they are less developed at the sub-national level and have not, to our knowledge, been employed to extend the resource use/pollution accounting and environmental trade balance analysis that has become common in the IO literature.

In this paper we demonstrate the potential added value in moving from IO accounting to CGE modelling techniques by building on our 2-region IO analysis in McGregor et al (2008). We develop a very simple 2-region, 3-sector variant of the UK AMOS framework (see Gilmartin et al. 2007a,b) to conduct some illustrative analysis and demonstrate the potential contribution of interregional CGE modelling techniques to environmental trade balance analysis.[2] We compare

[1] More information on application of the GTAP framework can be found at http://www.gtap.org.

[2] A project is currently underway as part of the UK Economic and Social Research Council's Climate Change Leadership programme to develop a more useful empirical IO and CGE framework with a greater degree of spatial and sectoral disaggregation. Contact karen.turner@strath.ac.uk for more details.

the results of introducing a positive demand stimulus in the UK economy using both IO and CGE interregional models of Scotland and the rest of the UK (RUK). In the case of the latter, we demonstrate how alternative specifications of a key element of supply-side behaviour at the regional and national levels, wage determination, effect model results, including the impact on the interregional $CO2$ 'trade balance'. However, it is important to note that, in contrast to conventional IO models, CGE can also be used to analyse the impacts supply-side disturbances (e.g. increases in energy efficiency).

The remainder of the paper is structured as follows. In Section 2 we use the interregional IO accounting technique proposed by Turner et al (2007) to calculate the base year (1999) CO2 trade balance between Scotland and RUK. We then use the conventional IO demand-driven modelling approach to examine the impacts on key economic variables and the CO2 trade balance of introducing the illustrative example of a 10% increase in export demand from the rest of the world to one of the production sectors in the Rest of the UK using the IO framework as a model. Then, in Section 3, we outline the broad characteristics that make CGE models more appropriate for analysing such a change in activity, and introduce our illustrative AMOSRUK interregional CGE model, which shares the IO database used in Section 2, but introduces an active supply-side and more theory-consistent specification of production and consumption behaviour (in particular, relaxing the assumption of universal Leontief technology). In Section 4, we introduce the same positive demand stimulus to the AMOSRUK CGE model and compare the qualitative results with those from the IO reported in Section 2. A summary and conclusions of our analysis are provided in Section 5.

2. Input-output analysis of pollution trade balances – an illustrative application for Scotland and the rest of the UK (RUK)

2.1 The interregional IO framework

As in McGregor et al (2008) we apply the 2-region framework as derived by Turner et al (2007), where the standard interregional IO framework (Miller and Blair, 1985) is augmented with a 1x2N vector of output-pollution coefficients for a single pollutant, CO2, $\mathbf{e}_{\mathbf{r}}^{\mathbf{x}}$, with elements e_i^r telling us the physical amount of CO2 directly generated per unit of output, x_i, produced by sector i in region r:

[1] $$e_i^r = p_i^r / x_i^r$$

so that

[2] $$\begin{pmatrix} p_{11}^y & p_{12}^y \\ p_{21}^y & p_{22}^y \end{pmatrix} = \begin{pmatrix} \mathbf{e}_1^{\mathbf{x}} & \mathbf{0} \\ \mathbf{0} & \mathbf{e}_2^{\mathbf{x}} \end{pmatrix} \begin{pmatrix} \mathbf{I} - \mathbf{A}_{11} & -\mathbf{A}_{12} \\ -\mathbf{A}_{21} & \mathbf{I} - \mathbf{A}_{22} \end{pmatrix}^{-1} \begin{pmatrix} \mathbf{y}_{11} & \mathbf{y}_{12} \\ \mathbf{y}_{21} & \mathbf{y}_{22} \end{pmatrix}$$

(where, in our illustrative analysis, Scotland is region 1 and RUK is region 2, here with the IO framework aggregated to the 3 sectors we are able to model in the interregional CGE framework, so that each region has i=1,.., N=3 production sectors producing j=1,.., N=3 commodities). The first subscript on each element of [1] identifies the producing region, r, and the second the consuming region, s. p_{rs}^y is a scalar telling us the amount of CO2 generated in production activities in region r to support region s final demand, for output produced in region r, $\mathbf{y}_{\mathbf{rs}}$ (an Nx1 = 10x1 vector). $[\mathbf{I} - \mathbf{A}]^{-1}$ is the symmetric 2Nx2N (6x6) partitioned interregional Leontief inverse (multiplier) matrix, with elements b_{ij}^{rs} telling us the amount of output of each producing sector i in region r required per unit of final demand for the output of consuming sector j in region s.

Note that the description of a 2*N*x2*N* (3x3) interregional Leontief inverse, where we have N=3 production sectors in each Scotland and RUK, is consistent with the conventional 'Type I' case where the A-matrix has elements a_{ij}^{rs} telling us the amount of output produced by each sector *i* in region *r*, x_{ij}^{rs}, required as input to production per unit of total input/output in consuming sector *j* in region *s*, X_j^s. Thus, each element of the A-matrix is formally defined as follows:

[3] $$a_{ij}^{rs} = x_{ij}^{rs} / X_j^s$$

In the conventional Type I case, the production sectors are those identified as production sectors in the IO accounts for the country in question. It is, however, possible to endogenise activities reported as final consumption sectors in the IO accounts – and, therefore, initially included in the partitioned matrix **Y** in the Type I case – by redefining the **A** and **Y** matrices.

Here, in order to make the IO analysis more consistent with a CGE analysis (where household income and expenditure is determined endogenously)[3], we carry out a Type II analysis, where household consumption is endogenised by subtracting household final consumption expenditure from each vector $\mathbf{y_r}$ and adding an additional column and row of input-output coefficients to the **A-**matrix. In the additional row x_{ij}^{rs} will record use of region *r* household production (additional production sector, *i*, as inputs to production in sector *j* in region *s* and X_j^s will be the total input/output of sector *j* in region *s* (as above). In an IO account, household production is solely composed of the provision of labour services, so the additional row entries will be payments to labour services, or 'income from employment', divided by total input/output. In the case of households, where no labour is directly employed the coefficient will collapse to zero. In the

[3] There will not be a one-to-one correspondence between the IO and CGE analyses in this regard as the CGE framework includes non-wage household income. Note also that since household expenditure does not tend to balance with household income in an IO framework (since not all elements of income and expenditure are included), strictly speaking we should retain a portion of household expenditure as being exogenously determined, or use a social accounting matrix (SAM) in place of the IO accounts.

additional column, x_{ij}^{rs} will record use of local inputs from each production sector, *i*, by the household sector, *j* (formerly recorded as final consumption) and X_j^s as the total input/output of households in region *s*, which is given by total payments to labour/income from employment.

If final consumers also directly generate emissions of CO2, in the Turner et al (2007) method these are determined using a 1x*Z* vector, $\mathbf{e_r^y}$, of coefficients giving the amount final expenditure-pollution coefficients for each final consumption group *z* in each region *r*, with each element e_z^r telling us the physical amount of CO2 directly generated per unit of final expenditure, f_z. In the current study only one final consumption group, households (hh), is responsible for direct emissions generation, and, in our Type II analysis households move into the production block as a fourth sector in each region. Therefore, direct emissions generation by households is accounted for by extending the $\mathbf{e_r^x}$ vector in each region with the additional elements e_i^r, where *i* represents the household sector producing labour services, and we have the physical amount of CO2 directly generated per unit of income from employment (the valuation of household labour services).

The 2x2 partitioned **P** matrix derived in [2] for the Type II case gives us total emissions in regions 1 and 2 attributed to final consumption demand in each region for the outputs of the 2 regions. The total emissions generated in region 1 (Scotland), p_1, are given by summing along the first row of each **P** matrix so that

[4] $$p_1 = p_{11}^y + p_{12}^y$$

while the total emissions in both regions of the UK that are supported by region 1 (Scottish) final consumption demand are given by summing down the first column of each **P** matrix so that

[5] $p_1^y = p_{11}^y + p_{21}^y$

The corresponding calculations for RUK are carried out using the second row and column of the **P** matrix.

According to Munksgaard and Pedersen's (2001) method, Scotland's CO2 trade balance with RUK would be calculated as the difference between [4] and [5]. However, the distinction here is that the UK is not a closed economy, with the implication that [5] does not fully account for Scottish emissions under Munksgaard and Pedersen's (2001) consumption accounting principle. This would require extending the interregional system in [2] to include other trading region(s), which would, among other things, require information on the commodity breakdown of imports and corresponding pollution technologies. The data to do this for the UK are not currently available. Other authors (e.g. Druckman et al, 2008) have attempted to extend IO attribution analyses under the consumption accounting principle using, for example, the assumption that domestic production and pollution technology applies to imports. In McGregor et al (2008) we address this issue by fully endogenising trade in what we refer to as a Trade Endogenised Linear Attribution System (TELAS), closing the system at the national level under the production accounting principle. Here, for simplicity (given the illustrative nature of our current analysis) we do not attempt any such treatment, instead allowing domestic emissions to be attributed to demand from the rest of the world (ROW), with the implication that emissions attributable to ROW demand for Scottish output will be allocated to Scotland's pollution account, and similarly for ROW demand for RUK outputs. However, appropriate extensions of the framework are being addressed in our current research (see Footnote 3).

2.2 Type II Scotland-RUK environmental trade balance results

A number of data problems were encountered in constructing the interregional IO and SAM framework used in this paper. These are explained in McGregor et al (2008). However, the questions over the reliability of the data mean that the quantitative results of any analyses using the Scotland-RUK environmental IO and CGE models should be regarded as provisional. Nonetheless, we believe that there is still merit in using the framework for an illustrative attribution analysis to examine the nature and level of interdependence between regions of the UK, specifically in terms of environmental spillover effects, the existence of a CO2 ‘trade balance’, and the impacts on key variables when a demand disturbance is introduced to the system. The reader is reminded that the motivation for the current paper is not to conduct an empirical analysis as such; rather the Scotland-RUK models are used to provide a simple numerical example of the potential added value in moving from IO to CGE analysis where interest lies in examining the impacts of marginal *changes* in acitivity

Table 1 shows the results of estimating equation [2] for the Type II case (i.e. with household expenditure endogenised within the interregional A-matrix), with all CO2 emissions generated in the UK allocated to the remaining final demand categories in each region. It shows the scale of the CO2 “trade” (or “spillovers”) that occur between Scotland and the rest of the UK. Of the total CO2 generated in the UK directly or indirectly as a result of conventional Scottish final demand expenditures, just over 45% is generated in RUK (i.e. not in Scotland). A smaller, but still significant, proportion (just over 38%) of CO2 generated in Scotland is to support, directly or indirectly, RUK final demand. Also note that Scottish exports to the rest of the world, which produce no direct CO2 outwith Scotland, still generate sizeable amounts of CO2 in the RUK as a result of the indirect impacts of the production of intermediate inputs, and similarly for the impact of RUK exports to the ROW in terms of CO2 emissions in Scotland.

There is a negative CO2 trade balance for Scotland, implying that the pollution generated in Scotland by production to support RUK final demands is less than the pollution generated in the RUK by production supporting Scottish final demands. This Type II Scottish CO2 trade deficit equates to around 13% of total CO_2 generated in Scotland. Note, however, that the precise levels and proportions of emissions attributable to different activities, and the size of the CO_2 trade balance in Table 1 are dependent on the Type II assumption employed here. See McGregor et al (2008) for the impacts of adopting different assumptions (Type I and TELAS) in the same framework For example, when trade is endogenised, under the TELAS assumption, Scotland's CO_2 trade deficit becomes a surplus, due to Scotland being a net exporter to the ROW, while the RUK region is a net importer.

2.3 Modelling the impacts of a change in demand using the interregional IO framework

The analysis above is an accounting exercise, where we attribute CO_2 emissions generated in the UK in the year to which our accounts relate (1999) to different elements of final demand for UK production. Here the elements of the A-matrix are taken to represent average input requirements in 1999, and the multipliers given by the Leontief inverse matrix tell us, on average, what levels of activity, including pollution generation, were supported by different types of final demand during this time period. However, multipliers can also be interpreted as telling us how activity will change if final demands increase or decrease. This transforms the IO accounting framework into a model and, as with all models, requires that we adopt a range of assumptions. The question is whether it is appropriate to adopt these assumptions.

Let us take the illustrative example of a 10% increase in export demand from the ROW to the RUK Primary, Manufacturing and Construction sector (see Table 2 for the definition of this sectors within the Scottish-RUK interregional IO framwork – note that this is highly aggregated purely for the purpose of the illustrative analyses presented in this paper). This is not intended to be a representation of a realistic, or likely, demand shock. Rather, our intention in this very aggregated framework is to illustrate the importance of interregional trade linkages in modelling the impacts of marginal changes.

The shock is introduced to the model by changing the value of the y_2^{ROW} vector in the matrix of final demand in equation [2] to represent a 10% increase in ROW export demand to sector 1 in region 2, RUK. Table 3 shows the impacts of the disturbance (in terms of percentages changes given by the base of the 1999 IO tables) on sectoral output (income from employment in the case of households), value-added (equating to GDP at basic/producer prices), employment and direct CO2 emissions. In examining the results, we again remind the reader that this is a simple numerical analysis intended to draw attention to qualitative issues in terms of the type of results we get from IO and CGE models.

There are two key points to note in examining the IO results in Table 3. First, note that at the sectoral level the percentage change in each variable is the same. This is due to the assumption of Leontief technology (if output changes by X%, use of all inputs changes by X%). Second, there is no indication as to the time taken to reach the new post-shock equilibrium. We will return to both these issues below.

The post-shock CO2 attribution and trade balance analysis is shown in Table 4. This is comparable with Table 1 above, and the difference between the two tables is shown in percentage terms in Table 5. In terms of the impact of the shock, the key result to note is that Scotland's CO2 trade balance improves in response to this shock. The deficit in Table 4 is reduced relative to the base case shown in Table 1. Table 5 shows that the driver of this is the fact that the amount of pollution generated in Scotland to support RUK final demand has risen by 6.72%. This leads to an 8.41% reduction in the size of Scotland's CO2 trade deficit with the RUK. Almost half (46%) of this change in the CO2 trade balance is due to the increase in emissions from the Scottish Electricity, Gas and Water Supply sector. This sector in Scotland is heavily trade-reliant, exporting almost 26% of its output to RUK in the base year of 1999 (in contrast to the RUK Electricity, Gas and Water Supply sector, which exported less than 1% of its output to Scotland in 1999).

However, the key point in terms of the methodological issues being discussed here is that the increase in Scottish and RUK UK emissions to support RUK final demand is the *only change* in Tables 4 and 5. This reflects the fact that there is no response in any other type of final demand, and this would not be expected given that (a) all other final demands are determined exogenously; (b) even if other final demands were determined endogenously, there is no change in prices to stimulate further changes. Again, as we will see below, in a CGE analysis neither of these assumptions is required.

3. The added value from developing on IO accounting analysis to CGE modelling analysis

3.1 Generic issues

The objective of the current paper is to investigate the potential added value from developing on the above IO accounting analysis of environmental trade balances for a given time period to the use of interregional general equilibrium frameworks for analysing the impact of any marginal *change* in activity. IO can be used for impact analyses. However, it is our argument that IO in general, and the interregional IO framework in the current context, is limited in this regard. First, the system in [2] is a conventional demand-driven IO model in which is silent on prices (and, thus any changes in prices and response to these changes) and assumes an entirely passive supply-side in the economy (i.e. all supply is infinitely elastic in response to changes in final demand, within the **Y** matrix, where all final demand is determined exogenously). Moreover, it is further restricted by the assumption of universal Leontief (fixed proportions) technology implied by the use of the **A** and Leontief multiplier matrices in production (which implies that, if relative prices were to change, there would be no input substitution as all goods and services are complements in production in consumption; this is demonstrated in the IO modelling analysis in Section 2.3 above).

It is possible to construct a supply-driven IO model (Oosterhaven, 1988, 1989) or a price dual to the demand model (Leontief, 1970, Allan et al, 2007b). However, in either case, the assumption of universal Leontief technology still applies and it is only possible to model supply *or* demand, or prices *or* quantities. That is, supply or demand must be passive (infinitely elastic) and only prices or quantities can be considered. Our argument is that, where analysis of marginal changes in activity is required, a more flexible interregional CGE approach, which models behavioural relationships in a more realistic and theory-consistent manner, is more appropriate and informative.

Generally, what CGE models offer is a more flexible approach to modelling both supply and demand behaviour, and consideration of how both prices and quantities may change in response to a change in activity. It is possible to incorporate a range of theoretical perspectives, different market conditions and macroeconomic closures. Moreover, CGE models need not be static; it is increasingly common to model dynamic adjustment processes from one equilibrium to another as the supply of different factors respond to changes in returns.

For example, where there are short-run constraints on capital stocks and labour supply, there will be ‘crowding out’ in the local economy if, for example, export or public sector demand increases. This will cause competition among production sectors for the use of limited factor inputs, driving up the return on these factors, which will in turn impact on local prices and competitiveness. This will impact on existing levels of intermediate and final demands – i.e. both will be respond endogenously, but this requires that the assumption of universal Leontief technology be relaxed (e.g. by using CES or Cobb-Douglas functions in modelling production and/or consumption behaviour). However, a change in factor returns will also induce a change in factor supplies. For example, if the return on capital increases, this will induce investment to increase the capital stock, or migration of labour if local wages increase relative to wages in other regions/countries. Following this type of argument, McGregor et al (1996) argue that an IO equilibrium (i.e. one where relative prices are unchanged relative to the initial equilibrium) may be replicated in the long run in a CGE analysis of a pure demand disturbance. However, if there are any constraints on the expansion of factors supplies (e.g. restrictions on migration to the region/country being modelled), a long-run IO equilibrium will not be replicated, but such constraints can be modelled in a CGE framework. Moreover, if the scenario being modelled involves a change in supply side behaviour (e.g. improved technological progress/increased efficiency in the use of inputs to production), there will be permanent changes in prices and an IO equilibrium will not be replicated even in the long run. It is also not clear how supply-side shocks could be introduced in an IO framework, where supply *or* demand are assumed passive, only prices *or* quantities are modelled and technology is of fixed Leontief form.

CGE models generally share the multi-sectoral economy-wide database of IO, but this is usually augmented to incorporate information on income transfers between economic agents in a social accounting matrix (SAM), which allows a wider range of issues to be examined (including, for example, changes in government revenues in response to any shock, and changes in policy instruments such as income taxes). How a CGE model is specified will depend on the economy (or economies) under study and the type of issues to be analysed. However, it is generally the case that it is possible to examine any given scenario under a range of theoretical perspectives regarding how different markets function, macroeconomic closures, the impacts of alternative assumptions regarding production technologies etc.

3.2 An illustrative CGE model: the AMOSRUK interregional model of Scotland and the rest of the UK

In this paper we present an illustrative example of the added informational and analytical content of a CGE analysis of the demand shock first introduced to our IO model in Section 2.3. We focus on modelling the adjustment process from one equilibrium to another in response to the increase in demand, with crowding out due to supply constraints (on labour and capital) in the short to medium run, and how this affects prices and competitiveness where all (intermediate and final) demands are determined endogenously and the assumption of Leontief technology is relaxed. We also demonstrate the impact of different assumptions about economic behaviour. Since our numerical example is an interregional one within a national economy, we take the example of how regional labour markets function as an area where different theoretical perspectives are of particular interest. Specifically, we introduce the same demand shock as presented in Section 2.3 three different times, vary our assumptions about how wage determination and population/migration processes operate between Scotland and the rest of the UK. Note that in our CGE framework it would be possible to model the impacts of a supply-side shock also. However, in order to compare 'like with like', in the current paper we focus on a demand disturbance, but use the CGE model to demonstrate how alternative specifications of supply-side behaviour at the regional and national levels effect model results. In all cases, we observe a qualitative difference in the environmental trade balance results relative to the IO case presented in Section 2.3, in terms of (a) the different stages of the adjustment process with crowding at the sectoral and regional level out due to the presence of supply constraints in early periods; (b) the impact of endogenous prices and final demands.

Fuller details of the AMOSRUK modelling framework used here are given in Gilmartin et al (2008) [4]. In summary, the main features through which the CGE model adds value in analysing the impacts of the marginal change in activity are as follows:

- A degree of substitutability (in response to changes in relative prices) is introduced between different inputs to production – labour, capital, locally supplied intermediates, imports from the other region and the rest of the world - and final consumption expenditure on goods and services (as production, excluding capital and labour).

[4] 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.

- 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 in terms of relative prices, but also the structure of all elements of intermediate and final demand in the other region.

- The model is dynamic with primary factor (labour and capital) stocks updating between periods. Given the annual data in the base year SAM[5], 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 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 one of the simulations reported below, regional labour forces can be adjusted through interregional migration within the UK.

4. CGE analysis of the CO2 trade balance between Scotland and RUK

4.1 Simulation strategy

[5] Details on the SAM used here can be found in McGregor et al (2008).

The analysis reported in this section replicates the demand disturbance introduced to the interregional IO model in Section 2.3. It considers the system-wide effects on Scotland and the RUK of a 10% increase in ROW export demand for the outputs of the RUK Primary, Manufacturing and Construction sector 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 changes in relative real wage and unemployment rates in Scotland and RUK.

These labour market configurations are summarised in Table 6 (fuller details are given in Gilmartin et al, 2008). Basically, since one of the core differences between IO and CGE models is the ability to model changes in prices and supply constraints, what we are doing in these three scenarios is looking at (a) the major source of changes in prices from the labour market, real wages and (b) the main constraint on labour as a factor of production, whether the labour supply in each region can adjust through interregional migration. We label the first scenario, Quasi IO because it is closest to IO with the real wage fixed. There is no interregional migration of the labour force, so that regional employment is determined solely by regional labour demand. Increased employment is met by increased regional labour market participation, but with no change in real wages, so neither region suffers adverse competitiveness effects generated specifically through the labour market as export demand expands. The nominal wage might change but only in response to changes in the regional consumer price index (CPI). Capital fixity dictates supply restrictions, so that marginal costs and prices rise in the short run when output expands. Over time, however, investment optimally adjusts capital stocks, relaxing capacity constraints, and for a demand shock the economy ultimately operates like an extended conventional IO system (McGregor et al, 1996). In the other two scenarios, we move further away from the IO case, first allowing the real wage to vary (but with population remaining fixed at the regional level) in the Bargaining scenario, then allowing both real wages and regional population to vary in the Flow Migration scenario.

Under each scenario the increase in export demand is introduced as a permanent step increase in demand in period 1 and the model is run forward for 75 periods (years). [6] As in the IO analysis in Section 2.3, the values of all other exogenous variables are held constant, and the changes from the initial base-period value are reported for the key variables. Crucially, though, all export demands are determined endogenously and respond to the relative price changes that occur in response to the initial exogenous demand shock. In all cases, investment is endogenous and sectoral capital stocks are updated between periods. As noted above, under the Flow Migration configuration the regional populations are adjusted in a similar manner but remain constant in the other two.

The model calibration process takes the economy to be initially in long-run equilibrium, so that if the model is run forward with unchanged exogenous variables and parameters, the endogenous variables continuously take their initial values. Introducing a step change drives the economy towards a new long-run equilibrium and it is the paths to the new, comparative static, equilibria that are reported here. The different model configurations generate both different long run equilibria and different adjustment paths.

[6] Note that it is possible to introduce disturbances (on the supply or demand side) more gradually to the CGE model, and shocks may be permanent or transitory. This is not the case in the IO model.

In each simulation, we run the model period-by-period (year-by-year) and use the results to create a new interregional IO table (incorporating the impacts of the demand shock) and use this to estimate the environmental trade balance between Scotland and the Rest of the UK using Equations [2] and [5] above.

4.2 Simulation results – economic impacts

When we introduced the 10% ROW export demand stimulus to the RUK Primary, Manufacturing and Construction sector in the IO model in Section 2.3, we found that this increases activity in RUK, as the region directly targeted with the shock, but also in Scotland. The boost to Scotland is indirect, driven by the need for RUK sectors to import intermediate inputs required to meet the increase in demand from Scotland. Since there were no supply constraints in the IO framework, activity in both regions increases with no changes in prices that may lead to negative competitiveness effects and, thus, the full initial increase in RUK export demand in reflected in the new equilibrium. In terms of the CO2 trade balance between Scotland and RUK, only one element changed – Scottish emissions supported by RUK final demand from ROW, because the latter is the only change in final consumption activity.

Overview of transmission of economic impacts under the three scenarios

In our CGE model, the first difference is that we model the adjustment process of the economy in response to the demand disturbance. There is not sufficient excess capacity in the system to meet the increase in demand at the outset. In the short run capital stocks are fixed, as is population in each region. In all three labour market scenarios identified above, capital stocks gradually update through investment, but the adjustment (or not) of regional labour supplies varies, as does the treatment of labour costs. However, in all three scenarios, there is an increase in total factor costs in the region directly targeted with the shock (RUK), at least through increased capital rental rates. This puts upward pressure on production costs and the price of output in all three RUK production sectors (not just the sector directly targeted with the shock). As a result there are negative competitiveness effects so that the initial increase in ROW export demand to the RUK Primary, Manufacturing and Construction sector is not fully realised from the outset, and ROW export demand actually initially falls in the other RUK production sectors – see Figure 1 (for the example of the Quasi IO scenario). This is because ROW export demand responds to changes in the price of outputs in the CGE model; this was not the case in the IO model where (a) there are no changes in prices, (b) all export demands are exogenously determined. Only as the capital market fully adjusts over time, are the full effects of the initial demand stimulus realised and the negative competitiveness effects disappear in the other production sectors.

The other region, Scotland, is not directly impacted by the ROW export demand shock. However, there is a positive demand stimulus, as in the IO case in Section 2.3, as RUK production sectors need to import intermediate imports from Scotland. However, Scotland also imports from RUK so there is also a negative supply shock in Scotland as a result of rising prices in RUK. Moreover, the indirect demand stimulus also puts upward pressure on capital rental rates in Scotland as well. Therefore, until capital markets in both regions fully adjust, there are also negative competitiveness effects in Scotland, as shown (for example) in Figure 2 in the quasi IO case. The key point is that in the IO analysis in Section 2.3, the export demand shock manifests as a pure (positive) demand shock, directly in the target region (RUK) and indirectly in the other region (Scotland). However, in the CGE analysis (all three scenarios), the presence of an active supply-side means that in both regions the effects of the disturbance are both supply and demand orientated, but in Scotland the supply-side effects dominate in the initial periods after the shock is introduced.

In terms of the pollution content of trade flows, the endogeneity (price responsiveness) of final demands mean that all elements of the CO2 trade balance are affected. We examine the environmental trade balance results in detail in Section 4.3. First, though, while the discussion above gives an overview of the economic impacts of the demand shock in broadbrush terms, our different assumptions regarding the labour market in each of the three scenarios detailed above lead to different results from the CGE model. Let us examine each of these in more detail.

Quasi IO scenario – economic impacts

In this case, the fixity of the real wage limits the negative competitiveness effects discussed above. However, nominal wages will rise due to increases in the consumer price index (feeding through from the increased price of capital). However, as reflected in Figure 1, the negative competitiveness effect does still prevent the full 10% increase in ROW export demand to the RUK Primary, Manufacturing and Construction sector being fully realised in the net increase in export demand to this sector. Indeed, given the size of the disturbance, it is never fully realised in the 75 period modelled here (i.e. it takes longer than 75 years for the economy to adjust to a new long-run equilibrium where all upward pressure on prices is relaxed). In Figure 1 ROW export demand to the target sector only increases by 9.94%. However, this is greater than in the Bargaining and Flow Migration scenarios where, as we discuss below, negative competitiveness effects are greater and ROW export demand to this sector only increases by 7.45% and 7.54% respectively in these two alternative scenarios. Overall, the fact that real wages are fixed in the Quasi IO scenario means that the biggest increase in RUK GDP is observed in this case (see Figure 3), and it also comes the closest to the magnitude of the RUK IO value-added result reported for the IO analysis in Table 3.

In terms of the other region, Scotland, which is not directly targeted with the demand stimulus, the biggest long run increase in GDP is also observed in the Quasi IO case (see Figure 4). However, note that in the first seven years after the shock, there is actually a negative impact on Scottish GDP even in the Quasi IO case (we return to the other two scenarios below). The biggest boost to interregional trade within the UK is found in the Quasi IO scenario because this is the case where there the negative competitiveness effect is smallest in RUK due to the real wage being fixed. However, the positive demand stimulus to Scotland takes time to feed through. In the initial years after the shock the increases in RUK output prices (affecting RUK import prices to Scottish production) and increases in nominal wages in Scotland reduce the competitiveness of the Scottish economy and reduce ROW export demand, as shown above in Figure 2.

The key point is that in the RUK region, there is an adverse supply reaction to the demand stimulus while supply constraints exist. However, the direct demand stimulus dominates so that overall GDP increases, even in the short run (Figure 3). Over time, supply constraints relax and the full effects of the demand shock are almost fully realised (Figure 1) and transmitted to the wider economy. Scotland, on the other hand, does not receive the initial ROW demand stimulus. The demand stimulus to Scotland is indirect through increased demand for intermediate and final demand for Scottish production in RUK, and these effects take time to feed through. Therefore, the adverse supply shock dominates in Scotland in early years. The increase in RUK prices feeds through to higher prices in Scotland and this negatively affects Scotland's external competitiveness and ROW export demand (Figure 2). Again, even by period 50 the increase in Scottish GDP in the Quasi IO case is similar in magnitude to the Scottish value-added result in the IO results in Table 3. However, what the latter doesn't give us is the adjustment process and short-run crowding effects observed in the CGE analysis.

Bargaining scenario – economic impacts

The results from the Quasi IO CGE model configuration serve as useful benchmark against which the Bargaining and Flow Migration results can be compared. The introduction of bargained real wages, either without migration (the Bargaining scenario), or with migration (the Flow Migration scenario), reduces the size of the relative GDP stimulus in both the RUK and Scottish economies, as the responsiveness of wage rates gives rise to negative competitiveness effects that are maintained into the long run (Figures 3 and 4). Even the long-run results of these two scenarios are quite different to what was observed in the IO analysis in Section 2.3.

Let us relax one assumption at a time and take the Bargaining scenario first, where we maintain the assumption that population is fixed at the regional level, but allow the real wage to vary in both regions (with wages inversely related to the unemployment rate – see Gilmartin et al, 2008). When the demand stimulus is introduced to the RUK Primary, Manufacturing and Construction sector, as before this stimulates the derived demand for labour. Without migration of labour (flexibility in the supply of labour) and/or sufficient excess capacity (equilibrium unemployment), this leads to an increase in RUK real wage rates, which, in turn, increases the upward pressure on the price of output in all RUK production sectors. As a result, the negative competitiveness effects that dampen ROW export demand for RUK goods and services are larger than in the Quasi IO case. This is reflected in the change in total ROW export demand to RUK under the three alternative model configurations in Figure 5.

The price of RUK exports to Scotland also rises. This acts to reduce Scottish import demand from RUK (see Figure 6). However, while in the Quasi IO case, this recovers so that interregional trade from RUK to Scotland increases over time (as supply constraints relax and the indirect demand stimulus works its way through), in the Bargaining (and also Flow Migration) case there is a permanent decrease in Scottish demand for RUK production due to the permanent supply-wide shock where real wages are variable. The adverse supply shock in Scotland is made worse by the fact that Scottish real wages are also variable, which further impacts on Scottish competitiveness so that ROW export demand for Scottish outputs are also permanently lower. Scottish exports to RUK do increase (in response to the large demand stimulus to RUK); however, Figure 8 shows that the growth in this trade flow is smaller under the Bargaining scenario than Quasi IO. Overall, the more adverse supply shock to the Scottish economy leads to a much smaller long run increase in Scottish GDP in response to the demand shock into the long run under the Bargaining scenario (Figure 4).

Flow migration scenario – economic impacts

However, if we compare the RUK and Scottish GDP results in Figures 3 and 4, we see that, while it is under the Bargaining scenario that we observe the smallest increase in RUK GDP, it is under the Flow Migration scenario that Scottish GDP performs worst. Indeed in the Flow Migration case, Scottish GDP actually continues to fall over time.

The Flow Migration scenario involves relaxing the regional population constraint and allowing interregional migration between Scotland and RUK in response to changes in relative real wage rates and unemployment in the two regions. This lessens the adverse effect observed in the RUK under the Bargaining scenario. Migration to the UK in response to increased real wage wages reduces the tightness in the RUK labour market. As we saw above, relaxing the Quasi IO assumption of fixed real wages reduces the competitiveness of RUK production in the Bargaining scenario. However, while this still applies in the Flow Migration case, when migration is allowed the increase in the real wage triggers in-migration of labour to RUK. The labour supply constraint still exists at the national level. However RUK producers can draw labour from Scotland as the UK real wage rate rises and the unemployment falls relative to those north of the border. This in-migration mitigates, to some extent, the rise in the RUK real wage over the longer run relative to the Bargaining scenario so that ROW export demand

(Figure 5) and GDP (Figure 3) increase by more under Flow Migration (but still by significantly less than in the Quasi IO case).

In Scotland, on the other hand, the introduction of interregional migration has a *negative* impact on long-run GDP (Figure 4). Migration works to counteract the indirect demand stimulus to Scotland. As labour is drawn out of Scotland, this has the opposite effect to what happens in RUK under Flow Migration: the Scottish labour market tightens as out-migration acts as an additional supply constraint, reducing the Scottish population and labour supply, and, consequently, pushing real wages up further than in the Bargaining scenario. This leads to bigger negative competitiveness effects as Scottish output prices rise by more so that export demand from ROW falls by the greatest amount (Figure 7) and export demand from RUK, which is still stimulated because of the initial demand stimulus, grows by the smallest amount (Figure 8) under the Flow Migration scenario.

4.3 Simulation results – pollution (CO2) trade balance

Just as the CGE model allows us to examine the adjustment of the economy in response to the initial demand shock, it also allows us to examine the consequent changes in the pollution content of trade flows between Scotland and the rest of the UK. We use the CGE model results to do this by recreate the interregional environmental IO table in each period, compute the Type II inverse and apply the base year Leontief output-pollution coefficients. Note that the assumption of a Leontief fixed proportional relationship between outputs (in quantities/real units) and emissions is not required in CGE modelling (see Turner, 2002, for a review). This can be relaxed as with all other technology assumptions. This assumption is applied for simplicity at this stage (but will be relaxed in future applications and development of the AMOSRUK framework). Similarly, a Type II analysis is not required, though the issue of exogenous household final demand in the IO framework is not easily related to the CGE case, where all demands can be endogenously determined.

Table 7 shows the new environmental trade balance between Scotland and the RUK in the first period when the shock is applied in the Quasi IO case. Table 8 shows the percentage difference from the 1999 Type II base given in Table 1. The first thing to note is that there are changes throughout the table, in contrast to the IO case (Table 5) where only emissions in Scotland and RUK supported by ROW export demand changed. This reflects the fact that both prices and quantities are determined endogenously in the CGE framework, and that the former also change due to the presence of an active supply side. This in turn induces further changes in local intermediate and final demands, as well as export demand for production in both regions, and both elements of Scotland's CO2 trade balance (emissions embodied in interregional exports and imports to and from RUK) change. In this first period, Figure 6 has already shown that RUK exports to Scotland fall initially (due to the increase in RUK prices) and this is reflected in the reduction in RUK emissions supported by Scottish final demand. Scottish exports to RUK, on the other hand, rise from the outset as shown in Figure 8 (to meet increased intermediate and final consumption demand) and so do Scottish emissions supported by RUK final demand. The composition of trade flows changes. This is due to the exogenous demand stimulus being focussed in the RUK Primary, Manufacturing and construction sector, with the corresponding Scottish sector receiving the largest demand stimulus from RUK (1.624%). The Electricity, Gas and Water Supply sector receives the smallest RUK export demand stimulus in period 1 (0.698%). However, given the relative emissions intensity of this sector, the emissions in this sector supported by RUK export demand to ROW rise more than proportionately (2.81%).

Table 9 shows the adjustment of Scotland's CO2 trade balance with RUK over the 75 periods modelled. As both Scottish imports from and exports to RUK (Figures 6 and 8) rise the positive impact on the trade balance narrows, but Scotland's CO2 deficit with RUK is reduced overall in all three cases, due to the larger boost in Scottish exports to RUK and the change in the composition of interregional trade.

In terms of CO2 emissions, the Quasi IO case again comes closest to the IO case by period 75 (see Tables 5 and 10). However, we have shown above that this model configuration may overestimate the boost to activity in response to the initial demand stimulus. In the Bargaining case, where real wages also change in response to the shock, reducing the size of the GDP stimulus in both Scotland and RUK, and in the Flow migration case, where the presence of migration work to counteract the extent of the stimulus to the Scottish economy, Scottish imports from RUK fall throughout the period modelled, while exports to RUK still increase (but to a lesser extent than in the Quasi IO case) – see Figures 6 and 8. Tables 11 and 12 show the CO2 trade balance in period 75 in these two cases. In both these cases the change in total regional and national emissions is considerably lower than in the IO or Quasi IO cases (Tables 5 and 10), as would be expected, given the more limited increase in activity.

In terms of the UK's commitment to reduce/limit CO2 emissions generation, the Flow Migration outcome is the most positive, with the lowest increase in national CO2 generation (0.98% compared to 1.02% in the Bargaining case and 3.06 in the Quasi IO case). This actually involves a reduction of 0.77% in total Scottish emissions, but as explained above, this involves a contraction in activity in the Scottish economy.

However, the greatest reduction in Scotland's CO2 trade balance with RUK is observed in the Bargaining case. Here the pollution embodied in exports to RUK rises by more (1.74%) in Period 75 than in the Flow Migration case (0.61%), which offsets a slightly bigger reduction in emissions embodied in imports to Scotland from RUK.

However, as noted above, one of the key benefits of using CGE analysis to inform policy is that we can examine the adjustment path of the economy in response to a given disturbance. With IO analysis, we move from one equilibrium to another, with no explanation of the transition process. We have seen here that convergence to long-run equilibrium may take a significant number of years, much more than the UK Treasury's stated 10-year time horizon for the analysis of regional policies. Table 13 shows the change in the CO2 trade balance at time intervals over the 75-year period modelled. While the ranking of the three configurations in terms of the size of the CO2 trade balance is the same throughout the whole period, the gap between each one changes significantly. Figure 9 illustrates how the absolute change and level of the CO2 trade balance is very similar under the 3 CGE model configurations over 10-year period that policymakers may initially be most interested in, and Figure 10 shows the percentage change in the pollution embodied in gross interregional trade flows between Scotland and RUK. However, if we consult Figures 6 and 8, we can see that only a portion of the adjustment in trade flows is achieved within this timeframe, and in Quasi IO case, there is a qualitative shift, with the change RUK exports to Scotland becoming positive after around 17 years. Therefore, without access to a full CGE analysis, or relying only on the type of IO results computed in Section 2.3, policymakers concerned with the impact of changes in economic activity on consumption-based measures of UK emissions would lacking important information.[7]

5. Summary and conclusions

There is currently a great deal of interest at the national and regional levels in the UK, and internationally, in accounting for carbon emissions using consumption based measures, such as

[7] Due to lack of appropriate data, we do not attempt a full consumption-based measure of UK emissions (including pollution embodied in imports from ROW); rather we focus on allocating total UK emissions (under the production accounting principle) to regional consumption demands (using the consumption

carbon footprints. In this paper we argue that, while IO is a powerful accounting tool in this respect, if there is a need to model the impacts of marginal changes in activity, the IO modelling framework is limited due to its assumption of a passive supply (or demand) side and silence on prices (or quantities). Instead we propose that interregional environmental IO frameworks be used for accounting applications (as is increasingly the case), but, if interest lies in assessing the likely impacts of *changes* in economic activity, that they be used as a database in developing more flexible CGE models. CGE models share the main strengths of IO in terms of a multi-sectoral, system-wide framework, but permit more theory-consistent modelling of both supply and demand-side behaviour. While at this early stage in our research in this area we are unable to offer an illustrative analysis using a more sectorally disaggregated framework, we would argue that sectoral disaggregation is not the key issue in the added value offered by moving to a CGE framework for impact analyses. Rather it is the flexibility in terms of relaxing IO modelling assumptions regarding technology and (the absence of) supply constraints, examining the impact of adopting different theoretical perspectives with regard to the functioning of different markets in the economy, and being able to examine the adjustment process of the economy in response to a demand *or* supply side disturbance.

We illustrate our argument by comparing the results of introducing a positive demand stimulus in the UK economy using both IO and CGE interregional models of Scotland and the rest of the UK (an illustrative supply disturbance, such as an increase in factor efficiency, would be possible in the CGE but not the IO model). In our CGE analysis, we demonstrate how alternative specifications of supply-side behaviour at the regional and national levels affect model results, including the impact on the interregional CO2 'trade balance'. We also show how the CGE framework can be used to track the path of the adjustment of the economy and key indicators (including the CO2 trade balance) over time.

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accounting principle). However, the same broad lessons learned from the analysis presented here would

We close by emphasising that the numerical results are not what we wish to focus upon here, particularly given the early stage we are at in developing our CGE framework. Our numerical results would be qualified on three counts. First, the demand shock introduced is somewhat blunt and unrealistic. CGE models can be used both for more focussed policy analysis (of both supply and demand side disturbances or policy instruments) and to compare results under different theoretical perspectives (as we have done here by configuring our model to represent different stylised versions of labour market configurations that are common in the labour market and regional macroeconomic literature). Second, as explained in McGregor et al (2008), our interregional IO and SAM data for the UK incorporate estimated and experimental data that may distort model results. Third, the 3-sector, 2-region national framework is likely to be too highly sectorally (and perhaps spatially) aggregated for analysis of environmental issues. We are currently in the process of addressing all of these issues in our ongoing programme of research in this area (where we are also developing interregional applications for the US and hope to also to attempt to examine international trade flow issues)[8].

Thus, the reader's attention should be focussed on the qualitative difference in the informational content of a CGE analysis over IO modelling applications where the specific area of interest is the impact of *changes* in economic activity on environmental indicator variables. The intention of this paper has been to bridge the gap between IO accounting analysis of the very important issue of pollution embodied in trade flows and interregional CGE modelling analysis, which, to date, has been mainly applied at a more global level, and not, to our knowledge, to the analysis of the trade in embodied pollution.

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apply to a full consumption-based accounting and modelling exercise.

[8] The basic research on modelling the pollution content of interregional trade flows reported in this paper is currently being developed as part of Karen Turner's ESRC Climate Change Leadership Fellowship (Grant reference RES-066-27-0029). For more details, please contact karen.turner@strath.ac.uk.

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Tables

Table 1. The CO_2 Trade Balance Between Scotland and RUK (tonnes, millions) - Type II Input-Output

	Pollution supported by:						
	Scottish Govt	Scottish Capital	Scot-ROW	RUK Govt	RUK Capital	RUK-ROW	Total regional emissions of CO2
Pollution generated in:							
Scotland	11.3	4.3	14.6	5.7	5.1	8.0	48.9
RUK	8.1	6.3	10.8	144.5	117.9	228.0	515.5
Total (UK) emissions supported by	19.3	10.6	25.4	150.1	122.9	236.0	564.4
Environmental trade balance:							
Scot pollution supported by RUK final demand	18.8						
RUK pollution supported by Scot final demand	25.2						
Scotland's CO2 trade balance	-6.4						

Table 2. Sectoral Breakdown of the Scot/ RUK Inter-regional IO System

Scot/RUK sector		IOC
1.	PRIMARY, MFR and CONSTRUCTION	1-84, 88
2.	ELEC, GAS and WATER SUPPLY	85-87
3.	SERVICES	89-123

Table 3. Percentage change in key variables in response to a 10% increase in ROW export demand to the RUK Primary, Manufacturing and Construction sector

	Output		Value-added		Employment		Direct CO2 emissions	
	Base (£million)	% change	Base (£million)	% change	Base (FTE, thousands)	% change	Base (tonnes, millions)	% change
Scotland:								
PRIMARY, MFR and CONSTRUCTION	52471	0.99%	17134	0.99%	483	0.99%	12.4	0.99%
ELEC, GAS & WATER SUPPLY	5047	1.52%	1508	1.52%	14	1.52%	16.3	1.52%
SERVICES	83723	0.81%	43982	0.81%	1334	0.81%	9.6	0.81%
HOUSEHOLDS	40415	0.87%					10.7	0.87%
Total Scotland			62624	0.87%	1832	0.86%	48.9	1.10%
RUK:								
PRIMARY, MFR and CONSTRUCTION	506584	4.46%	198046	4.46%	5581	4.46%	145.4	4.46%
ELEC, GAS & WATER SUPPLY	42067	2.91%	12896	2.91%	142	2.91%	128.9	2.91%
SERVICES	1031837	1.90%	504567	1.90%	16754	1.90%	109.0	1.90%
HOUSEHOLDS	453771.00	2.63%					132.3	2.63%
Total RUK			715508	2.63%	22477	2.54%	515.5	3.06%
Total	2215914	2.60%	778132	2.49%	24309	2.41%	564.4	2.89%

Table 4. Post-shock CO_2 Trade Balance Between Scotland and RUK (tonnes, millions) - Type II Input-Output

	Pollution supported by: Scottish Govt	Scottish Capital	Scot-ROW	RUK Govt	RUK Capital	RUK-ROW	Total regional emissions of CO2
Pollution generated in:							
Scotland	11.3	4.3	14.6	5.7	5.1	**8.6**	**49.4**
RUK	8.1	6.3	10.8	144.5	117.9	**243.8**	**531.3**
Total (UK) emissions supported by	19.3	10.6	25.4	150.1	122.9	**252.3**	**580.8**
Environmental trade balance:							
Scot pollution supported by RUK final demand	**19.3**						
RUK pollution supported by Scot final demand	**25.2**						
Scotland's CO2 trade balance	**-5.9**						

Table 5. Post-shock CO_2 Trade Balance Between Scotland and RUK (% change from base) - Type II Input-Output

	Pollution supported by: Scottish Govt	Scottish Capital	Scot-ROW	RUK Govt	RUK Capital	RUK-ROW	Total regional emissions of CO2
Pollution generated in:							
Scotland	0.00%	0.00%	0.00%	0.00%	0.00%	6.72%	1.10%
RUK	0.00%	0.00%	0.00%	0.00%	0.00%	6.92%	3.06%
Total (UK) emissions supported by	0.00%	0.00%	0.00%	0.00%	0.00%	6.91%	2.89%
Environmental trade balance:							
Scot pollution supported by RUK final demand	2.88%						
RUK pollution supported by Scot final demand	0.00%						
Scotland's CO2 trade balance	-8.41%						

Table 6: Simulation set-ups

	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 7. Post-shock CO_2 Trade Balance Between Scotland and RUK (tonnes, millions) - CGE period 1 (Quasi IO)

	Pollution supported by: Scottish Govt	Scottish Capital	Scot-ROW	RUK Govt	RUK Capital	RUK-ROW	Total regional emissions of CO2
Pollution generated in:							
Scotland	11.3	4.3	14.3	5.6	5.1	**8.3**	**48.9**
RUK	7.9	6.1	10.4	143.4	116.8	**233.5**	**518.2**
Total (UK) emissions supported by	19.2	10.4	24.7	149.0	121.9	**241.8**	**567.0**
Environmental trade balance:							
Scot pollution supported by RUK final demand	**19.0**						
RUK pollution supported by Scot final demand	**24.5**						
Scotland's CO2 trade balance	**-5.5**						

Table 8. Post-shock CO_2 Trade Balance Between Scotland and RUK (% change from base) - CGE Period 1 (Quasi IO)

	Pollution supported by: Scottish Govt	Scottish Capital	Scot-ROW	RUK Govt	RUK Capital	RUK-ROW	Total regional emissions of CO2
Pollution generated in:							
Scotland	-0.09%	0.05%	-1.84%	-0.34%	0.23%	3.04%	-0.08%
RUK	-1.60%	-2.37%	-3.92%	-0.78%	-0.93%	2.43%	0.51%
Total (UK) emissions supported by	-0.72%	-1.39%	-2.72%	-0.76%	-0.88%	2.45%	0.46%
Environmental trade balance:							
Scot pollution supported by RUK final demand	1.26%						
RUK pollution supported by Scot final demand	-2.79%						
Scotland's CO2 trade balance	-14.63%						

Table 9. Post-shock CO_2 Trade Balance Between Scotland and RUK (% change from base) - CGE adjustment (Quasi IO)

	Period/year after demand disturbance introduced: 1	5	10	15	20	30	50	75
Environmental trade balance:								
Scot pollution supported by RUK final demand	1.26%	1.58%	1.84%	2.03%	2.21%	2.62%	2.94%	3.06%
RUK pollution supported by Scot final demand	-2.79%	-2.34%	-1.84%	-1.48%	-1.20%	-0.70%	-0.33%	-0.23%
Scotland's CO2 trade balance	-14.63%	-13.78%	-12.59%	-11.75%	-11.16%	-10.41%	-9.90%	-9.83%

Table 10. Post-shock CO_2 Trade Balance Between Scotland and RUK (% change from base) - CGE Period 75 (Quasi IO)

	Pollution supported by: Scottish Govt	Scottish Capital	Scot-ROW	RUK Govt	RUK Capital	RUK-ROW	Total regional emissions of CO2
Pollution generated in:							
Scotland	-0.06%	0.93%	-0.10%	-0.60%	2.34%	6.09%	1.21%
RUK	-0.47%	0.55%	-0.50%	-0.50%	2.38%	6.43%	3.24%
Total (UK) emissions supported by	-0.23%	0.70%	-0.27%	-0.50%	2.38%	6.42%	3.06%
Environmental trade balance:							
Scot pollution supported by RUK final demand	3.06%						
RUK pollution supported by Scot final demand	-0.23%						
Scotland's CO2 trade balance	-9.83%						

Table 11. Post-shock CO_2 Trade Balance Between Scotland and RUK (% change from base) - CGE Period 75 (Bargaining)

	Pollution supported by: Scottish Govt	Scottish Capital	Scot-ROW	RUK Govt	RUK Capital	RUK-ROW	Total regional emissions of CO2
Pollution generated in:							
Scotland	0.01%	0.01%	-1.64%	-0.03%	0.27%	3.91%	0.18%
RUK	-1.52%	-1.52%	-3.18%	-0.77%	-0.51%	3.48%	1.10%
Total (UK) emissions supported by	-0.63%	-0.90%	-2.30%	-0.74%	-0.48%	3.50%	1.02%
Environmental trade balance:							
Scot pollution supported by RUK final demand	1.74%						
RUK pollution supported by Scot final demand	-2.23%						
Scotland's CO2 trade balance	-13.84%						

Table 12. Post-shock CO_2 Trade Balance Between Scotland and RUK (% change from base) - CGE Period 75 (Flow migration)

	Pollution supported by: Scottish Govt	Scottish Capital	Scot-ROW	RUK Govt	RUK Capital	RUK-ROW	Total regional emissions of CO2
Pollution generated in:							
Scotland	-0.31%	-1.45%	-2.70%	-1.20%	-0.79%	2.76%	-0.77%
RUK	-0.90%	-2.06%	-3.54%	-0.74%	-0.42%	3.54%	1.15%
Total (UK) emissions supported by	-0.56%	-1.81%	-3.06%	-0.76%	-0.44%	3.52%	0.98%
Environmental trade balance:							
Scot pollution supported by RUK final demand	0.61%						
RUK pollution supported by Scot final demand	-2.32%						
Scotland's CO2 trade balance	-10.89%						

Table 13. Post-shock CO_2 Trade Balance Between Scotland and RUK (% change from base) - CGE adjustment (alternative visions of the labour market)

	Period/year after demand disturbance introduced: 1	5	10	15	20	30	50	75
Scotland's CO2 trade balance								
Quasi IO	-14.63%	-13.78%	-12.59%	-11.75%	-11.16%	-10.41%	-9.90%	-9.83%
Bargaining	-15.00%	-14.86%	-14.42%	-14.06%	-13.93%	-13.84%	-13.84%	-13.84%
Flow migration	-15.00%	-14.50%	-13.59%	-12.78%	-12.31%	-11.58%	-11.03%	-10.89%

Figures

Figure 1. Impact on ROW export demand for outputs of RUK production sectors in response to a 10% increase in ROW export demand to the Primary, Manufacturing and Construction sector (% changes from base year equilibrium)

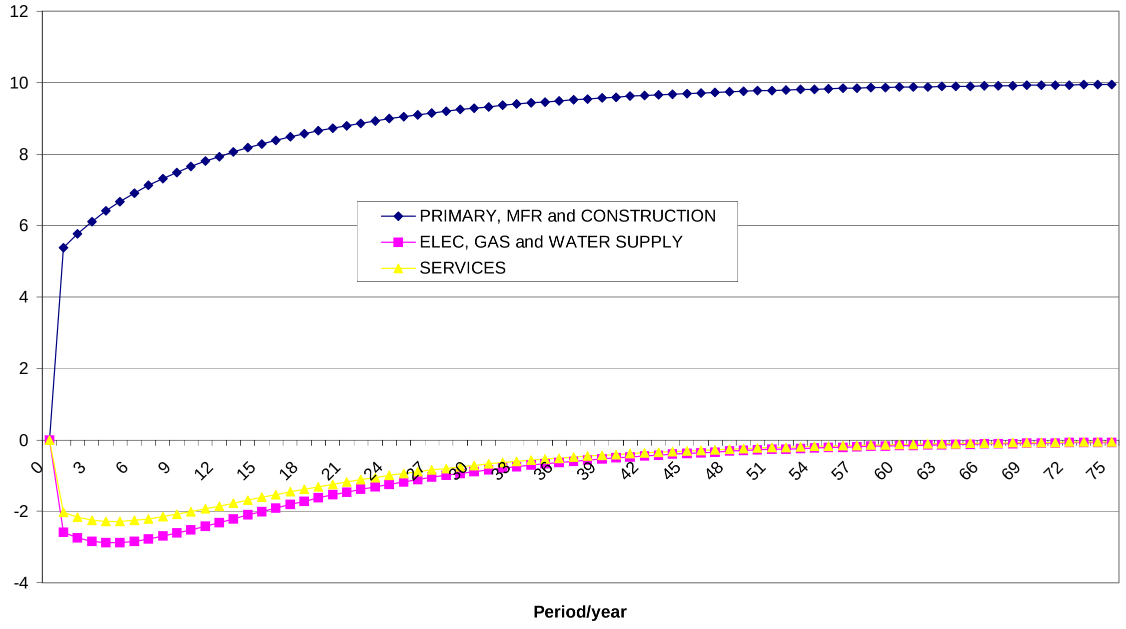

Figure 2. Impact on ROW export demand for outputs of Scottish production sectors in response to a 10% increase in ROW export demand to the Primary, Manufacturing and Construction sector (% changes from base year equilibrium)

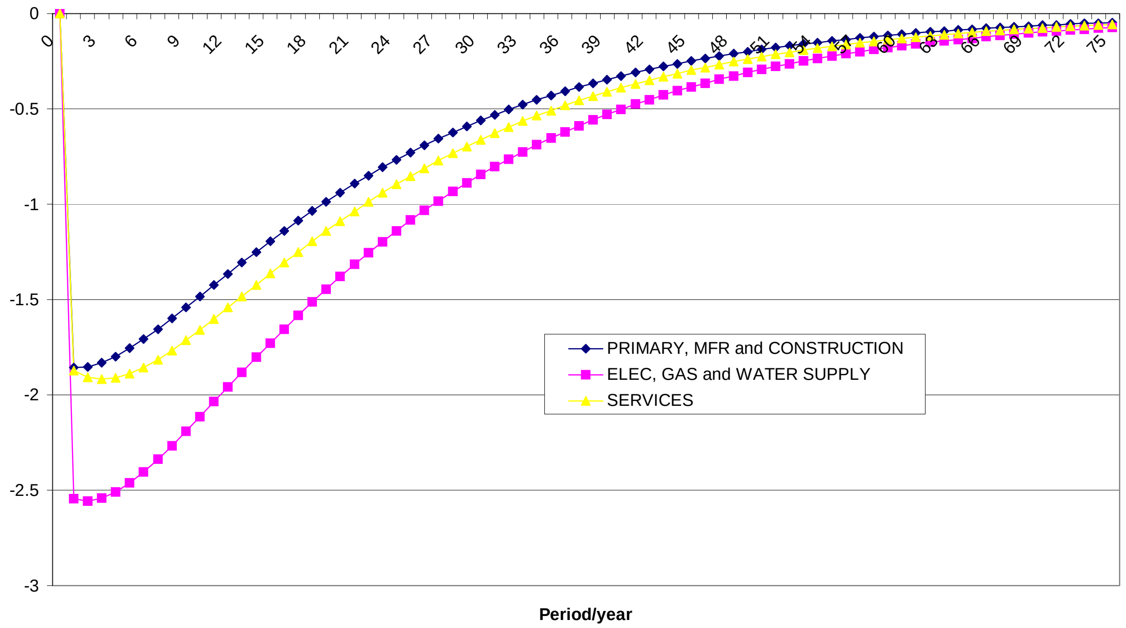

Figure 3. Impact on RUK GDP from a 10% increase in ROW export demand to the RUK Primary, Manufacturing and Construction sector (% change from base year equilibrium)

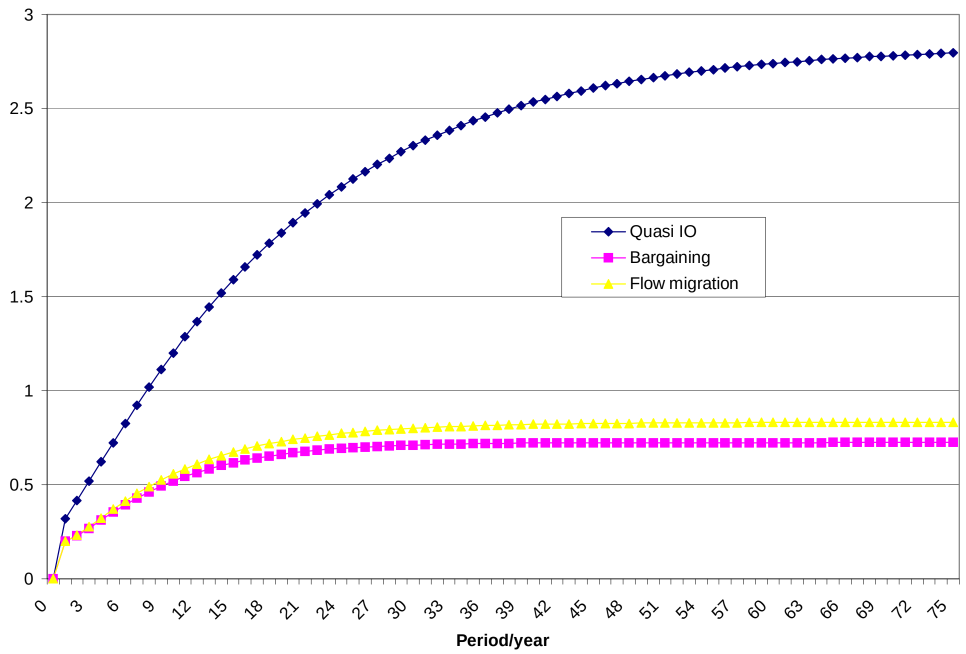

Figure 4. Impact on Scottish GDP from a 10% increase in ROW export demand to the RUK Primary, Manufacturing and Construction sector (% change from base year equilibrium)

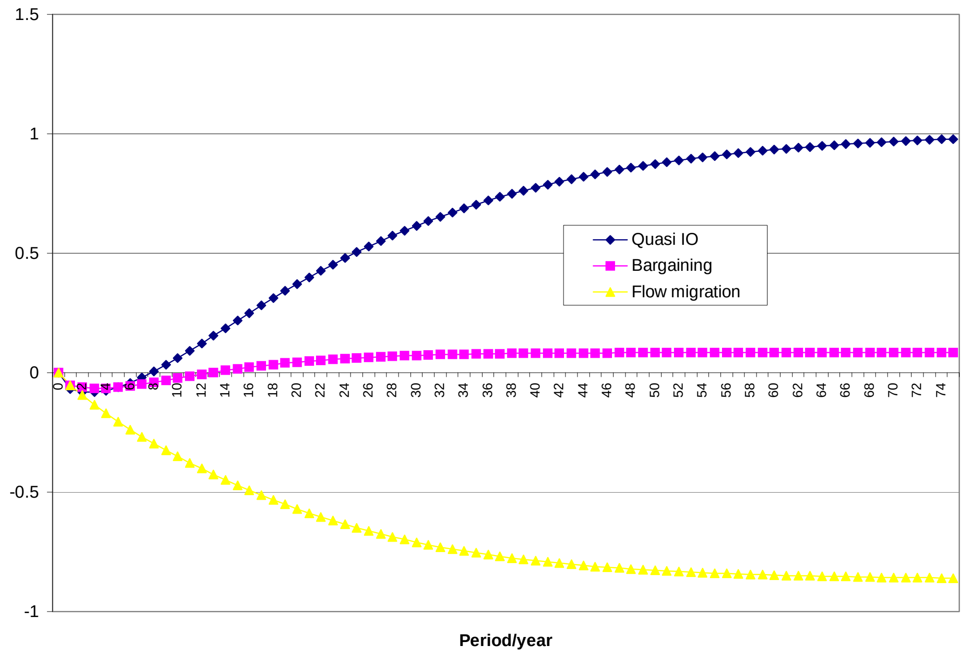

Figure 5. Impact on ROW export demand for total RUK production in response to a 10% increase in ROW export demand to the Primary, Manufacturing and Construction sector (% changes from base year equilibrium)

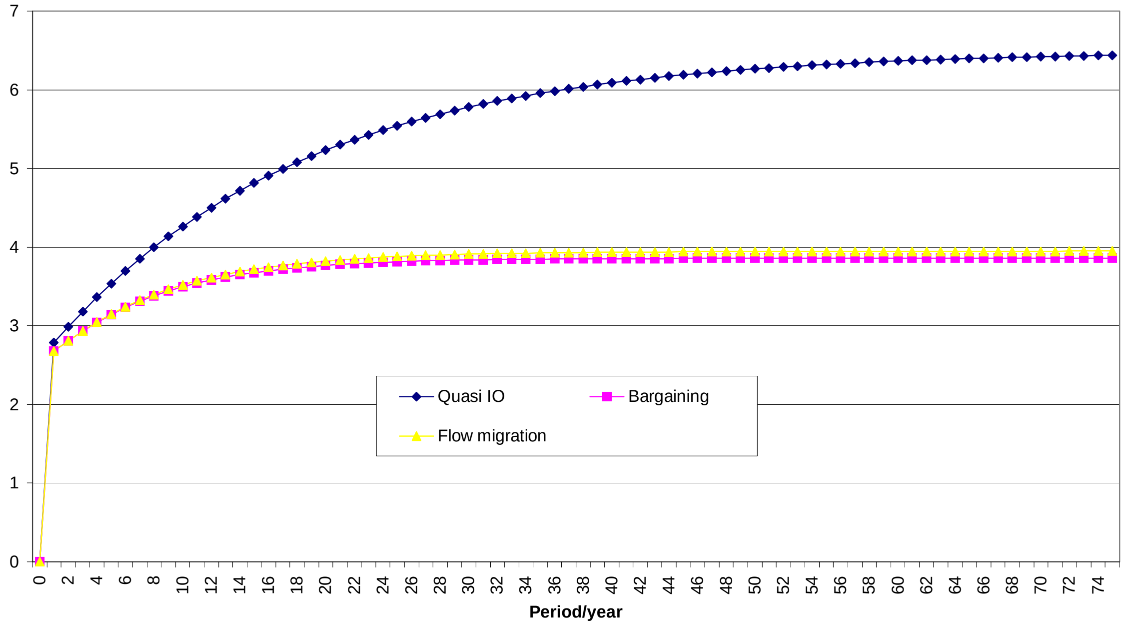

Figure 6. Impact on RUK exports to Scotland in response to a 10% increase in ROW export demand to the Primary, Manufacturing and Construction sector (% changes from base year equilibrium)

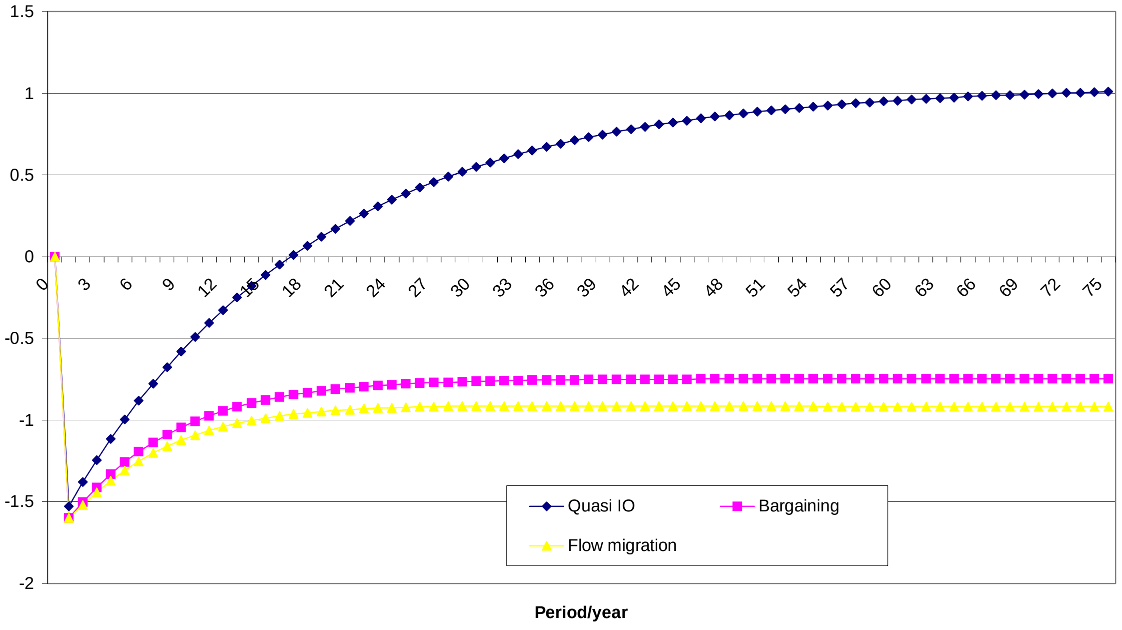

Figure 7. Impact on ROW export demand for total Scottish production in response to a 10% increase in ROW export demand to the Primary, Manufacturing and Construction sector (% changes from base year equilibrium)

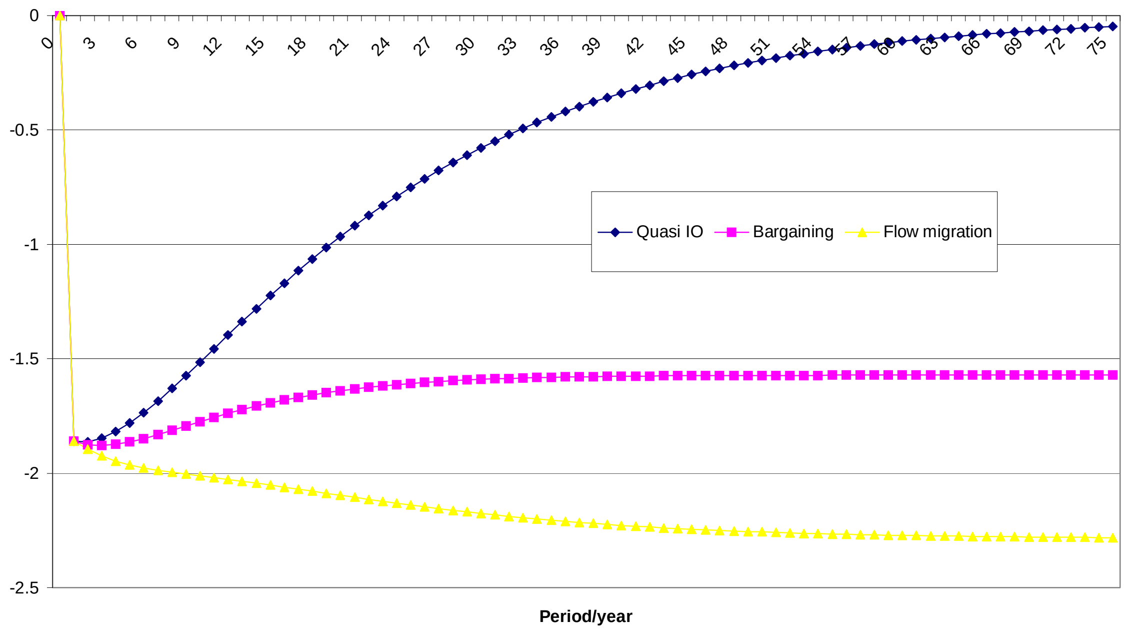

Figure 8. Impact on Scottish exports to RUK in response to a 10% increase in ROW export demand to the Primary, Manufacturing and Construction sector (% changes from base year equilibrium)

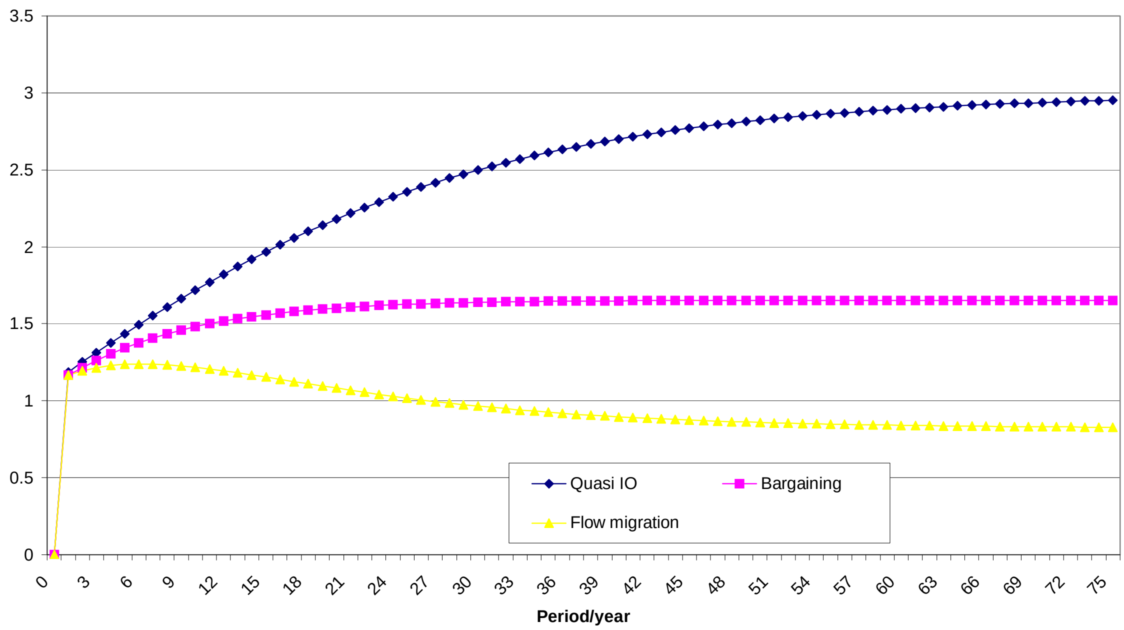

Figure 9 Scotland's CO2 trade balance with RUK in the 10 years following the demand shock (millions of tonnes CO2)

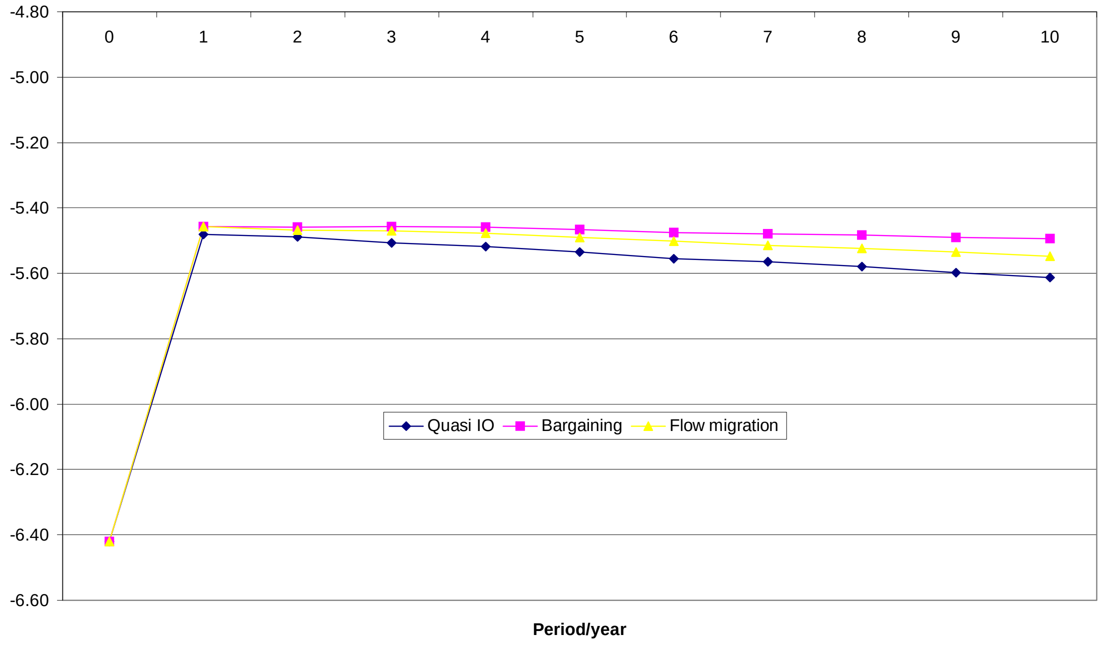

Figure 10. CO2 embodied in gross interregional trade flows between Scotland and RUK in the 10 years following the demand shock (% change from base year equilibrium)