Incorporating jurisdiction issues into an analysis of carbon attributable to Welsh final consumption under different economic conditions: an integrated IO and CGE analysis

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Abstract

This paper considers the combined use of regional input-output (IO) and computable general equilibrium (CGE) methods to examine regional pollution problems from different consumption and production orientated perspectives. The first stage of the analysis involves using a regional input-output framework and data derived on direct CO2 (as carbon) generation by industry (and in household final consumption) to examine regional accountability for CO2 generation. In doing we consider an accounting method that permits greater accountability of regional private and public (household and government) final consumption as the main driver of regional carbon generation, while retaining focus on the local production, technology and consumption decisions that fall under the jurisdiction of regional policymakers.

However, we go on to argue that a potential issue arising from the increasing focus on consumption-based 'carbon footprint' type measures is that regional CO2 generation embodied in export production is attributed outside of the region, while regional consumers are likely to benefit from such production. We demonstrate our argument by using a regional CGE model to simulate the impacts of an increase in export demand for regional production on key macroeconomic variables, including GDP, employment and household consumption, as well as on different measures of CO2 attributable to regional consumption. In terms of the latter, we demonstrate how CGE model results may be used to create 'post-shock' IO accounts to permit the calculation of CO2 generation under the various production and consumption accounting principles considered in the first part of the paper. Our empirical analyses focus on the case example of the Welsh regional economy and an anticipated increase in export demand for the output of one of the biggest polluting sectors, Iron and Steel production.

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Introduction

This paper uses an integrated input-output (IO) and computable general equilibrium (CGE) analysis to examine regional pollution problems using both production and consumption accounting principles (Munksgaard and Pedersen, 2001). Application of regional and interregional IO analyses to attribute pollution generation to different production and consumption activities has become commonplace in the academic literature, though largely with a national/international rather than a regional focus (see Munksgaard and Pedersen, 2001, and Turner et al, 2007, for methods; and Wiedmann, 2009; Wiedmann et al, 2007, for reviews). This reflects growing public and policy interest in accounting for pollution problems using a consumption accounting principle – e.g. carbon footprints, where concern lies with *global* pollution required to support regional consumption – while global agreements on emissions reduction tend to focus on pollution generation within the geo-political borders of individual nations (the production accounting principle).

In this context, we follow Jensen et al (2009, 2010) in considering the question of why policymakers have been slow to enact targets based on limiting emissions under consumption accounting principle measures. They argue that this may be due to the fact that policymakers in one jurisdiction do not have control over production technologies used in other jurisdictions. On this basis Jensen et al (2009, 2010) propose a uni-directional (or quasi multi-region[1]) IO accounting approach that uses a combined use matrix partitioned to identify use of domestic and imported commodities, but adopts a 'domestic technology assumption' (DTA) with respect to polluting technology. They argue this IO accounting approach permits greater accountability of regional private and public (household and government) final consumption as the main driver of regional emissions generation, while retaining focus on the local production technology and consumption decisions that fall under the jurisdiction of regional policymakers. In particular, the

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[1] See Druckman and Jackson (2008, 2009a,b).

key motivation for adopting a DTA approach – where the pollution content of all commodities used in the regional economy is assessed on the basis of the direct pollution intensities (physical pollution generation per monetary unit of output or final consumption expenditure) that apply in the region – is the argument that while regional consumers (and policymakers) may be held responsible for what and how much they import for consumption purposes, they are likely to have little control (or jurisdiction) over polluting technologies employed in exporting countries. Thus, under the consumption accounting principle, pollution content is assessed on the basis of the *savings* made in terms of regional pollution levels by not producing domestically, rather than the actual *costs* in terms of pollution generation in the exporting country.

Our first step in this paper is to recreate Jensen et al's (2010) IO analysis of regional CO2 (as carbon) for the empirical example of the Welsh economy (in 2003) under a production accounting principle (PAP) and a consumption accounting principle under the domestic technology assumption (CAP DTA). However, we focus our analysis (carried out at the 25-sector aggregation of the Welsh economy adopted for the CGE analysis later in the paper rather than the full 74 sector breakdown used in Jensen et al's, 2010, study – see Appendix 1) on the implications of the treatment of carbon attributable to export demands from the rest of the UK (RUK) and rest of the world (ROW) under PAP and CAP. We argue that in addition to the treatment of polluting technology in other countries[2], that a potential problem with 'carbon footprint' type measures is the subtraction of domestic CO2 generation embodied in export production in moving from PAP to CAP (accompanied by the addition of CO2 embodied in improts). The problem centers on the fact that regional consumers are likely to benefit from production to meet export demand, which raises the issue as to whether an exporting region should be entirely alleviated of responsibility for the generation of pollution to meet external demands. That is, in addition to the problem of who should be held responsible for the polluting technology used to produce goods and services for exports, it is not clear that CAP measures such as carbon footprints offer an appropriate treatment of responsibility of activity levels required to meet consumption demands.

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[2] Indeed in later iterations of the current study we intend to relax the DTA assumption using data provided by OECD to identify the actual pollution intensity of production in countries/regions that Wales imports from.

We illustrate our argument by using a regional CGE model calibrated on a Welsh social accounting matrix (SAM), which incorporates the IO accounts used in the initial attribution analysis for 2003, to simulate the impacts of an increase in export demand for regional production on key macroeconomic variables, including GDP, employment and household consumption. The CGE results are also used to assess the impacts of the change in activity on the different (PAP and CAP) measures of CO2 attributable to regional consumption: in this respect, we follow Gilmartin et al (2009) in demonstrating how CGE model results may be used to create 'post-shock' IO accounts to permit the calculation of CO2 generation under the various production and consumption accounting principles considered in the first part of the paper. The specific export demand shock simulated focuses on a current policy issue for the Welsh economy. That is an anticipated expansion in one of the most (directly) polluting sectors of the economy, Iron and Steel (with ferrous metals and metal castings) – see Appendix 1. This is a particularly useful illustrative example, given that production in this sector is heavily export (and intermediate) demand driven.

The remainder of the paper is structured as follows. In the second section, we provide an overview of the policy context of our analysis for Wales. While some of the issues raised may be quite Welsh specific, we would contend that similar types of problems are faced by both regional and national policymakers around the world. In the third section we introduce the IO accounting framework used to produce base year carbon measures under CAP and PAP. This is followed in the fourth section with an overview of the CGE model used to simulate the impacts of a change in export demand to the Welsh Iron and Steel sector, and its use to construct 'post-shock' IO accounts to examine the impacts of the demand shock on the CAP and PAP measures. The fifth section offers some preliminary conclusions and lays out the proposed programme of research to complete the current study.

Policy context – carbon generation and attribution in the Welsh economy

One context of our paper is that different methods of carbon attribution could produce very different messages for policymakers in the Welsh economy. We expect regional economic conditions in Wales in terms of a strong trading propensity are replicated elsewhere meaning that the policy ramifications of our work might be generalised.

Currently the Welsh Assembly Government reports against an extensive basket of sustainable development indicators[3]. Headline pollution indicators are generally reported in production accounting principle terms. For example, greenhouse gas emissions reporting focuses on pollution points within Wales, while waste reporting also reflects what is produced in the regional economy (see also Jensen et al., 2009). Table 1 shows recently reported Welsh greenhouse gas emissions compared to those for other parts of the UK. Production within Wales accounts for around 7% of UK reported emissions, although Wales accounts for less than 5% of the UK's economic activity revealing a relatively higher propensity to pollute. For example, the carbon dioxide emissions per capita for the UK countries in 2007 saw Wales well above other parts of the UK, at 13.1 tonnes per capita, compared to an England and Scotland average of 8.4 tonnes per capita (NAfW, 2009). This reflects not just an economy with a relatively high level of manufacturing compared to most other parts of the UK, but also speaks to specific types of manufacturing activity (see below).

One interesting issue here is that a focus on a production accounting approach means that Welsh industrial emissions could fall significantly in the period to 2020 as older polluting industries with ageing capital move offshore. Moreover, the figures in Table 1 would also be very sensitive to the closure of just one or two key plants in industrial South Wales. A corollary here is that while structural change might lead to the achievement of regional pollution 'targets' then these same targets may be less meaningful if the region merely imports goods connected with high levels of environmental externalities.

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[3] See http://wales.gov.uk/topics/statistics/headlines/sustain2010/100826/?lang=en

In spite of a reporting focus on pollution points (i.e. a production accounting approach) there has been some consideration of the need to understand the externalities connected to Welsh consumption, and then the adoption of the ecological footprint measure as one headline sustainable development indicator. How far a footprint speaking to global land areas needed to sustain current levels of Welsh consumption can be used to inform policy decisions has been questioned (Munday and Roberts, 2006), and with practical issues in collecting appropriate data to inform ecological footprint estimates (Collins et al., 2005). At the same time the very move to at least consider a consumption accounting approach speaks to expected differences in results from the two very different accounting perspectives.

Expected differences in footprint results between a consumption and production accounting perspective are grounded in the importance of trade to a small open regional economy. Something of the issue is highlighted simply by reference to Table 2 and Figure 1. Table 2 shows the concentration of emissions in just a few geographical locations and with the top four pollution points contributing almost 50% of reported carbon dioxide emissions in 2007. However, closer inspection of the main pollution points in Welsh industry also reveals that these same sectors are also at the heart of regional exports. Figure 1 shows the Welsh industries contributing to an estimated £8.7bn of overseas exports in the year to 2010 quarter 2. Metal production, energy and chemicals production are among the main exporting groups. Moreover, this does not include exports to the remainder of the UK and with much of Welsh output in terms of steel, chemicals and automotive products being intermediate products for large scale producers in other regions of the UK.

In summary the carbon intensity of Wales most important industries, coupled with their pivotal role in supporting regional exports, lead to an a priori expectation of a consumption accounting of carbon giving very different results from that derived from a production accounting perspective.

This reality directly led to the case in this paper. While the general analysis begins with an overall Welsh footprint derived using production and consumption accounting principles, the detailed case focuses on the iron and steel sector and how an increase in export demand could be understood under different accounting principles.

The iron and steel industry is never far away from headlines in Wales being a major employer in an industry characterised by extensive peaks and troughs. The main Welsh producer is Tata of India which took over the steelmaking operations of Corus (previously British Steel) in 2007. There are a few smaller steel production sites in industrial South Wales but these are dwarfed by the crude steel production capacity of around 5m tonnes available at the Port Talbot works of Tata. Recent times have seen a reduction in regional employment in basic metals production, and a reduction in the contribution of the sector to Welsh gross value added. Coupled to this have been strong increases in labour productivity, albeit with a proportion of this increase resulting from increased levels of subcontracting in the industry. Tata facilities in Wales employ around 7,000 people, the majority of which are at the large Port Talbot mill. In spite of uncertainty about the future of the Port Talbot mill, the new owners have moved to invest heavily in the plant. Most recently in 2009-10 this has included planned investment to reduce carbon emissions and an expected £185m investment to rebuild a blast furnace (from 2012) and with the rebuild raising capacity at the mill by around 400,000 tonnes per year.

Connected to steel industry output in Wales are strong indirect effects. This is seen in relatively high earnings compared to other manufacturing and services sectors in Wales, as a result of prior strong bargaining by the main steel unions. Indeed steel industry jobs represent an increasingly rare commodity in contemporary Wales – predominantly full time, well paid jobs, encompassing a full quotient of skills. Moreover although steel producing firms import a large proportion of their raw materials from abroad (the Port Talbot steel mills sits adjacent to a deep water port), their local non-wage spending is still significant. Finally regional steel products (either as coil, slab, special or coated products) are a critical input for UK and overseas industries. Much of the output of the largest mills goes as an input to other manufacturing facilities (including in the Welsh case to other parts of the Tata group in Wales) but also directly to industries such as automotive in other parts of the UK.

Reported direct (see Table 2) and indirect pollution externalities from a steel mill reflect complex global linkages. Externalities within Wales are bounded because of the limits on what can be purchased locally. Generally raw materials (e.g. coal and iron ore), alloys, and special metals tend to be purchased globally. For other products there is a trend towards more purchases at the European or UK level such as refractories, industrial paints, and rolls. Local purchasing is more significant in areas such as road transport; engineering and maintenance services; repair and construction; and other on-site services. However, much of the energy is produced on site, and here is one cause of high direct pollution coefficients.

The scenario modelled later in this paper results from increased confidence in the regional steel sector as prefigured in recent investment decisions. Clearly we model a final demand shock in the iron and steel sector. However, on the ground this is most likely to be seen in an increase in the demands for the slab and strip steel products produced by the Port Talbot mill and other ancillary regional operations. Much of the steel product finds its way to intermediate users of strip and coated steels including the car, white goods and electronics industries. Then such a change in final demands is expected to increase the carbon emissions from the steel maker, and result in increases in regional emissions recorded on a production accounting principle. However, our analysis permits a different perspective by showing that much of the industry output goes to exports and with a small proportion supporting final demands in the region. The more complex analysis within the CGE framework also permits a series of feedback effects to be explored which we believe will be of interest to policy makers.

Carbon attribution in the environmental IO framework

Analytical model

We follow Jensen et al (2010) in using the Welsh analytical input-output tables for 2003 as the basis for the attribution analysis. The input-output tables for 2003 provide information on the sales and purchases of 74 defined sectors (see Bryan et al., 2004 and WERU, 2007). Also available are a symmetrical domestic use matrix and an imports matrix, the latter revealing the imports going to these same sectors. These matrices are necessary for the estimation of more complex attributions of carbon emissions discussed later. Data on the emissions generation (carbon dioxide as carbon, and in terms of global warming potential) for 91 defined industries and for the domestic household sector for Wales were derived from information collected as part of the REWARD project (Regional and Welsh Appraisal of Resource Productivity and Development, see REWARD, 2000). This information was aggregated first into the 74 defined industries plus household final demand expenditure within the Welsh input-output framework (see below), then into the 25 sectors identified in Appendix 1. This provides a means of estimating direct emissions generation per £1million of industry gross outputs and per £1million of household final expenditure for 2003 (the base year for the IO and CGE frameworks used here).

We apply Leontief's (1970) basic demand driven input-output accounting framework extended for pollution generation in production and final consumption to report total CO2 (as carbon) emissions generated in the region to meet total final consumption demand, e^R, in the following way:

$$(1) \qquad e^R = \boldsymbol{\varepsilon}^{\mathbf{P}}[\mathbf{I}-\mathbf{A}]^{-1}\mathbf{y} + \boldsymbol{\varepsilon}^{\mathbf{C}}\mathbf{y}^*$$

Where **A** is the inter-industry input-output matrix reported for i=j=1,…,N industries and industry outputs with elements a_{ij} giving the input of industry i required in per monetary unit of output j and $[\mathbf{I}-\mathbf{A}]^{-1}$ is the Leontief inverse multiplier matrix with elements b_{ij} giving the total production of industry i required per monetary unit of final demand for output j . $\boldsymbol{\varepsilon}^{\mathbf{P}}$ is a 1xN vector of direct output-carbon coefficients with elements $\varepsilon_i=e_i/x_i$, where e_i is the physical amount of carbon directly generated by each production sector i in producing its output, x_i. $\mathbf{y}$ is a Nx1 vector of total final demands for the output of each sector, i, with elements y_i. $\boldsymbol{\varepsilon}^{\mathbf{P}}[\mathbf{I}-\mathbf{A}]^{-1}$ is a 1xN vector of output-carbon multipliers for each industry output j, with elements κ_j, which give us the total physical amount of emissions generated in production (across all N=25 production sectors) to meet one unit of final demand for sectoral output j. There are z=1,...Z final consumption groups. For carbon emissions directly generated by final consumers (here limited to households), one defines $\boldsymbol{\varepsilon}^{\mathbf{C}}$ as a 1xZ vector of direct final expenditure-pollution coefficients with elements $\varepsilon_z = e_z/y_z$, where e_z is the physical amount of emissions generated by each final consumption group z in consuming goods and services in the process of its total final expenditure, y_z. The Zx1 vector of total final expenditures for each type of final consumption group (column totals from the input-output tables) is distinguished from the Nx1 vector, **y**, as **y*** (transposed and reported as a column vector).

In the empirical framework used here, there are N=25 industries and Z=6 final consumer groups. The latter is composed of regional household and government consumption, capital formation, rest of UK/World (RUK and ROW) export demand and external tourists. Calculating (1) with these definitions of N and Z would represent the standard Type I case (Miller and Blair, 2009). The Type I case accounts for direct and indirect (backward linkage) effects by endogenising the N industries identified in the input-output accounts in the **A** and $[\mathbf{I}\text{-}\mathbf{A}]^{-1}$ matrices. Induced effects related to household income from employment (i.e. a Type II analysis) are not considered as this would involve removing household consumption from the exogenous final demand vector **y** that drives production and associated pollution activity. Such an approach would seem to be inconsistent with the commonly held belief that human consumption decisions lie at the heart of environmental problems. Note, however, that in the CGE analysis below we are able to consider the impacts of household income and consumption effects in response to a disturbance and reflect this in the post-shock IO tables.

Here, in order to focus attention on regional and external consumption demands, and given the importance of capital as an input to production, we have selected to endogenise capital formation/investment as covering depreciation/payments to capital, represented by other value-added in the input-output accounts (see for example, McGregor et al., 2008; Jensen et al, 2010). This is done by adding another row and column to the A matrix, where the row coefficients are given by payments to other value added divided by total inputs for each sector. The new column coefficients are given by local sectoral outputs produced to meet final consumption in the form of gross regional capital formation, divided by the total output of the (consuming) capital sector. The latter is given by total regional payments to capital or other value-added. Thus A becomes an (N+1)x(N+1) matrix. The additional entries in the y vector will be equal to zero, given that final consumers do not make payments to other value-added.

With no *changes* in final demand (at this stage), the system in (1) provides the same figure for e^R as one would get from an analysis using the direct carbon emissions intensities of each production and final consumption activity (total outputs for each industry, i, and final expenditure group, z:

(2) $$e^R = \boldsymbol{\varepsilon}^{\mathbf{P}}\mathbf{x} + \boldsymbol{\varepsilon}^{\mathbf{C}}\mathbf{y}^*$$

Thus, (1) attributes carbon emissions generated in the regional economy (during the single time period that the input-output accounts are reported for – usually one year) to final demands for regional outputs, rather than the production of those outputs, as in equation (2). The approach in (1) focuses on what Munksgaard and Pedersen (2001) term the 'production accounting principle'. As these authors demonstrate, in a closed economy with no external trade linkages (1) would equate to an analysis under the consumption accounting principle, or a 'carbon footprint'.

However, regional economies tend to be very open economies. Included in the y (and y*) vectors in the calculation of (1) are external (export) demands. This means that a portion of carbon emissions generated under the production accounting principle (equation 2) are attributed to *external* demands where equation (1) is used to calculate regional emissions under the consumption accounting principle. Moreover, analysis using (1) also fails to take account of the emissions that are embodied in imports, which would be added to the Welsh account in a carbon footprint calculation.

Turner et al. (2007) explain how an interregional input-output system can be used to calculate the actual carbon emissions embodied in each region's final consumption demands, allocating the carbon embodied in trade flows to end users in different regions. Such an interregional approach thus constitutes a technique by which actual carbon (or other environmental) footprints can be measured across trading regions/nations (and is increasingly being applied for this purpose – see Wiedmann et al, 2007; Wiedmann, 2009, for reviews).

However, there are two practical issues that prevent our adoption of such an approach in the current study. First, as explained by Turner et al. (2007), in the presence of extensive global trade, one is likely to effectively require a world interregional input-output framework, identifying all of the target region's direct and indirect trade partners and differences in production and carbon emitting technologies therein. Such a database is simply not available at present.[4] This means that any interregional feedback effects (i.e. the production of goods and services imported *to* Wales may require exports *from* Wales as intermediate inputs in the region/country of production). Such interregional feedback effects are likely to be particularly important in terms of Welsh trade with other UK regions. However, we do not take the step of developing an interregional UK framework (as in McGregor et al, 2008; Gilmartin et al, 2009; or Ha et al, 2009 for the US Midwest states) for a second practical reason. This is that regional and national policymakers in the UK who are responsible for reporting pollution measures such as those constructed here have expressed a desire that the first step in developing an empirical framework for analysis be based on the use of currently available rather than estimated input-output data. Thus, at this stage we attempt to develop the basic environmental input-output technique introduced above in such a way that allows us to focus on regional private and public (household and government) final consumption as the driver of pollution generation, and with specific focus on the issue of regional jurisdiction. Moreover, the single region focus is consistent with the dimensions of CGE modelling framework that we employ below. However, some level of fuller interregional extension is a priority for future research.

In the current study we focus our attention on developing the technique in (1) to permit an attribution under CAP; that is, taking account of the carbon content of imports rather than exports in addition to regional pollution supported by regional consumption.

Following Jensen et al (2009, 2010), we adjust (1) first by introducing a variant of the **A** matrix that records the combined use of (regional and imported) intermediate inputs to production. In

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[4] It is important to note that many IO studies make use of the GTAP database as a proxy for a world interregional IO framework. However, given our sub-national focus, it is not possible to integrate this with the Welsh regional IO tables.

this respect, the CAP approach introduced here requires slightly more data in input-output format (an imports matrix), but it retains a focus on intermediate and final consumption in the target economy without extending to a full interregional analysis. The $\mathbf{[I\text{-}A]^{-1}}$ matrix then gives the (hypothetical) global multiplier effects for the portion of the global economy that serves regional consumption. The $\boldsymbol{\varepsilon}^{\mathbf{P}}\mathbf{[I\text{-}A]^{-1}}$ multiplier vector then gives the global output-carbon multiplier effects. Here, in the first instance, we follow Jensen et al (2010) in applying the DTA so that ε^{P} is given by the Welsh vector – i.e. assuming that each external sector i shared the emissions characteristics of the corresponding sector i in the region under study – but this is not a necessary assumption (see below).

Thus, following the CAP (DTA) approach, the total carbon implications of regional final consumption, e^{T}, are estimated as:

$$(3) \qquad e^{T} = \boldsymbol{\varepsilon}^{\mathbf{P}}[\mathbf{I} - (\mathbf{R} + \mathbf{M})]^{-1}(\mathbf{y}^{\mathbf{R}} + \mathbf{y}^{\mathbf{M}}) + \boldsymbol{\varepsilon}^{\mathbf{C}}\mathbf{y}^{*}$$

Where the domestic intermediate matrix in (1) is relabelled **R** and **M** is the (N+1)x(N+1) – with capital endogenised - matrix of imported intermediate inputs. Similarly, $\mathbf{y}^{\mathbf{R}}$ corresponds to the regional (Welsh) final consumption portion of **y** in (1) – i.e. with all external demands subtracted - while $\mathbf{y}^{\mathbf{M}}$ gives us imports to exogenous regional final consumption by commodity/external sector output.

As noted above, the 'domestic technology assumption' (see also Druckman et al., 2008, 2009) is not necessary. In previous studies the 'domestic technology assumption' has been regarded as a necessary assumption to fill data gaps regarding the pollution profile of production in other regions/countries. Jensen et al (2009, 2010) propose that it may be a useful assumption in the context of the issue of production being located outwith the jurisdictional authority of policymakers in the consuming region. One way of thinking about this may be in terms of focusing attention on the pollution savings a region gains by importing goods and services, rather than the actual costs in other regions, the nature of which local consumers may have little influence over.

However, it would be possible to relax the DTA assumption in (3) by replacing with a weighted vector of direct CO2 (as carbon) intensities, ε^P, that reflects both the source country/region of imports and the corresponding direct carbon intensity of output in that country/region. The weights would be given by the share of commodity output i from region/country s in total Welsh use of commodity i. The Welsh uses would ideally be identified by intermediate consumer (production sector), j, and final consumer, z. Such data are available for Welsh imports from the rest of the UK (the RUK IO imports matrix), but for the rest of the world data are currently available for use of commodity output i by each user j and z from the ROW as a whole (the ROW IO imports matrix) or by all users together from the rest of the world broken into key countries and regions. The latter data have been made available by colleagues at OECD, and the dataset includes corresponding direct carbon intensity data. Thus it would be possible to calculate a weighted ε^P vector as

(4) $$\varepsilon^p = \sum_{s=0}^{S} \frac{x_{i,s}}{X_i} \varepsilon^p{}_s$$

Note, however, that this approach would not capture output-carbon multiplier effects in the source country/region (or any interregional multiplier effects involved in producing goods for export to Wales). The approach in (3) instead focuses on the multiplier effects implied by the combined use variant of the Leontief inverse.

At the time of writing, we are still in the process of constructing the weighted ε^P vector for the 25-sector Welsh case. Results of calculating the CAP measure with the DTA assumption relaxed will be included in the next iteration of this paper.[5] At this stage we limit our attention to the PAP calculation using (1), which is not sensitive to the use of DTA given its focus on domestic pollution generation, and the CAP (with DTA) calculation using (3), which are reported in the first and second columns (respectively) of Table 1. However, note that in the CGE analysis below, we do use (4) to reflect the fact that the price of output changes in Wales (in the short term, due to the presence of supply constraints), while exogenous (import) prices of goods and services produced in RUK

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[5] Please contact the corresponding author at karen.turner@stir.ac.uk if you would like to be updated on the progress of this paper.

and ROW do not. Therefore, in order to maintain Welsh direct carbon intensities in real terms, the domestic ε^P vector must be deflated by the change in sectoral output prices, while those attached to imported commodities are not. In short, this change in carbon intensities requires the use of (4) where the post-shock IO tables are reported in value (nominal) terms.

Empirical results

The entries in the top row of the first two columns of Table 3 show the results of estimating Welsh CO2 (as carbon) under PAP (i.e. carbon generated from economic activity within the Welsh economy in the accounting year of 2003), just under 11.8million tonnes, which may be calculated using (1) or (2), and under CAP (i.e. carbon generated around the world to support Welsh final consumption in 2003, under the DTA assumtpion), just under 11.5million tonnes, which is calculated using (3). We return to Table 3 and why the CAP figure is lower than the PAP figure momentarily. In the first instance it is useful to examine the difference in the type of activities that are important under different accounting approaches.

Figure 2 shows the impact of attributing pollution generation in different ways. First, the bars labelled ‘contribution to direct carbon generation (PAP)’ show the shares of carbon under PAP (11.8million tonnes) that are generated in each production sector and by households. This is calculated using (2). Second, the bars labelled ‘share attributable to total final consumption demand for Welsh sectoral commodity outputs (PAP)’ show the shares of the 11.8million that are attributable to total final demand (regional and external) for the output of each Welsh production sector (direct carbon emissions in households are the same in absolute terms throughout). This is calculated using (1). Finally, the bars labelled ‘share attributable to Welsh final consumption demand for commodity output (all sources) (CAP DTA)’ show the shares of carbon under CAP (11.5million tonnes attributable to Welsh regional demand (households and government final consumption) for Welsh and imported commodity outputs. This is calculated using (3).

Note that in terms of direct carbon generation (calculated using (2) and shown in the first bar, Electricity production accounts for the largest share in terms of production of output. However, if we refocus our attention to consider carbon intensity of production *to meet final demand* – using equation (1) - the share attributable to Electricity falls. This is because a significant share of Electricity is produced to meet intermediates demands; that is it is used in production by other sectors to meet final demand for their own outputs. On the other hand, the share attributable to other sectors, such as Wholesale and Retail, with a relatively low direct pollution intensity, rises when indirect carbon emissions embodied in input purchases (such as from the Electricity sector) are taken into account.

Note from Figure 2 that in the target sector of our CGE analysis to follow, Manufacture of Iron and Steel (with Non-Ferrous and Metal Casting), the direct carbon intensity is high but with only very small (but positive) indirect carbon content in production to meet final demand. This indicates that the sector does not have strong backward or forward carbon linkages in the Welsh economy and is reflected in the fact that the bulk of output (85%) is produced to meet external (export) demand.

However, if we examine the third bar, with calculation using (3) focussing on domestic and imported carbon attributable to Welsh final consumption under the CAP (DTA) measure, the picture is quite different. The key point to note is that there is a shift in attribution towards commodity outputs that are consumed within the region (regardless of their source of production). Now, carbon attributable to final demand for Iron and Steel outputs falls to just 0.3% from 20.7% under the PAP measure. This happens for two reasons. First, Iron and Steel tends to be sold to intermediate consumers, i.e. producers, as an input to production of other manufactured goods (e.g. white goods, machinery, vehicles etc.). Therefore, if we were looking at a global analysis, or if the Welsh economy were closed, it is unlikely that much carbon would be attributable to this sector if the focus is on final demand as in the approaches under (1) and (3). Thus, here it is important under the PAP attribution to final user using (1) because external demands are treated as final demands.

The carbon profile of production to meet export demand in Wales also provides the explanation as to why total carbon emissions attributable to Welsh consumption under CAP (DTA) are lower than the actual carbon generated within Wales in 2003 under PAP. Reading down both the first and second column of Table 3, note that domestic carbon generation in Wales attributable to domestic consumption is the same under both measures. The difference arises from carbon embodied in imports and exports. The PAP calculation, which focuses on pollution generated within Welsh borders, regardless of where consumers are located, includes carbon embodied in exports. Note that at just under 7.67million tonnes, this equates to 65% of total carbon generation within Wales in our accounting year of 2003. 31% of this (2.37million tonnes) is generated in export production in the Iron and Steel sector.

However, when we move to the CAP measure in the second column of Table 3, carbon embodied in exports is subtracted and replaced with carbon embodied in imports (here as estimated under the DTA assumption). While, at 7.83million tonnes and accounting for 64% of Wales's total 'carbon footprint' this is a very significant figure, it is lower than the carbon embodied in exports, which implies that Wales is a net exporter of carbon (i.e. it pollutes more than it requires for its own consumption needs). At the bottom of the second column of Table 3 we can see that this implies a net carbon trade surplus of 283 thousand tonnes. However, it is also important to note that the relationship is a deficit one with ROW (carbon embodied in imports, 4.38million tonnes, is greater than carbon embodied in exports – excluding tourists, which are not disaggregated by source outside of Wales – at 2.06million tonnes). The surplus relationship arises from trade with other UK regions, where carbon embodied in exports is almost double that embodied in imports. Given that UK responsibilities under Kyoto (a PAP measure) lie at the national level, this finding has interesting implications in terms the devolution of responsibility for sustainable development in the UK as it suggests that a disproportionate level of direct pollution generation (relative to consumption requirements) may be located in peripheral regions (McGregor et al, 2008, report a similar finding for Scotland within the UK – mainly due to Scotland being a net exporter of electricity to the rest of the UK).

Nonetheless, our specific concern here is the implication that carbon embodied in export demands is removed from the carbon footprint calculation under CAP. This is because Welsh consumer would be expected to benefit from the location of export-led industries in their region. To illustrate our point in the next section we use a CGE model of the Welsh economy (which incorporates the IO accounting framework above) to examine the economic and carbon impacts of an increase in export demand to the Iron and Steel sector.

AMOW – A computable general equilibrium Model Of Wales

The aim of this paper is to consider the impact of an anticipated expansion in total export demand to the Welsh Iron and Steel sector of £90million. This equates to a 3.71% increase in export demand to this sector (which, in the absence of better information at this stage, we will distribute evenly across export demand from RUK and ROW). Given that this is a demand shock and, in the central case scenario reported in this draft of the paper (sensitivity analysis will follow in the next iteration) there are no long-run supply constraints, it would be possible to model this scenario in a conventional IO model using multipliers computed above.

However, despite investment in the Iron and Steel sector in anticipation of the export demand stimulus (see above), we would expect some short-run supply constraints, which will impact on prices throughout the economy at least in the short run. Therefore, while as an accounting framework IO tables and IO demand-driven multiplier techniques are absolutely appropriate for pollution attribution analyses (given that they provide all the required information on pollution embodied in intersectoral interactions and interregional trade flows), we follow Gilmartin et al (2009) in arguing that where there is a need to examine the impact of *changes* in activity, IO is unlikely to be appropriate. This is because IO is only a very special case of a wider set of general equilibrium approaches. Instead, as this stage we contend that it is useful to complement the IO accounting framework with a more flexible regional CGE modelling framework so that we can better examine the adjustment process of the economy and the carbon measures introduced above in response to a disturbance in activity. We use the CGE framework to model the impacts of a change in activity, then use the model results to inform the IO analysis for the accounting/attribution analysis of pollution attributable to Welsh consumption activity before and after the change is introduced. Specifically, we use the CGE model results on changes in prices and quantities throughout the economy to post-shock IO tables in value terms.

The Welsh model, named AMOW is developed using the AMOS CGE modelling framework - initially developed by Harrigan et al (1991) using Scottish data – on a Welsh SAM for 2003 which incorporates the IO tables used in the analysis above. A condensed model listing is provided in Appendix 2. The main features of the model are as follows:

- There are 3 internal transactor groups (households, firms, government)
- There are 25 production sectors/commodities (see Appendix 1)
- There are also two external transactors (Rest of World, Rest of US). Export demand is price sensitive (Armington, 1969), with elasticity of 2.0 in central case scenario (Gibson, 1990), but all other determinants of export demand are exogenous.
- All commodity markets taken to be competitive
- Wales modelled as a small open economy in that impacts of changes in Welsh prices externally are assumed sufficiently negligible that they are not anticipated to feedback to Wales. This assumption is stronger in a UK context, and implies that Wales is a price taker in UK markets.
- We assume cost minimisation in production and employ multi-level production functions (with Welsh output prices determined through the price dual). See below.
- The model is recursive dynamic in that there is period-by-period (year-by-year) adjustment of capital and labour stocks via region-specific investment – see below - and interregional migration (Harris & Todaro, 1970; Layard et al, 1991).
- In the central case scenario reported here, wages are determined through a regional wage bargaining function (Blanchflower & Oswald, 1994; Minford et al, 1994; Layard et al, 1991).

The nested production function can be specified with CES, CD or Leontief technology at each nest. Here we specify as follows:

- We allow substitution between capital and labour to form value-added. In the central case we assume an elasticity of 0.3 (Harris, 1989). However, in our intended sensitivity analysis, we aim to introduce an estimated value for the commodity ‘Basic Metals and Fabricated Metals’ in the UK that we will apply in the target sector, Iron and Steel, with Non-Ferrous and Metal Casting. This is a lower value than our default at 0.18.

- Value-added combines with an intermediate composite in the production of output. At the bottom nest, we allow substitution between local and imported intermediates to form intermediates composite. In the central case we assume an Armington elasticity of 2.0 (Gibson, 1990).
- However, within the Welsh, RUK and ROW composites, we assume Leontief technology in combining the 25 commodity outputs in each case. That is, in the absence of better information, we retain the standard IO assumption.
- We also retain the IO Leontief technology assumption for combination of intermediates and value-added in production of gross output. The main motivation for this is so that we can reasonably retain the IO assumption of a Leontief relationship CO2 generation and output. This is not necessary in a CGE analysis, even where we are generating IO tables (the output-pollution coefficient may change). However, due a lack of information in terms of sources of sectoral CO2 (energy-use, processes etc), at this time we retain the Leontief assumption, particularly given the importance of non-energy related carbon generation in Iron and Steel production.

Simulation Strategy

As explained above, we introduce a 3.71% permanent step increase in exogenous export demand from each RUK and ROW for output of Welsh ‘Iron and Steel’ sector (the £90million expansion is precisely split into a 3.714% expansion in the dominant RUK export demand and 3.713% in ROW export demand). This is introduced in the first period simulated. Ideally, in order to reflect investment in the Iron and Steel sector in anticipation of the increase in export demand, we would introduce an investment shock prior to export demand shock (e.g. Gillespie et al, 2001). However, there is a limitation with respect to the current AMOW model in that we are not able to model such an exogenous shock alongside the endogenous investment throughout economy that is required for all sectors to adjust.

The endogenous investment process is as follows. Within each period of the multi-period simulations using AMOSENVI, both the total capital stock and its sectoral composition are fixed, and commodity markets clear continuously. Each sector's capital stock is updated between periods via a simple capital stock adjustment procedure, according to which investment equals depreciation plus some fraction of the gap between the desired and actual capital stock. The desired capital stock is determined on cost-minimisation criteria and the actual stock reflects last period's stock, adjusted for depreciation and gross investment. The economy is assumed initially to be in long-run equilibrium, where desired and actual capital stocks are equal.[6]

In order to reflect expansion in productive capacity of sector prior to export stimulus through the endogenous investment process, we set the speed of adjustment of capital stock in 'Iron and Steel' to 1.0 (the AMOW default value is 0.3 – i.e. 30% of the gap between actual and desired capital stock). Here, it has the desired effect of swift adjustment of capital stock in the Iron and Steel sector. However, in the first period, where capital stocks are fixed, it does cause displacement effects. Therefore, in Table 4, we report the adjustment process from period 2 (the year after export shock and investment in target sector, but where capital stock has been able to adjust). While we are likely to reconsider this treatment in future iterations of this paper, we should note that this treatment does not affect the long-run outcome presented here (when labour and capital stocks have both fully adjusted).

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

CGE simulation results

The impacts of the export demand stimulus to Welsh Iron and Steel are reported in Table 4 for periodic intervals as the economy adjusts to long-run equilibrium. Note that in the long-run, the results are qualitatively as one would expect from an IO model: in the absence of any long-run supply constraints, the economy adjusts so that there are no lasting impacts on any price variables but real growth in quantities throughout the system (e.g. GDP expands by 0.188%, aggregate household consumption by 0.214%, and employment and population by 0.172%) though this is most concentrated in the Iron and Steel sectors, where capacity expands by 3.43%).

However, in the short- to medium-run, before labour and capital stocks are fully adjusted, there are price changes, stemming from upward pressure on wages and capital rental rates. This causes some crowding out of activity (as shown for period 2 in Figure 3), and note from Table 4 that the exogenous increase in export demand to Iron and Steel is partially offset in early periods as the increased price of output in this sector impacts on competitiveness (i.e. the endogenous export demand response is negative). However, the net increase in export demand throughout is concentrated in Iron and Steel (increases in output prices in all sectors cause a contraction elsewhere). The increase in imports, on the other hand, is driven by substitution and income effects throughout the economy. Even in sectors where there is a contraction in activity in early periods, there may be an increase in imports as producers substitute away from more costly local production in favour of imported goods, the price of which has not changed. However, over time, as the spike in Welsh prices dissipates (due to in-migration of labour pushing real wages back to their pre-shock levels and capital formation returning the capital rental rate to a level equal to the user cost of capital), these substitution effects disappear and the long-run increase in imports is driven by the general increase in activity (i.e. the use of all inputs to production increases as activity levels increase across the economy).

We use the CGE model results to generate post-shock IO tables for each period. The CGE model reports all quantity changes in real terms but also provides information on price changes throughout the system, which allows us to derive post-shock IO tables reported in the conventional value format. The post-shock IO tables for each period following the export demand stimulus are then used to repeat the IO analysis of the PAP and CAP (DTA) measures using equations (1) and (3) above. The headline results are included in Table 3, with Figure 4 and the third and fourth columns of Table 3 providing a breakdown of the composition of these indicators. The last two columns in Table 3 show the percentage change relative to the base year calculations discussed above in the IO section of the paper.

The first thing to note is that the increase in the PAP measure is considerably bigger than the increase in CAP (DTA). This is because most of the growth in activity, and related carbon emissions, is in Iron and Steel production to meet the exogenous increase in export demand. For both the PAP and CAP (DTA) measures, the increase in domestic carbon emissions supported by Welsh demand is just 0.19%, which, taken with the 0.18% increase in carbon embodied in imports, account for the total increase in the CAP (DTA) measure, which increases by 0.18%, slightly less than total household consumption (0.214%). The larger growth in PAP is due to the 1.17% increase in carbon emissions embodied in exports. The composition of the change in the PAP and CAP measures is shown in Figure 3. Overall, at the bottom of Table 3, we can see that Wales carbon trade surplus increases, with the deficit with ROW cut by 1% and the surplus with RUK increased by 2.12%.

Conclusions and directions for continued/future research

The key result from the integrated IO and CGE analysis above is that the Welsh economy benefits from an economic expansion, but with an environmental cost in that carbon generation within Wales rises (PAP) by more than the increase in GDP, consumption and its carbon footprint (CAP, calculated here using a DTA assumption). However, it may be argued that Wales has instigated the change in activity brought about by the export expansion, particularly given the investment made to facilitate it. This raises questions as to what the CAP and PAP impacts tell us in terms of the sustainability of economic growth and who should be held responsible for carbon generation in different jurisdictions. Perhaps the answer in trying to take a more consumption-orientated focus is not as straightforward as subtracting carbon embodied in exports and adding that embodied in imports, and some form of shared responsibility criteria is required, between producers and consumers generally and/or between importing and exporting countries. This will be considered in the next iteration of this paper.

In terms of prioritising other steps in this study, the first issue to investigate is the added value that may be gained by relaxing DTA in the CAP account. Colleagues at OECD have kindly made data available to us to allow this step (which we have tested for the cases of Scotland and the UK). For imports from the rest of the UK, we will make use of UK Environmental Accounts data. It may be that comparing CAP (DTA) and CAP (relax DTA) may provide some insight as to what form a shared responsibility criteria may take. However, note that any difference between these two CAP measures would be entirely driven by differences in polluting technology. The question would still remain as to how to allocate responsibility with respect to activity levels when both producers and consumers benefit economically when these are higher.

We also aim to introduce sensitivity analysis in terms of the following:

- The design of shock (e.g. the source of the export demand shock - given the existing differences in the Welsh carbon ‘trade balance’ with RUK and ROW, a stronger stimulus from either may have a qualitative as well as quantitative difference on this aspect of the carbon account)
- The treatment of investment in target sector (and more generally)
- Specification of key parameters, particularly substitution elasticities (e.g. introducing an econometrically estimated parameter for the combination of capital and labour) within the nested production function and/or in the import and export demand functions
- Implications of introducing long-run supply constraints and different treatments of wage setting behaviour (e.g. national rather than regional bargaining).

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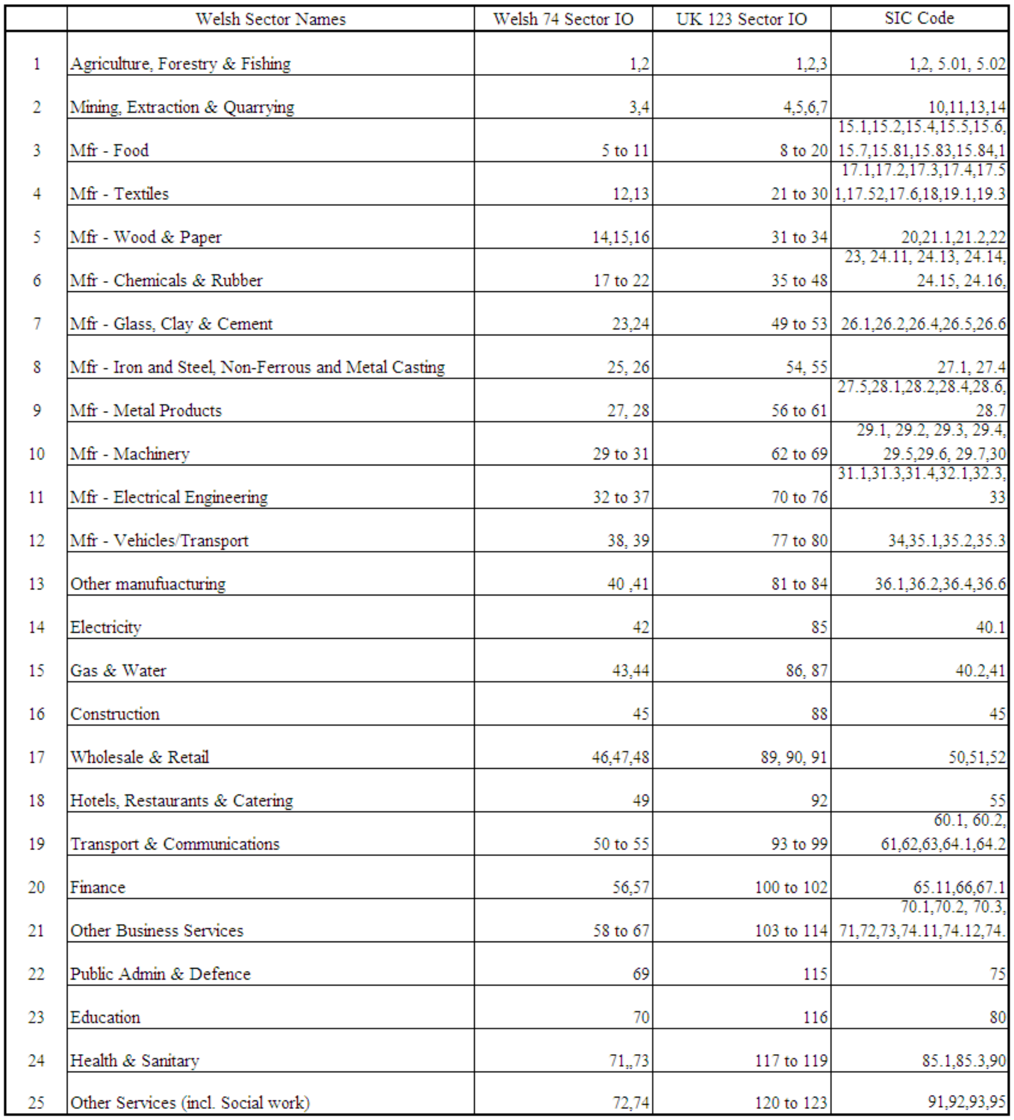
APPENDIX 1. CLASSIFICATION OF PRODUCTION SECTORS/COMMODITY OUTPUTS IN THE AMOW CGE MODEL



	Welsh Sector Names	Welsh 74 Sector IO	UK 123 Sector IO	SIC Code
1	Agriculture, Forestry & Fishing	1,2	1,2,3	1,2, 5.01, 5.02
2	Mining, Extraction & Quarrying	3,4	4,5,6,7	10,11,13,14
3	Mfr - Food	5 to 11	8 to 20	15.1,15.2,15.4,15.5,15.6, 15.7,15.81,15.83,15.84,1
4	Mfr - Textiles	12,13	21 to 30	17.1,17.2,17.3,17.4,17.5 1,17.52,17.6,18,19.1,19.3
5	Mfr - Wood & Paper	14,15,16	31 to 34	20,21.1,21.2,22
6	Mfr - Chemicals & Rubber	17 to 22	35 to 48	23, 24.11, 24.13, 24.14, 24.15, 24.16,
7	Mfr - Glass, Clay & Cement	23,24	49 to 53	26.1,26.2,26.4,26.5,26.6
8	Mfr - Iron and Steel, Non-Ferrous and Metal Casting	25, 26	54, 55	27.1, 27.4
9	Mfr - Metal Products	27, 28	56 to 61	27.5,28.1,28.2,28.4,28.6, 28.7
10	Mfr - Machinery	29 to 31	62 to 69	29.1, 29.2, 29.3, 29.4, 29.5,29.6, 29.7,30
11	Mfr - Electrical Engineering	32 to 37	70 to 76	31.1,31.3,31.4,32.1,32.3, 33
12	Mfr - Vehicles/Transport	38, 39	77 to 80	34,35.1,35.2,35.3
13	Other manufuacturing	40 ,41	81 to 84	36.1,36.2,36.4,36.6
14	Electricity	42	85	40.1
15	Gas & Water	43,44	86, 87	40.2,41
16	Construction	45	88	45
17	Wholesale & Retail	46,47,48	89, 90, 91	50,51,52
18	Hotels, Restaurants & Catering	49	92	55
19	Transport & Communications	50 to 55	93 to 99	60.1, 60.2, 61,62,63,64.1,64.2
20	Finance	56,57	100 to 102	65.11,66,67.1
21	Other Business Services	58 to 67	103 to 114	70.1,70.2, 70.3, 71,72,73,74.11,74.12,74.
22	Public Admin & Defence	69	115	75
23	Education	70	116	80
24	Health & Sanitary	71,,73	117 to 119	85.1,85.3,90
25	Other Services (incl. Social work)	72,74	120 to 123	91,92,93,95

APPENDIX 2. A CONDENSED VERSION OF THE AMOW CGE MODEL

Equations	Short run
(1) Gross Output Price	$pq_i = pq_i(pv_i, pm_i)$
(2) Value Added Price	$pv_i = pv_i(w_n, w_{k,i})$
(3) Intermediate Composite Price	$pm_i = pm_i(pq)$
(4) Wage setting	$w_n = w_n\left(\frac{N}{L}, cpi, t_n\right)$
(5) Labour force	$L = \bar{L}$
(6) Consumer price index	$cpi = \sum_i \theta_i \, pq_i + \sum_i \theta_i^{RUK} \overline{pq}_i^{RUK} + \sum_i \theta_i^{ROW} \overline{pq}_i^{ROW}$
(7) Capital supply	$K_i^s = \bar{K}_i^s$
(8) Capital price index	$kpi = \sum_i \gamma_i \, pq_i + \sum_i \gamma_i^{RUK} \overline{pq}_i^{RUK} + \sum_i \gamma_i^{ROW} \overline{pq}_i^{ROW}$

(9) Labour demand	$N_i^d = N_i^d(V_i, w_n, w_{k,i})$
(10) Capital demand	$K_i^d = K_i^d(V_i, w_n, w_{k,i})$
(11) Labour market clearing	$N^s = \sum_i N_i^d = N$
(12) Capital market clearing	$K_i^s = K_i^d$
(13) Household income	$Y = \Psi_n N w_n (1 - t_n) + \Psi_k \sum_i w_{k,i}(1 - t_k) + \bar{T}$
(14) Commodity demand	$Q_i = C_i + I_i + G_i + X_i + R_i$

(15) Consumption Demand	$C_i = C_i\left(pq_i, \bar{p}q_i^{RUK}, \bar{p}q_i^{ROW}, Y, cpi\right)$
(16) Investment Demand	$I_i = I_i\left(pq_i, \bar{p}q_i^{RUK}, \bar{p}q_i^{ROW}, \sum_i b_{i,j} I_j^d\right)$ $I_j^d = h_j\left(K_j^d - K_j\right)$

(17) Government Demand	$G_i = \bar{G}_i$
(18) Export Demand	$X_i = X_i\left(p_i, \bar{p}_i^{RUK}, \bar{p}_i^{ROW}, \bar{D}^{RUK}, \bar{D}^{ROW}\right)$
(19) Intermediate Demand	$R^d_{i,j} = R^d_i\left(pq_i, pm_j, M_j\right)$ $R^d_i = \sum_j R^d_{i,j}$
(20) Intermediate Composite Demand	$M_i = M_i\left(pv_i, pm_i, Q_i\right)$
(21) Value Added Demand	$V_i = V_i\left(pv_i, pm_i, Q_i\right)$
Multi-period model	**Stock up-dating equations**
(22) Labour force	$L_t = L_{t-1} + nmg_{t-1}$

(23) Migration	$\frac{nmg}{L} = nmg\left(\frac{w_n(1-t_n)}{cpi}, \frac{w_n^{RUK}(1-t_n)}{cpi^{RUK}}, u, u^{RUK}\right)$
(24) Capital Stock	$K_{i,t} = (1-d_i)K_{i,t-1} + I_{i,t-1}^d$

NOTATION

Activity-Commodities

i, j are, respectively, the activity and commodity subscripts (There are twenty-five of each in AMOW: see Appendix 1)

Transactors

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

Functions

pm (.), pq(.), pv(.)	CES cost function
k^S(.), w(.)	Factor supply or wage-setting equations
K^d(.), N^d(.), R^d(.)	CES input demand functions
C(.), I(.), X(.)	Armington consumption, investment and export demand functions, homogenous of degree zero in prices and one in quantities

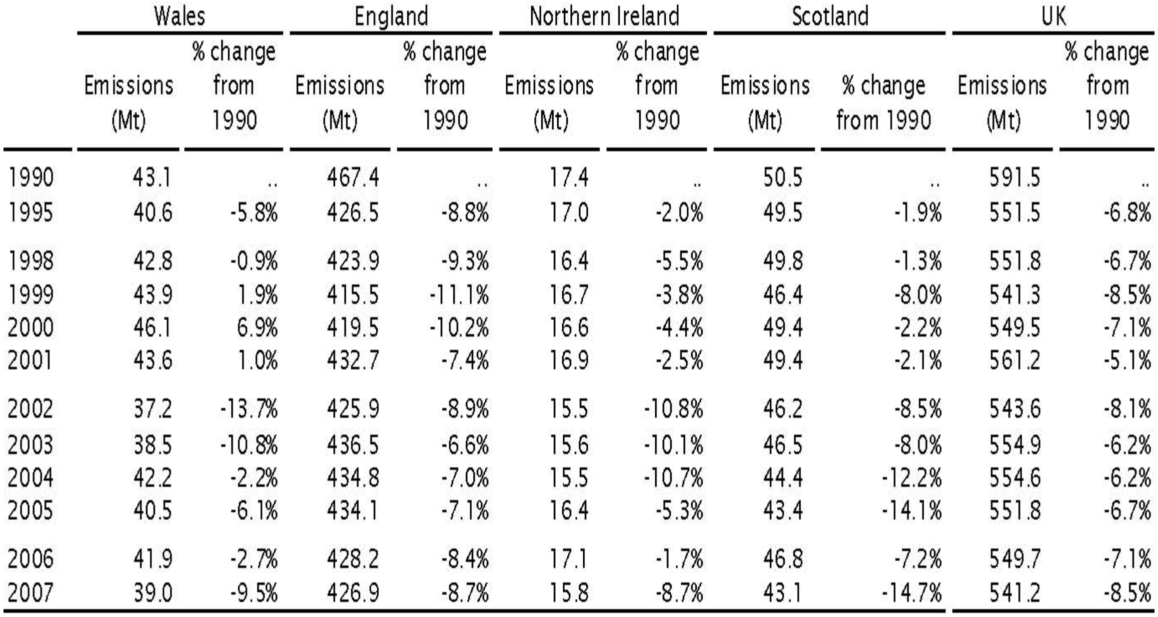
Variables and parameters

C	consumption
D	exogenous export demand
G	government demand for local goods
I	investment demand for local goods
$\mathbf{I^d}$	investment demand by activity
$\mathbf{K^d}$, $\mathbf{K^S}$, **K**	capital demand, capital supply and capital employment
L	labour force
M	intermediate composite output
$\mathbf{N^d}$, $\mathbf{N^S}$, **N**	labour demand, labour supply and labour employment
Q	commodity/activity output
R	intermediate demand
T	nominal transfers from outwith the region
V	value added
X	exports

Y	household nominal income
$\mathbf{b}_{\mathbf{ij}}$	elements of capital matrix
cpi, kpi	consumer and capital price indices
d	physical depreciation
h	capital stock adjustment parameter
nmg	net migration
pm	price intermediate composite
pq	vector of commodity prices
pv	price of value added
$\mathbf{t}_{\mathbf{n}}, \mathbf{t}_{\mathbf{k}}$	average direct tax on labour and capital income
u	unemployment rate
$\mathbf{W}_{\mathbf{n}}, \mathbf{W}_{\mathbf{k}}$	price of labour to the firm, capital rental
$\boldsymbol{\Psi}$	share of factor income retained in region
θ	consumption weights
γ	capital weights

Tables

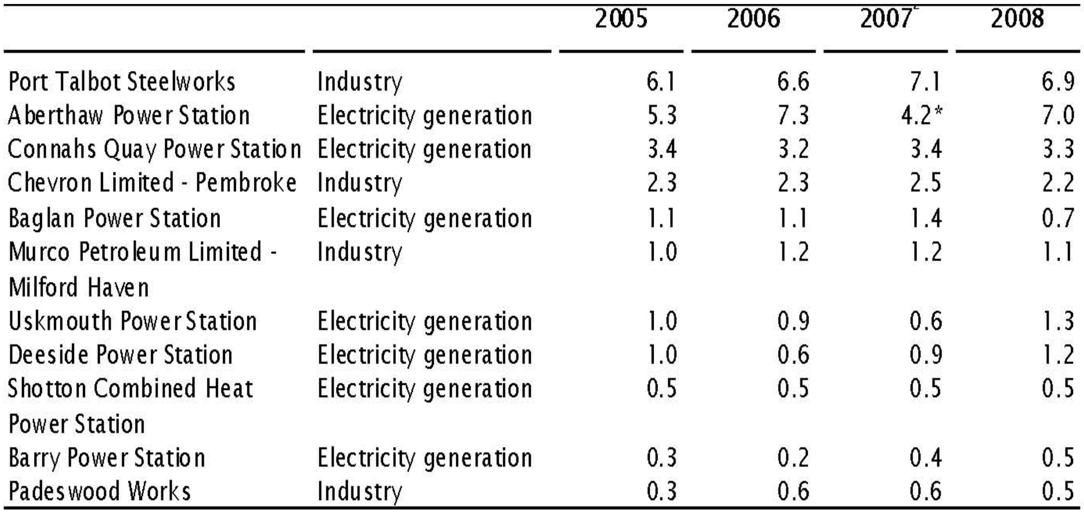
Table 1: Carbon Dioxide Emissions for Wales and Home Countries



	Wales		England		Northern Ireland		Scotland		UK	
	Emissions (Mt)	% change from 1990	Emissions (Mt)	% change from 1990	Emissions (Mt)	% change from 1990	Emissions (Mt)	% change from 1990	Emissions (Mt)	% change from 1990
1990	43.1	..	467.4	..	17.4	..	50.5	..	591.5	..
1995	40.6	-5.8%	426.5	-8.8%	17.0	-2.0%	49.5	-1.9%	551.5	-6.8%
1998	42.8	-0.9%	423.9	-9.3%	16.4	-5.5%	49.8	-1.3%	551.8	-6.7%
1999	43.9	1.9%	415.5	-11.1%	16.7	-3.8%	46.4	-8.0%	541.3	-8.5%
2000	46.1	6.9%	419.5	-10.2%	16.6	-4.4%	49.4	-2.2%	549.5	-7.1%
2001	43.6	1.0%	432.7	-7.4%	16.9	-2.5%	49.4	-2.1%	561.2	-5.1%
2002	37.2	-13.7%	425.9	-8.9%	15.5	-10.8%	46.2	-8.5%	543.6	-8.1%
2003	38.5	-10.8%	436.5	-6.6%	15.6	-10.1%	46.5	-8.0%	554.9	-6.2%
2004	42.2	-2.2%	434.8	-7.0%	15.5	-10.7%	44.4	-12.2%	554.6	-6.2%
2005	40.5	-6.1%	434.1	-7.1%	16.4	-5.3%	43.4	-14.1%	551.8	-6.7%
2006	41.9	-2.7%	428.2	-8.4%	17.1	-1.7%	46.8	-7.2%	549.7	-7.1%
2007	39.0	-9.5%	426.9	-8.7%	15.8	-8.7%	43.1	-14.7%	541.2	-8.5%

Source: NAfW, 2009

Table 2: Wales – Top emissions points 2007



		2005	2006	2007	2008
Port Talbot Steelworks	Industry	6.1	6.6	7.1	6.9
Aberthaw Power Station	Electricity generation	5.3	7.3	4.2*	7.0
Connahs Quay Power Station	Electricity generation	3.4	3.2	3.4	3.3
Chevron Limited - Pembroke	Industry	2.3	2.3	2.5	2.2
Baglan Power Station	Electricity generation	1.1	1.1	1.4	0.7
Murco Petroleum Limited - Milford Haven	Industry	1.0	1.2	1.2	1.1
Uskmouth Power Station	Electricity generation	1.0	0.9	0.6	1.3
Deeside Power Station	Electricity generation	1.0	0.6	0.9	1.2
Shotton Combined Heat Power Station	Electricity generation	0.5	0.5	0.5	0.5
Barry Power Station	Electricity generation	0.3	0.2	0.4	0.5
Padeswood Works	Industry	0.3	0.6	0.6	0.5

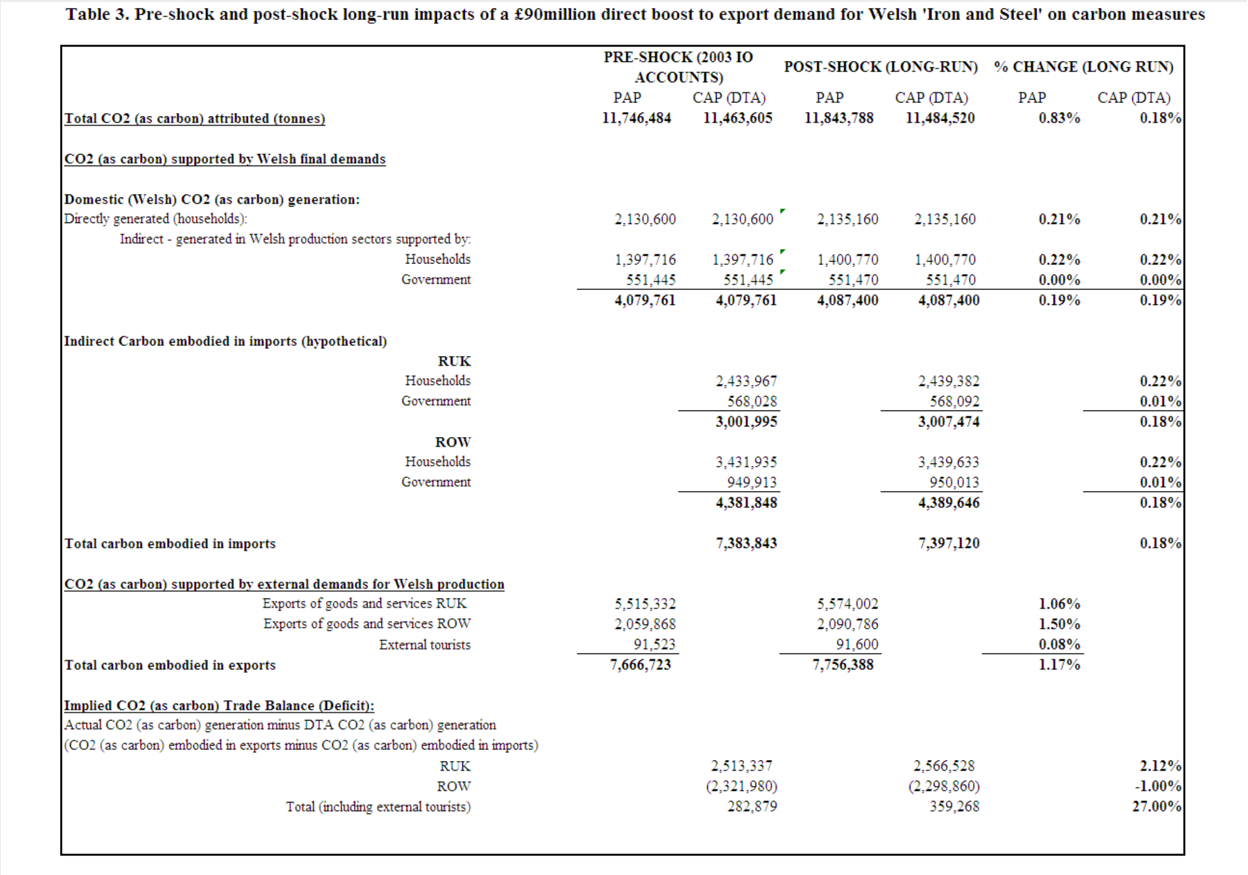


Table 3. Pre-shock and post-shock long-run impacts of a £90million direct boost to export demand for Welsh 'Iron and Steel' on carbon measures

	PRE-SHOCK (2003 IO ACCOUNTS)		POST-SHOCK (LONG-RUN)		% CHANGE (LONG RUN)	
	PAP	CAP (DTA)	PAP	CAP (DTA)	PAP	CAP (DTA)
Total CO2 (as carbon) attributed (tonnes)	**11,746,484**	**11,463,605**	**11,843,788**	**11,484,520**	**0.83%**	**0.18%**
CO2 (as carbon) supported by Welsh final demands						
Domestic (Welsh) CO2 (as carbon) generation:						
Directly generated (households):	2,130,600	2,130,600	2,135,160	2,135,160	**0.21%**	**0.21%**
Indirect - generated in Welsh production sectors supported by:						
Households	1,397,716	1,397,716	1,400,770	1,400,770	**0.22%**	**0.22%**
Government	551,445	551,445	551,470	551,470	**0.00%**	**0.00%**
	4,079,761	**4,079,761**	**4,087,400**	**4,087,400**	**0.19%**	**0.19%**
Indirect Carbon embodied in imports (hypothetical)						
RUK						
Households		2,433,967		2,439,382		**0.22%**
Government		568,028		568,092		**0.01%**
		3,001,995		**3,007,474**		**0.18%**
ROW						
Households		3,431,935		3,439,633		**0.22%**
Government		949,913		950,013		**0.01%**
		4,381,848		**4,389,646**		**0.18%**
Total carbon embodied in imports		**7,383,843**		**7,397,120**		**0.18%**
CO2 (as carbon) supported by external demands for Welsh production						
Exports of goods and services RUK	5,515,332		5,574,002		**1.06%**	
Exports of goods and services ROW	2,059,868		2,090,786		**1.50%**	
External tourists	91,523		91,600		**0.08%**	
Total carbon embodied in exports	**7,666,723**		**7,756,388**		**1.17%**	
Implied CO2 (as carbon) Trade Balance (Deficit):						
Actual CO2 (as carbon) generation minus DTA CO2 (as carbon) generation						
(CO2 (as carbon) embodied in exports minus CO2 (as carbon) embodied in imports)						
RUK		2,513,337		2,566,528		**2.12%**
ROW		(2,321,980)		(2,298,860)		**-1.00%**
Total (including external tourists)		282,879		359,268		**27.00%**

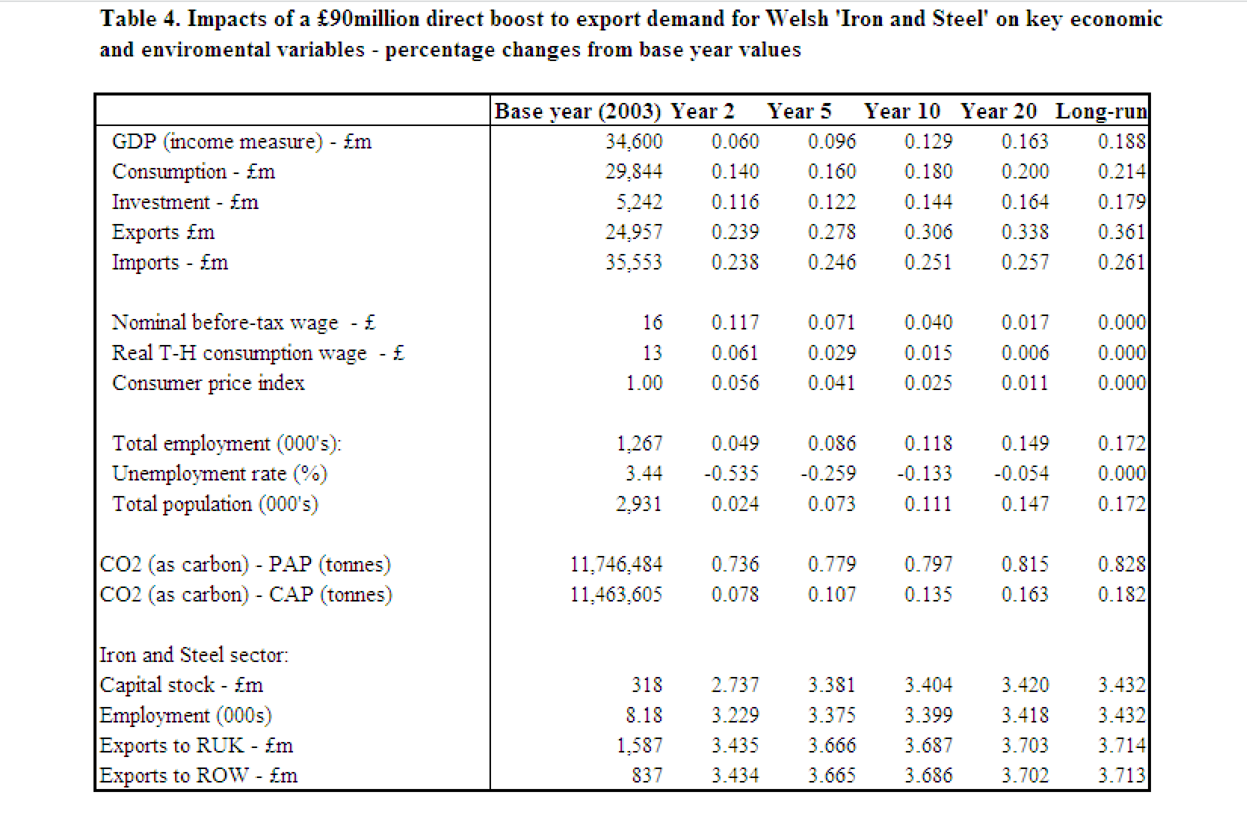
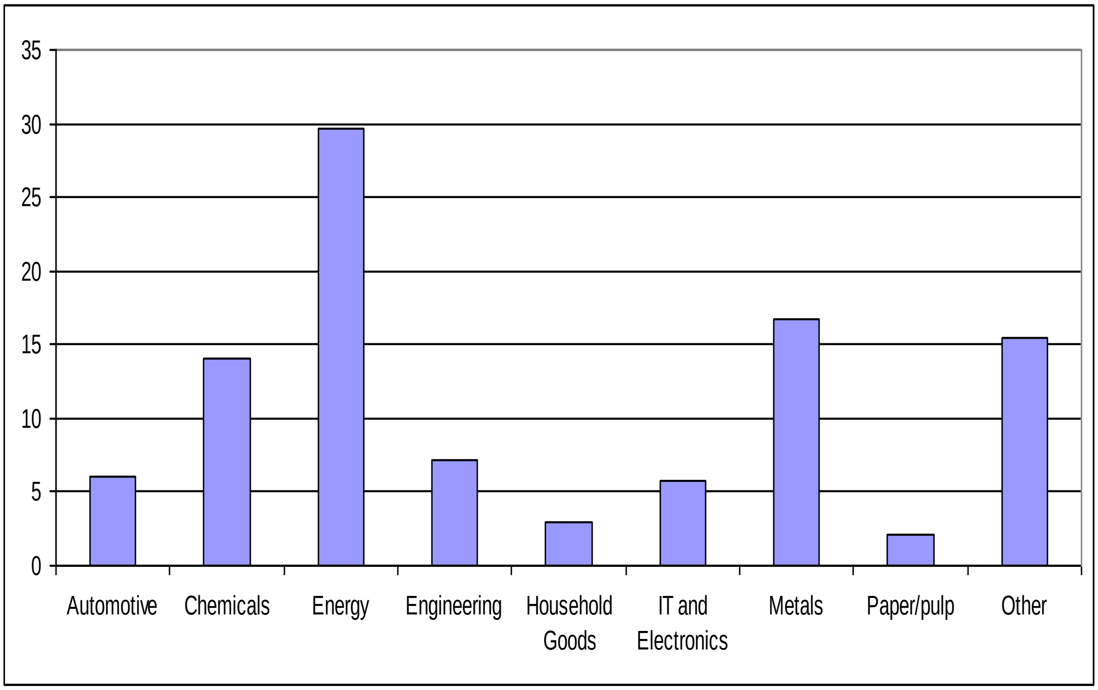


Table 4. Impacts of a £90million direct boost to export demand for Welsh 'Iron and Steel' on key economic and enviromental variables - percentage changes from base year values

	Base year (2003)	Year 2	Year 5	Year 10	Year 20	Long-run
GDP (income measure) - £m	34,600	0.060	0.096	0.129	0.163	0.188
Consumption - £m	29,844	0.140	0.160	0.180	0.200	0.214
Investment - £m	5,242	0.116	0.122	0.144	0.164	0.179
Exports £m	24,957	0.239	0.278	0.306	0.338	0.361
Imports - £m	35,553	0.238	0.246	0.251	0.257	0.261
Nominal before-tax wage - £	16	0.117	0.071	0.040	0.017	0.000
Real T-H consumption wage - £	13	0.061	0.029	0.015	0.006	0.000
Consumer price index	1.00	0.056	0.041	0.025	0.011	0.000
Total employment (000's):	1,267	0.049	0.086	0.118	0.149	0.172
Unemployment rate (%)	3.44	-0.535	-0.259	-0.133	-0.054	0.000
Total population (000's)	2,931	0.024	0.073	0.111	0.147	0.172
CO2 (as carbon) - PAP (tonnes)	11,746,484	0.736	0.779	0.797	0.815	0.828
CO2 (as carbon) - CAP (tonnes)	11,463,605	0.078	0.107	0.135	0.163	0.182
Iron and Steel sector:						
Capital stock - £m	318	2.737	3.381	3.404	3.420	3.432
Employment (000s)	8.18	3.229	3.375	3.399	3.418	3.432
Exports to RUK - £m	1,587	3.435	3.666	3.687	3.703	3.714
Exports to ROW - £m	837	3.434	3.665	3.686	3.702	3.713

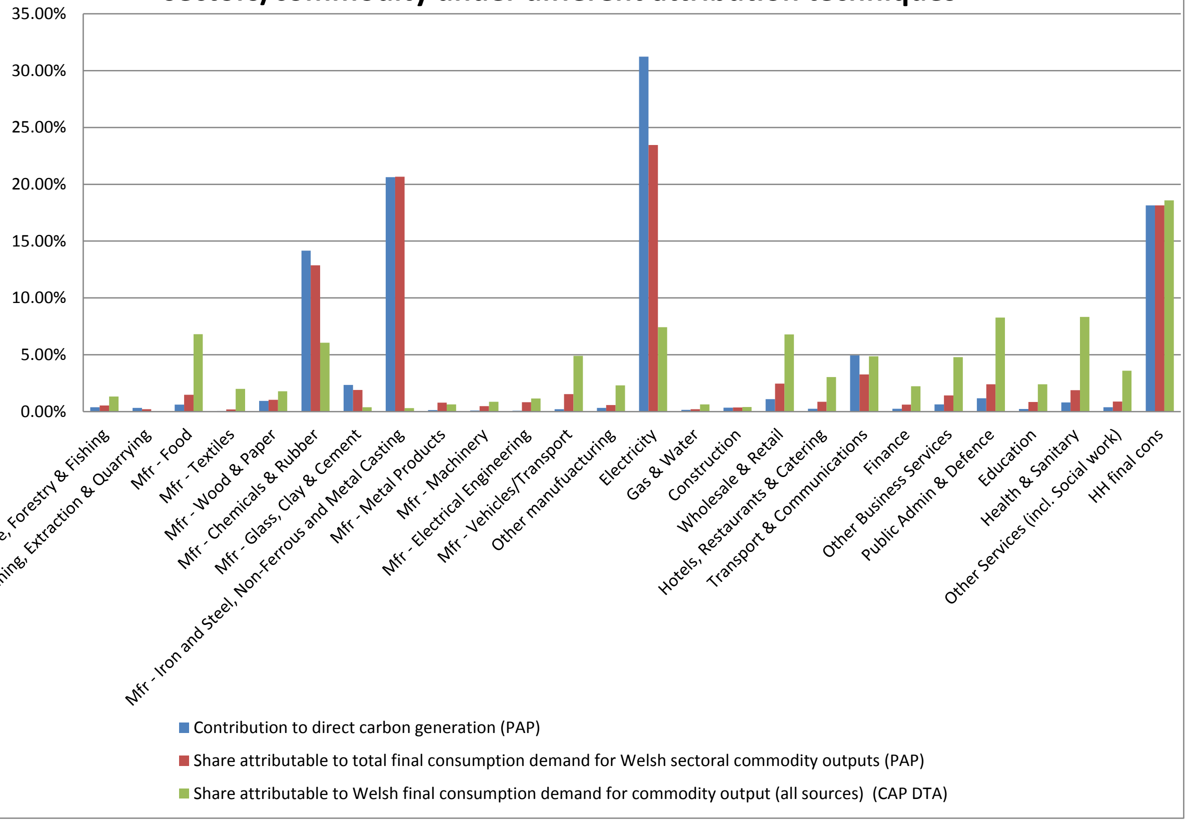
FIGURES

Figure 1: Wales – Main Exporting Sectors by % Total Exports year to 2010Q2



Source: StatWales

Figure 2. Percentage shares of carbon emissions attributable to sectors/commodity under different attribution techniques



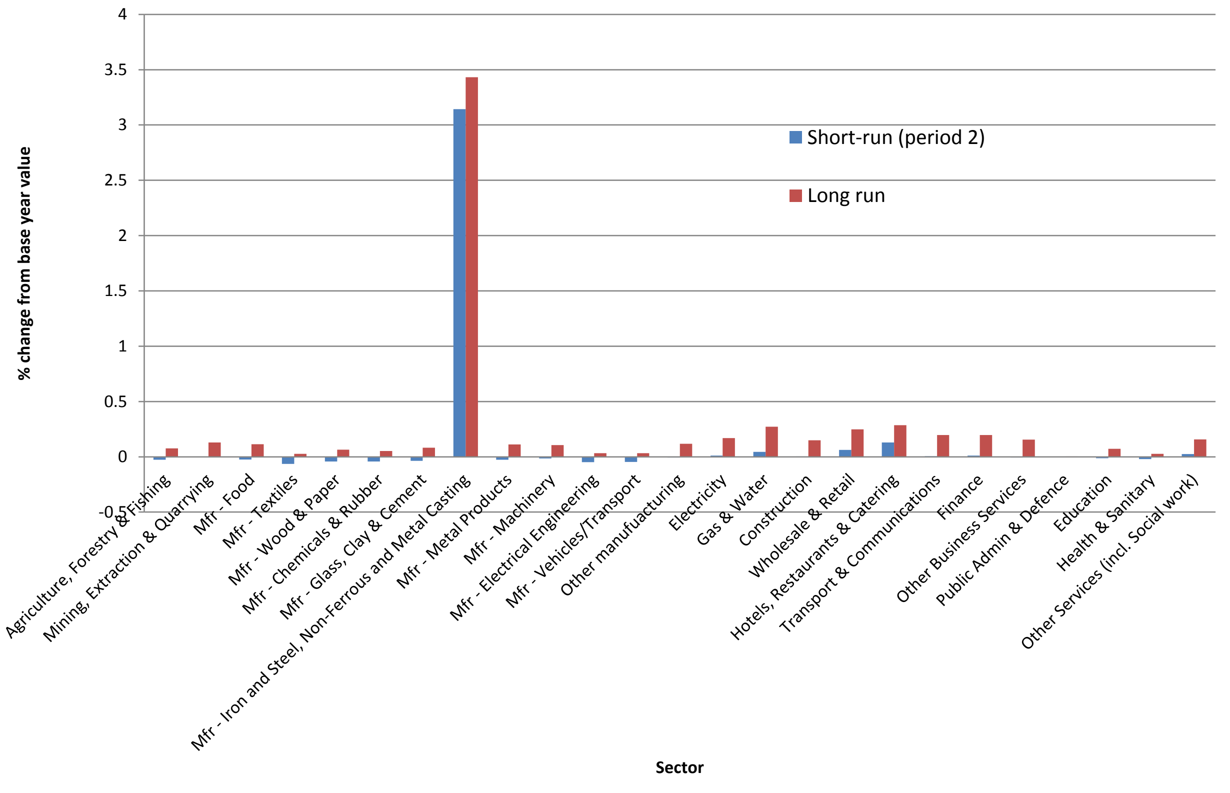


Figure 3. Impact of a £90million export demand shock in Welsh Iron and Steel on the composition of output

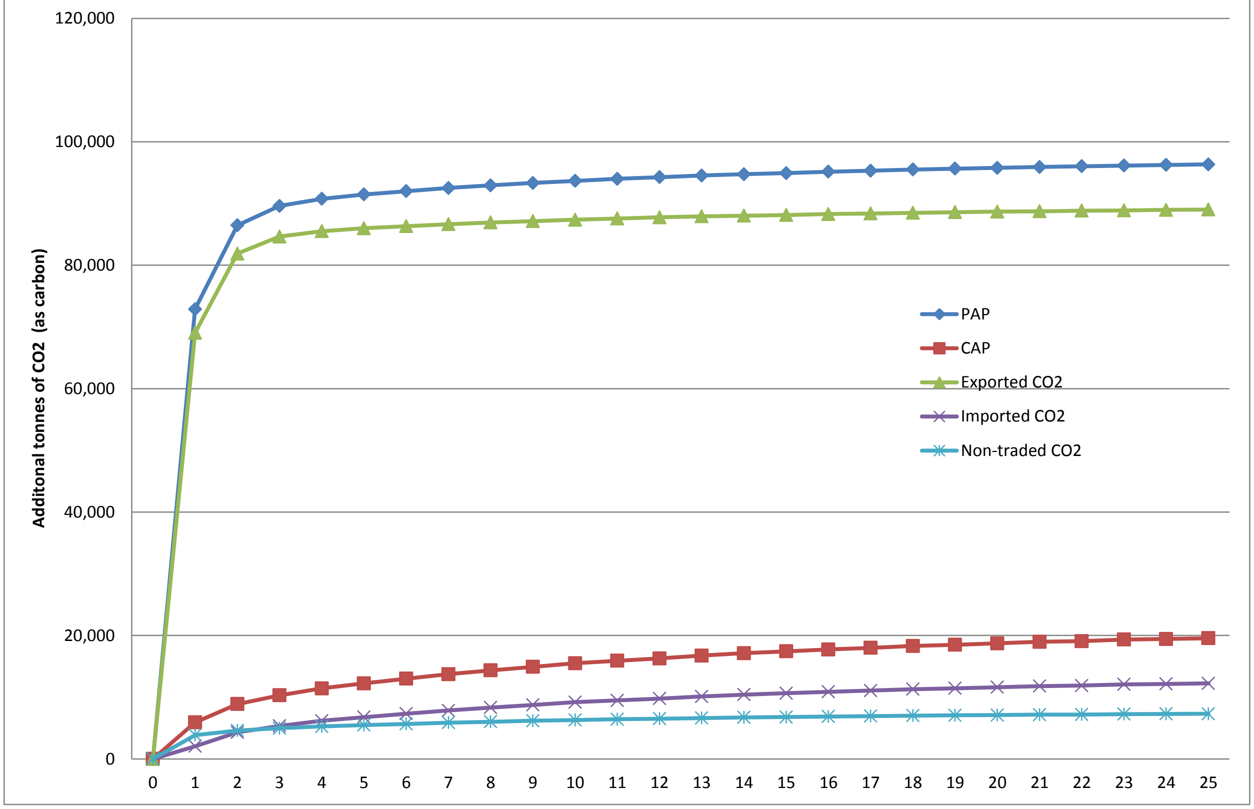


Figure 4. Additional CO2 (as carbon) embodied in Welsh trade flows as a result of a £90million export demand shock in Iron and Steel sector