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INCORPORATING JURISDICTION ISSUES INTO REGIONAL CARBON ACCOUNTS UNDER PRODUCTION AND CONSUMPTION ACCOUNTING PRINCIPLES

BY

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Incorporating jurisdiction issues into regional carbon accounts under production and consumption accounting principles

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Abstract. Despite increased public interest, policymakers have been slow to enact targets based on limiting emissions under full consumption accounting measures (such as carbon footprints). This paper argues that this may be due to the fact that policymakers in one jurisdiction do not have control over production technologies used in other jurisdictions. The paper uses a regional input-output framework and data derived on carbon dioxide emissions by industry (and households) to examine regional accountability for emissions generation. In doing so, we consider two accounting methods that permit 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. We propose that these methods permit an attribution of emissions generation that is likely to be of more use to regional policymakers than a full global footprint analysis.

Key words: pollution attribution; regional economy; input-output analysis; Wales
JEL Category: C67, Q01, Q53, R15

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Introduction

This paper reviews the ways in which environmental input-output frameworks can be used to examine the issue of carbon dioxide emissions attribution at the regional level. In particular the paper investigates issues of regional jurisdiction and responsibility for carbon dioxide emissions and argues that the environmental input-output framework can be used to provide innovative perspectives on regional responsibilities for emissions.

We argue that these perspectives are of real value in framing policy, given the need to consider issues linked to carbon dioxide emissions embodied in regional production ('smokestack') and consumption ('tailpipe') activity. The paper uses the case of Wales (a devolved region of the UK) to illustrate the approaches developed, and their potential value in better understanding some important issues of emissions dependence and attribution.

Background and context

Taking the UK regional case as an illustrative example, there are an increasing array of emissions reduction targets that apply to the UK and its devolved administrations. Figure 1 summarises some of these key targets and aspirations as they apply to carbon dioxide CO_2 (and equivalent) emissions for the UK and the devolved administrations. The introduction of such targets inevitably generates demands for an accounting framework that can accurately and practically express where responsibility for emissions lies, particularly for those emissions that are potentially associated with climate change. At one level there has been a great deal of progress in accounting for regional responsibilities through the construction of detailed carbon dioxide inventories at different geographical levels (see Munday and Roberts, 2006; Baggott et al., 2005; Digest of UK Energy Statistics, 2009). In most respects the development of these inventories has been based on a production or 'smokestack' principle focusing, for example, on where carbon dioxide emissions are actually produced, rather than focusing on how these emissions are connected to household consumption activity. Indeed, one vein of economic research on the regulation and measurement of environmental externalities has argued that there has been too much focus on the producer ('smoke-stack') as opposed to consumer generated ('tailpipe') pollution (see for example, McAusland, 2008).

A potential corollary of the above is that short term emissions targets for the UK, and regions such as Scotland and Wales, when based on a production accounting principle, could actually be achieved with ease. The structural changes that are expected to occur in these regions, coupled with stricter environmental regulations, might push out the more polluting industries out to other international locations. This might be deemed to be linked to a pollution haven hypothesis (Helland and Whitford, 2003). Fundamentally, the benefits from selected production and consumption may be retained in the home economies while undesirable environmental externalities are created in other jurisdictions. However, sustainable development objectives for the UK and its devolved regions speak strongly to a series of global responsibilities. For example, the sustainable development scheme of the Welsh Assembly Government stresses as a key outcome: "Living within environmental limits: by setting out a pathway to using only our fair share of the earth's resources, and becoming a One Planet nation within the lifetime of a generation" (Welsh Assembly Government, 2009, p.11).

Insert Figure 1 about here

In this context, and where sustainable development duties speak to more global responsibilities, there is value in approaches that can examine carbon dioxide emissions and other externalities based on a consumption accounting principle and give due consideration to the responsibilities of households (Munksgaard and Pedersen, 2001; Turner et al., 2007).

For the devolved administrations of the UK, the general jurisdiction and responsibility issues associated with 'production' and 'consumption' approaches to accounting for environmental externalities have not been ignored (see for example, Wiedmann et al., 2007). 'Footprint' style approaches are purported to provide insights into how regional consumption activities are linked to global environmental consequences. For example, the ecological footprint has gained currency internationally as a means of connecting local consumption behaviours to a global land area needed to support that consumption behaviour. Ecological footprint studies for the UK regions have demonstrated that in regard to a 'fair earth share', consumption patterns are clearly unsustainable (see for example Moffatt et al., 2001; Ravetz et al., 2007; Arup, 2008). In some cases the ecological footprint has been adopted as a headline indicator of sustainable development (Welsh Assembly Government, 2010a). A value of this general approach is that in exploring progress towards economy-wide sustainable development objectives, it is necessary to consider both production and consumption activity.

More generally the concept of a consumption 'footprint' at different spatial scales requires an exploration of the pollution content of trade flows (Druckman and Jackson, 2009). Consequently while such a consumption accounting approach is conceptually appealing there are a series of difficulties in moving towards such an analysis, particularly at the sub-national level. For example, in the devolved administrations of Scotland and Wales while there have been aspirations to better establish a consumption based measure, it is acknowledged that the trade data available to inform such an approach are limited. This further limits our knowledge of the pollution that is created to produce the goods and services being imported into and consumed within regional boundaries.

We argue in this paper that an approach grounded in an environmental input-output framework is a useful means of exploring the attribution, technical and jurisdictional issues connected to better accounting for the environmental externalities associated with regional consumption. To illustrate the analysis the focus is on Wales, one of the devolved regions of the UK. This is an interesting reference region for the analysis, given that the Welsh Assembly Government regularly reports carbon dioxide emissions as one of its headline indicators of progress towards a series of sustainable development objectives (see for example, Welsh Assembly Government, 2010b).

Interest in better understanding the attribution of carbon dioxide emissions in the region is also contextualised by the relatively high level of carbon dioxide emissions in Wales given its small size. For example, in 2007 of the 46 countries that signed up to the UN Framework Convention on Climate Change, Wales was ranked 6th highest in terms of carbon dioxide emissions per capita (13.1 tonnes per capita GWP, compared to 8.4 tonnes per capita for each England and Scotland). Wales intends to reduce carbon dioxide (equivalent) emissions by 3% per annum by 2011 in areas of devolved competence, and to reduce net carbon dioxide emissions by 80% in comparison to 1990 levels by 2050 (see National Assembly for Wales, 2009). In their general reporting of greenhouse gas emissions the Welsh Assembly Government acknowledge a difference in production and consumption (end user) approaches and the connection to trading propensities. Undoubtedly the regional industrial structure can be closely associated with the high level of carbon dioxide emissions per capita. For example, in 2007 around 30% of carbon dioxide emissions deriving from just 4 sites (and with much of this generated from the large Port Talbot steelworks and the Chevron oil refinery in Pembrokeshire).

We find in this paper that a large proportion of these carbon dioxide emissions are produced to serve export demands, and that more conventional means of accounting for this pollution place inadequate emphasis on regional consumption as a pollution driver. This is important because elements of regional interventions in achieving sustainable development objectives have been aimed at changing consumption and household behaviours. However, the evidence base linking regional consumption behaviour to carbon dioxide emissions at region, national and international level is underdeveloped because of the paucity of data on the pollution content of trade flows.

We therefore discuss whether approaches developed using an environmental input-output framework provide innovative ways of examining the attribution of emissions to regional consumption. The perspectives developed in the paper may be helpful in shedding new light on regional progress towards emissions reduction targets, and provide information that can be used by the policy community in shaping effective interventions. We believe this is important because questions of the attribution of carbon dioxide emissions are connected to questions of how we understand the jurisdiction of devolved administrations on sustainability issues. In the conclusions we argue that in the implementation of environmental policies our understanding of regional jurisdiction matters. Furthermore the impact of interventions critically depends on who ultimately is understood to be generating pollution, be it producers or consumers (see also Helland and Whitford, 2003; McAusland, 2008).

The remainder of this paper is structured as follows. The third section considers the general issue of emissions attribution within the environmental input-output framework. Using the case of Wales we demonstrate how the environmental input-output system can be used to explore attribution on a production accounting principle. Here the focus is on more conventional approaches to identifying industries that are connected to relatively high levels of carbon dioxide emissions both directly and then indirectly through emissions created in respective supply chains.

In the fourth section of the paper we demonstrate two more innovative approaches for examining emissions using the environmental input-output system. These approaches provide useful insights into the question of attribution. The first is the trade endogenised linear attribution system (TELAS). The second is an approach using a domestic technology assumption (DTA) to extra-regional trade. In both cases insights are provided into how regional consumption behaviour drives carbon-dioxide emissions. The fourth section also explores the practical issues in both attribution methods, and discusses the perspectives offered by the approaches. Again the case of Wales is used to demonstrate the techniques. The fifth section concludes and argues that an approach using a domestic technology assumption might be a particularly useful means through which to understand jurisdictional issues.

Examining carbon attribution in a basic input output framework

The Welsh analytical input-output tables form the basis for the attribution analysis (see Bryan et al., 2004 and WERU, 2007). The input-output tables for 2003 provide information on the sales and purchases of 74 defined sectors. 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. While carbon dioxide (as carbon) generation data for Wales are currently available for 2007 and 2008, the input-output framework used means that an older industry emissions dataset is used in this paper. Data on the emissions generation (carbon dioxide as carbon, and in terms of global warming potential) for 91 defined industries 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 dataset also reported carbon dioxide emissions generation associated with the domestic household sector (divided into travel and non-travel related emissions). This information was aggregated into the 74 defined industries plus household final demand expenditure within the Welsh input-output framework (see below). This provides a means of estimating emissions generation per £m of industry gross outputs for 2003 (the base year for the input-output framework used).[1]

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 carbon dioxide 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 $[\mathbf{I}\text{-}\mathbf{A}]^{-1}$ 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 pollution coefficients (or a matrix if more than one type of emission is

[1] It is accepted that this assumes that the physical relationship between output and carbon dioxide generation is fixed in the accounting year. However, in the attribution analysis in this paper we take this as an average relationship and do not seek to consider the impacts of any changes in activity.

being analysed) with elements $\varepsilon_i=e_i/x_i$, where e_i is the physical amount of emissions 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-pollution 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 production sectors) to meet one unit of final demand for sectoral output j. There are z=1,...Z final consumption groups. Where carbon dioxide emissions are directly generated by final consumers (e.g. 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, $\mathbf{y}$, as $\mathbf{y^*}$ (transposed and reported as a column vector).

In the Welsh input-output tables for 2003 there are N=74 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, 1985). 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 $\mathbf{A}$ and $[\mathbf{I}-\mathbf{A}]^{-1}$ 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 $\mathbf{y}$ 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.

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). 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.

With no *changes* in final demand (which would require a modelling framework), 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:

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

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. For Wales, calculation of equation (1) or equation (2) gives an estimated figure of 11.7m tonnes of carbon dioxide (as carbon) emissions generated in the region, e^R. Included in the y (and y*) vectors in the calculation of (1) are three broad sets of external demands. These are the vectors of export demands from the rest of the UK (RUK) and rest of the world (ROW) for Welsh goods and services, and external tourist demands of the domestic Y matrix in the regional input-output accounts. As shown in Figure 2, this means that a portion of Welsh domestic 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. In the Welsh case shown in Figure 2, around two thirds of domestic carbon dioxide generation is attributable to external demands (exports and tourists) and should thus should be excluded from a Welsh 'carbon footprint' under the full consumption accounting principle. However, the single region input-output analysis above 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.

Insert Figure 2 around here

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) for a review).

However, there are two practical issues involved with adopting such an approach. 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.

Second, even if it were possible to identify such a database to analyse the resource requirements of final consumption in the region of interest, it would seem that there is also an issue of jurisdiction. This boils down to the fact that decisions regarding production technology and resulting resources used in the regions/countries that the target region directly or indirectly imports from, are likely to lie outwith the jurisdictional authority of government in the region whose consumption behaviour is under examination.

It is this second issue that is the focus of this paper. In the next section 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 while retaining attention on the issue of regional jurisdiction.

Exploring the attribution of carbon in the context of jurisdiction issues

TELAS analysis of regional consumption requirements under the production accounting principle

The first question explored is whether the standard input-output approach in equation (1) can be adapted to focus on regional rather than total (including external) final consumption as the driver of total regional emissions under the production accounting principle, e^R. To this end McGregor et al. (2008) propose a Trade Endogenised Linear Attribution System (TELAS). This involves endogenising trade in much the same way as we endogenise capital in the analysis above. Instead of counting external export (including tourist) demands for outputs of regional production sectors as elements of final consumption demand within the vector **y** in (1), the TELAS approach creates an additional regional production sector in the **A** matrix, a *Trade* sector that 'produces' the imports required in the economy as a whole (i.e. exports are produced for the purpose of facilitating imports). The row entries for each local (consuming) sector j are that sector's total imports from the external sector as a share of the total input/output of sector j. The additional column entries are the outputs that are produced for export to the external sector via the trade sector by each local (producing) sector i, per unit of output in the *Trade* sector, which equates to total imports.[2]

When equation (1) is calculated with trade endogenised, each individual (production or consumption) sector that imports from the external sector is attributed the carbon dioxide emissions embodied in the share of total domestic export production required to finance these imports (i.e. one monetary unit of imports is attributed the carbon embodied in the average monetary unit of exports required to finance these imports).

The results of calculating equation (1) under the TELAS approach for the case example of Wales are given in the second column of Table 1 (the Type I results, with capital endogenous, are tabulated in the first column. The key point to note is that the total carbon dioxide emissions attributed under TELAS (shown in the first row) are the same as in the Type I case above. That

[2] Note that, as in a Type II analysis (where household expenditures are taken as inputs and labour services as outputs), or when capital is endogenised (with capital formation/investment as inputs and other value-added/capital services as outputs) it is unlikely that total inputs to the *Trade* sector (exports) will equal total outputs (imports). Where exports are greater than imports, a proportion of export demand may be retained as exogenous in **y**. If it is not, the exporting country is effectively providing a free good to the importing ones. On the other hand, where imports are greater than exports, the rest of the world is partly supporting imports to consumption in the local economy. To examine the nature of the balance of trade through a region's current and capital accounts, McGregor et al. (2004, 2008) demonstrate that it would be necessary to extend the analysis to a social accounting matrix (SAM).

is, e^R=11.7m tonnes of carbon (Welsh domestic carbon emissions under the production accounting principle) in both cases. However, with trade endogenised, all of these emissions are now attributable to regional private and public (household and government) final consumption demands. That is, the two thirds of carbon emissions that were attributable to external demands in the Type I analysis are still produced. However, under TELAS these are attributed to the imports required to (directly or indirectly) meet local consumption demands (with the reallocation to local demands reflecting the import profile of the local outputs consumed).

Insert Table 1 around here

Thus, TELAS retains focus on the generation of pollution within the region, but allows us to consider the import and export requirements of the regional economy, and the implied domestic pollution requirements therein of different types of consumption (private or public, or any disaggregation therein – e.g. household consumption may be split to identify different income or other socio-economic groupings).

One policy implication that may be inferred from analysing the Type I and TELAS results alongside one another is that there is a need for Wales to export and import less, and adjust local consumption patterns in order to maintain total consumption levels. Alternatively, imports may remain constant, but the structure and type of export production required to finance these imports would have to change (so that the full local resource cost of imports as reflected in an average unit of export production is lowered). Use of the basic Type I input-output framework in the last section augmented with the TELAS analysis introduced above allows detailed analysis of the structure of pollution problems from this perspective. Figure 3 shows the composition of the carbon emissions embodied in Welsh exports from the Type I case.

Insert Figure 3 around here

Here we see that just 8 of the 74 sectors identified in the Welsh input-output tables account for just under 95% of the total exported emissions in Wales, with exports of electricity generation and supply and iron and steel production being key drivers of Welsh carbon emissions in 2003. Moreover, Figure 4 shows that emissions embodied in exports from these sectors were largely supported by demand from the rest of the UK. This is particularly the case with electricity exports. In this respect, it may be useful to conduct separate analyses for the RUK and ROW cases, given that Wales is a devolved region of the UK and that binding agreements such as those under the Kyoto Protocol apply at the national level. As argued by McGregor et al (2008), if electricity can be generated using less polluting technology at the regional level, it may be better for the national economy as a whole if production is located there. However, the location of polluting activities in the national interest would seem to be an important, but not previously (or explicitly) considered, issue in the context of the devolution settlement.

Insert Figure 4 around here

In extending the conventional Type I analysis with TELAS, perhaps the most useful tool is the output-pollution multipliers. Each element κ_j of the TELAS variant of the $\boldsymbol{\varepsilon}^{\mathbf{P}}[\mathbf{I}\text{-}\mathbf{A}]^{-1}$ vector in equation (1) gives us the total physical amount of carbon dioxide emissions generated in production (across all production sectors) to meet one unit of final demand for sectoral output j. For example, Figure 5 shows the TELAS multipliers for six Welsh production sectors which have relatively low direct and indirect carbon dioxide emissions-intensities (the latter reported in the standard Type I output-carbon dioxide multipliers). The large difference between the Type I and TELAS output-emissions intensities of these sectors reflects their import intensity, which (under the TELAS perspective that export production is necessary to facilitate imports) implies that there will be relatively large carbon dioxide emissions impacts throughout the economy should activity in these sectors expand (though note that all have a lower TELAS carbon dioxide multiplier than the average unit of exports in the Welsh economy, reflected in the 'Trade' sector multiplier). Given that the six sectors identified in Figure 5 would not generally be regarded as 'important' sectors in terms of their conventional pollution profile, what the TELAS analysis does is focus attention on the importance of import dependence in the Welsh economy, and the likely emissions implications and wider resource requirements of financing these imports.

Insert Figure 5 around here

Note, however, that in the case of Wales in 2003, the value of imports (£36.5bn) was greater than the value of exports (£30bn). That is, in financial terms, Welsh imports of goods and services were partly supported by the external (rest of UK and rest of the world) sector. TELAS multipliers are therefore likely to be understated and policymakers may wish to consider the impacts of increased export production to finance import demand.[3]

In more general terms, a key point to note is that under TELAS no attempt is made to estimate the carbon emissions generated in other regions/countries in producing the commodities that are imported (i.e. the carbon embodied in imports). In other words, TELAS does not address carbon emissions generated outside the target region to support local consumption. Instead it focuses on carbon emissions generated *within* the target region to support regional consumption (i.e. regional emissions under the production accounting principle). The philosophy underlying this approach is basically a neo-classical, resource-constrained, view of the open economy where the

[3] It is important to note that in all cases examined here a modeling framework would be required to analyse the impacts of changes in activity, for example how shifts in activity to increase export production may be achieved, and what their implications would be. While input-output is an entirely appropriate framework for accounting for the structure of pollution problems (as we do here), it is only a very special and limited case of general equilibrium modeling, and likely to be too restrictive to analyse the impacts of such shifts in economic structure, and how they may be achieved.

essential purpose of export production is to finance the imports required to fulfill local consumption demands.

However, on the other hand, there is increasing public concern over the global impacts of human consumption decisions. This has led to increasing focus on ‘footprint’ measures, which require consideration of emissions embodied in imports (not considered as part of the TELAS analysis above). Despite this fact, policymakers have been slow to enact firm targets based on limiting emissions under full consumption accounting measures, such as carbon footprints. It is our speculation that this may reflect the fact that policymakers in any one jurisdiction do not have control over technologies used in other jurisdictions. Therefore, we propose a second adjustment to the basic single region input-output attribution technique that does attempt to take account of the pollution content of imports, but retains focus on the jurisdictional limits to the authority of regional policymakers.

DTA analysis of regional consumption requirements under a limited application of the consumption accounting principle

The attribution technique that we consider next involves adopting what is referred to as the ‘domestic technology assumption’ (see also Druckman et al., 2008, 2009). This involves assessing the pollution content of the combined (total) use of commodities (regional and imported) according to the domestic pollution technology in the $\boldsymbol{\varepsilon}^{\mathbf{P}}$ vector in equations (1) and (2) for the target economy. 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. Here we 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. We may think of the approach in terms of the pollution implications if the region of study (here, Wales) were to produce the commodities it chooses to consume itself. We apply the 'domestic technology assumption' to a variant of the **A** matrix that records the combined use of (regional and imported) intermediate inputs to production. In this respect, the DTA approach 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 gives the global output-carbon multiplier effects if each external sector i shared the emissions characteristics of the corresponding sector i in the target region. Thus, the total carbon implications of regional final consumption, e^{T}, are estimated under the domestic technology assumption (hereafter DTA) 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 **y** in (1) while $\mathbf{y}^{\mathbf{M}}$ gives us imports to exogenous final consumption by commodity/external sector output. Note that, as we include imports, export demands simultaneously drop out of the final demand vectors – i.e. we focus our attention on *local* (regional) final consumption demands.

Here, we apply the approach in equation (3) to examine the carbon dioxide emissions attributable to final consumption demand in Wales (for 2003). Again, as in the analyses above, we endogenise capital in order to focus on regional private and public (household and government) final consumption demands.

The final column of Table 1 shows the results of calculating equation (3) to give us attribution to local final consumption demands under the DTA assumption. Here, note that while the allocation between regional household and government consumption is broadly similar to that in the TELAS case (second column), the total amount being attributed, e^T, (10.9 million tonnes) is less than the actual carbon emissions generated in Wales in 2003, e^R, (11.7 million tonnes) in equations (1) and (2). This suggests that the carbon dioxide emissions embodied in Welsh imports (under DTA) are less than the emissions embodied in exports. More detailed examination of the DTA results relative to the conventional Type I results from Section 2 demonstrate this point. Table 2 shows that domestic (Welsh) emissions generation supported by households and government is the same under both measures. However, while the Type I analysis in column one gives us the actual carbon dioxide emissions generation supported by external demands (7.7 million tonnes, around two thirds of actual carbon dioxide emissions generated in Wales in 2003), we require the DTA analysis to get even an estimated measure of the emissions embodied in imports. Here we are able to identify the emissions embodied in direct imports to Welsh households and government (final consumption vector $\mathbf{y}^{\mathbf{M}}$ in equation (3)) and also indirect emissions embodied in imports to Welsh production to meet Welsh final consumption for regional outputs (vector $\mathbf{y}^{\mathbf{R}}$). In Table 2 these are respectively the 3.5 million tonnes of carbon embodied in direct imports to regional household and government final consumption and the 3.3 million tonnes embodied in imports to intermediate demands. Thus, combined use of the results from the standard Type I analysis above and the DTA analysis here, we are able to examine the components of the implied carbon trade balance.

Insert Table 2 around here

That key result of the DTA analysis for Wales (2003) is that of a 'carbon trade surplus' (i.e. emissions embodied in exports are greater than those embodied in imports). This raises several issues. First, this 'regional carbon footprint' of regional consumption demands is unlikely to equal the actual global carbon footprint of Welsh consumption as we would expect production technologies to differ from those that apply in Wales. That is, the import results in Table 2 will be sensitive to the assumptions regarding production technology associated with imports.. However, Welsh policymakers do not have any jurisdiction over the latter, with the implication that the hypothetical measure reported in the final column of Table 1 and in Table 2 may be of more practical use at the local level.

This raises a second issue. In the Welsh example here, in focussing on technologies over which local policymakers have jurisdiction, we get the result that the region is effectively 'exporting sustainability' despite the fact that (at least in the accounting year of 2003) it runs a trade deficit. This may be regarded as a 'good' footprint result. However, the problem in the current policy configuration (where emissions targets tend to be set in terms of the production accounting principle) is that upward pressure is being put on Welsh domestic carbon dioxide emissions generation by consumption demands in the rest of the UK and internationally.

Discussion and conclusions

The paper has examined how a regional environmental input-output system can be used to derive estimates of the carbon dioxide emissions connected with regional consumption patterns. One context of the paper was that much of the regional reporting of carbon dioxide emissions and other externalities is undertaken on a production basis. At one level the monitoring of point sources of emissions is critical for regulatory purposes and fulfils obligations that the UK has towards international treaties on emissions reduction. However the paper also argued that the sustainable development duties being faced by devolved regions in the UK speak to global as well as local responsibilities, which implies a requirement to understand how regional consumption patterns create externalities outside regional boundaries. While there has been a growing focus on footprint style measures which connect local consumption to global environmental consequences, it was argued that the paucity of data on regional trade and the pollution content of this trade set limits on what can be achieved. Moreover, policymakers may be reluctant to set targets for measures that are influenced by factors outwith their jurisdictional authority.

The importance of making firm connections between regional consumption and environmental effects is also highlighted in the nature of regional interventions to meet with a broad range of sustainable development objectives. For example in the Welsh case examined in this paper, the future achievement of sustainable development objectives is expected to focus on the promotion of consumer behaviour change, and with the regional assembly government anxious to develop a "robust evidence base [that] will help us evaluate and develop effective evidence based policies related to motivating pro-environmental behaviour…we will continue to address unsustainable consumption patterns and promote behaviour change in individuals, households, communities and organisations." (Welsh Assembly Government, 2009).

This paper argues that if such a focus is retained on regional consumption as the key determinant of emissions generation and a focus of attribution, then measures like TELAS and DTA allow the region to 'take responsibility' for supported emissions, but within a framework over which they have jurisdiction, i.e. those regional consumption demands which support these emissions. Consequently instead of a reliance on territorial emissions as a benchmark for emissions reductions, more use could be made of the DTA Emissions balance. Clearly this approach is based on a 'what if' (or hypothetical) analysis, but this paper reveals that it does focus attention on the pattern of emissions supported by regional consumption decisions in a way that allows for greater regional 'responsibility' while at the same time staying within the jurisdiction of the regional government.

More generally the techniques investigated in this paper also provide a useful basis for scenario analysis. For example, as the case region faces a prolonged period of structural change the approaches lay a foundation for an analysis of how resulting changes in consumption induced trading patterns may affect the levels of associated emissions. However, such a scenario analysis is likely to require relaxation of some of the restrictive assumptions of the input-output model in a more flexible general equilibrium framework.

The approaches outlined also have the advantage that they can be practically developed. Munday and Roberts (2006) in a review of approaches to monitoring and measuring regional progress towards sustainable development objectives highlight issues of development practicality, cost, and transparency. The TELAS and DTA techniques can be executed using data commonly available at the regional level. However, a full consumption accounting would require an inter-regional and international input-output framework. The paper reveals (using the case example of Wales) that all is required for TELAS and DTA analysis are data produced within the region itself as opposed to the considerable amounts of economic, trade, and emissions data from regional and national economies that are linked to the relatively open Welsh economy through trade. We surmise that few UK regions have access to the resources and expertise which would make the estimation of a full carbon footprint possible.

However, set against the above strengths are a series of issues that need to be stressed. The use of the techniques is not without difficulty and all approaches grounded in an input-output framework will be subject to its general limitations (see Miller and Blair, 1985 for a review of these limits). Moreover, at a practical level not all of the UK regions have input-output data published in a format that would enable the analysis undertaken in this paper. However, this situation continually improves and with the additional possibility of deriving regional tables from the UK input-output framework where regional tables do not exist.

In both the TELAS and DTA cases there is also no account taken on the *actual* emissions content of regional imports. We justify this on the basis of the limited jurisdiction of regional authorities. It is accepted that the DTA and TELAS approaches move one only part way to a full accounting of the environmental externalities associated with regional consumption. However, we propose that it provides a series of insights into the carbon dioxide emissions associated with regional consumption, and enables the analyst to consider issues of underlying regional jurisdiction which would be difficult practically using other available methods.

In a practical policy context, even if data on the pollution profile of industries that export to the target region are available to transform the DTA model in equation (3) into a (uni-directional) actual footprint calculation, we propose that it would be useful for policymakers to consider such a measure alongside the results of the DTA analysis. This would allow policymakers to focus on the implications of the limits to their jurisdictional authority and perhaps to consider some type of policy coordination with authorities in the exporting region. Indeed, a key point in the DTA analysis presented here is that Wales is absolved of responsibility for the technology decisions in its own production to meet export demand. From a global environmental perspective, responsibility needs to be taken for the technology decisions underlying pollution embodied in trade flows. In the context of UK devolution (where legal commitments, such as those under the Kyoto Protocol, apply at the national level) there may be a case for a mixed approach that measures actual pollution embodied in interregional trade flows (i.e. trade with the rest of the UK) while retaining the DTA assumption in examining imports from the rest of the world.

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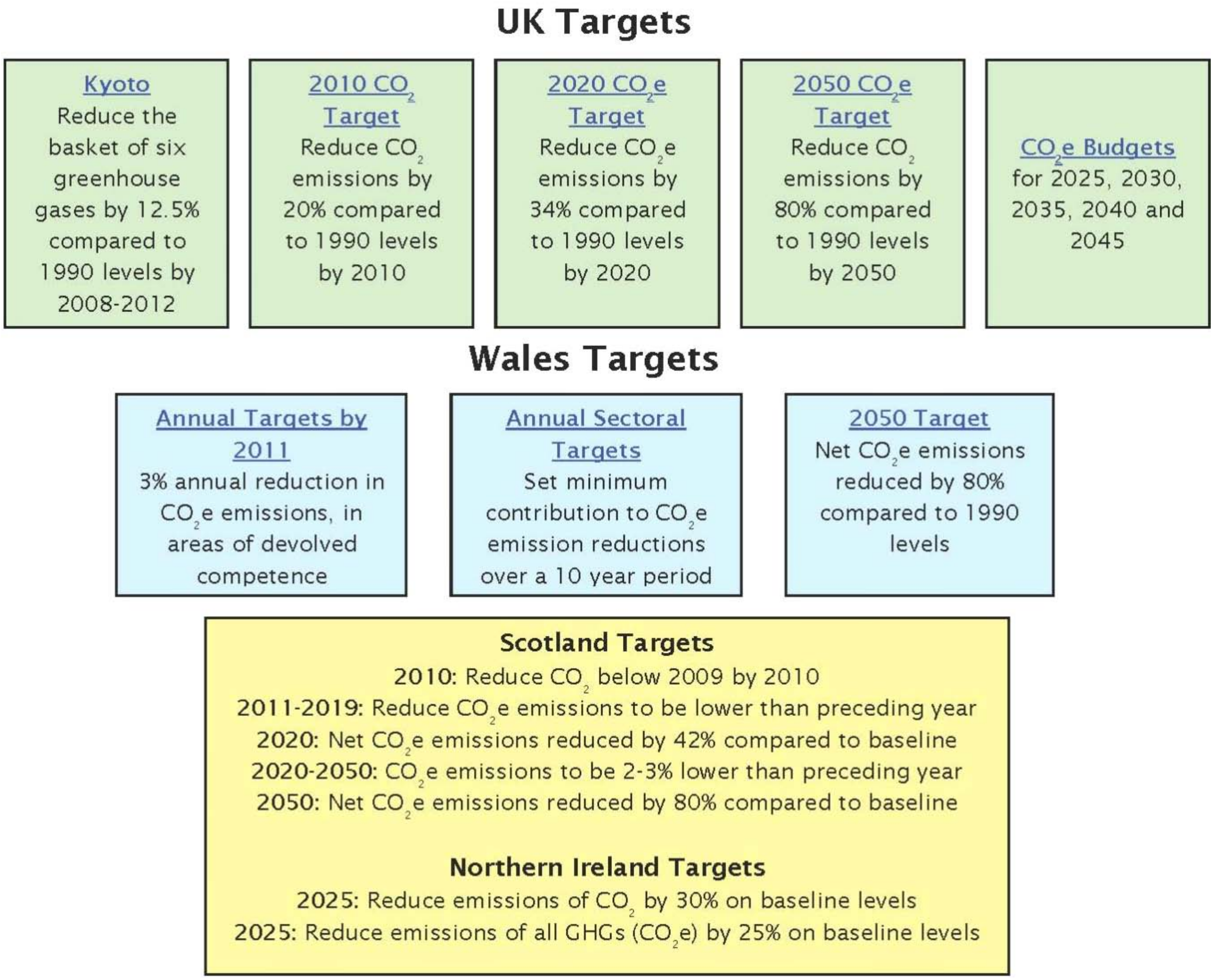
Table 1: Summary of Attribution of Total CO_2 as Carbon (Tonnes) to Final Consumers in Wales (2003)

	Type I (endogenous capital)	**TELAS (endogenous trade and capital)**	**DTA (endogenous capital)**
Total CO_2 as carbon attributed (tonnes)	**11,746,484**	**11,746,484**	**10,864,875**
Percenatages shares attributed to different consumers:			
Welsh households	29.68%	81.63%	83.83%
Welsh government final consumption	4.69%	18.37%	16.17%
Total local (private and public) consumption demand	**34.37%**	**100.00%**	**100.00%**
RUK exports (goods & services)	46.21%		
ROW exports (goods & services)	17.17%		
Total exports (goods & services)	**63.38%**	**0.00%**	**0.00%**
Total external tourists	**2.25%**	**0.00%**	**0.00%**
Total CO_2 as carbon attributable to final consumers	**100.00%**	**100.00%**	**100.00%**

Table 2: Input-Output Accounting of the Welsh Carbon Trade Balance (2003)

	Actual generation (Type 1)	Hypothetical generation (DTA)
Total CO_2 as carbon attributed (tonnes)	**11,746,484**	**10,864,875**
CO_2 supported by Welsh household and government final consumption		
Domestic (Welsh) CO_2 generation:		
Directly generated (households)	2,130,600	2,130,600
Indirect - generated in Welsh production sectors	1,906,466	1,906,466
	4,037,066	4,037,066
	-	
Indirect emissions embodied in imports (hypothetical)		
Imports to households and government		3,523,966
Intermediate imports		3,303,843
		6,827,809
CO_2 supported by external demands for Welsh production	7,709,418	
Implied CO_2 Trade Balance (Surplus):		
Actual CO_2 generation minus DTA CO_2 generation		
(CO_2 embodied in exports minus CO_2 embodied in imports)	881,609	

Figure 1: Emissions targets for the UK and Devolved Administrations



Source: National Assembly for Wales, 2009

Figure 2: Welsh Type I Emissions by Final Demand Category

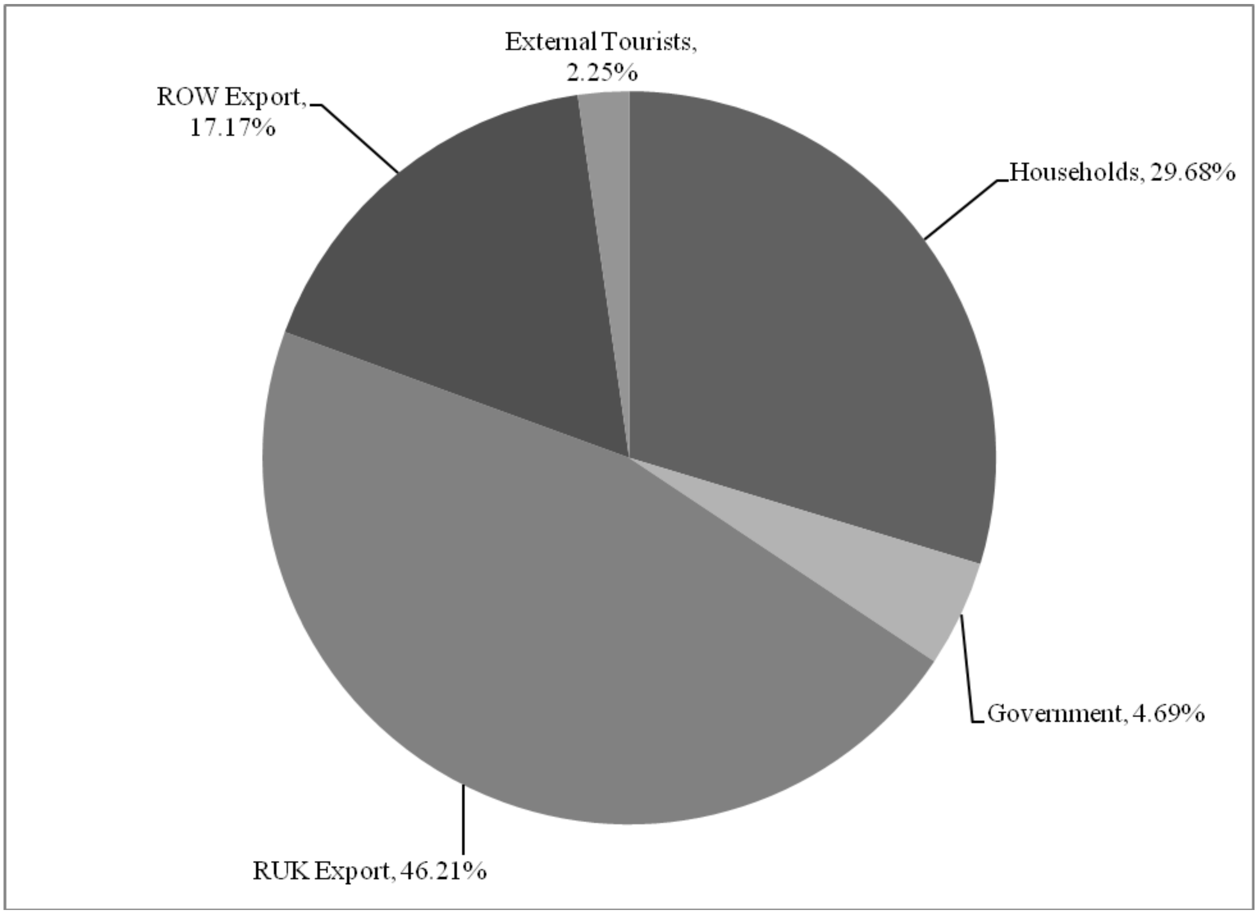


Figure 3: Composition of emissions embodied in export demand from Wales by sector

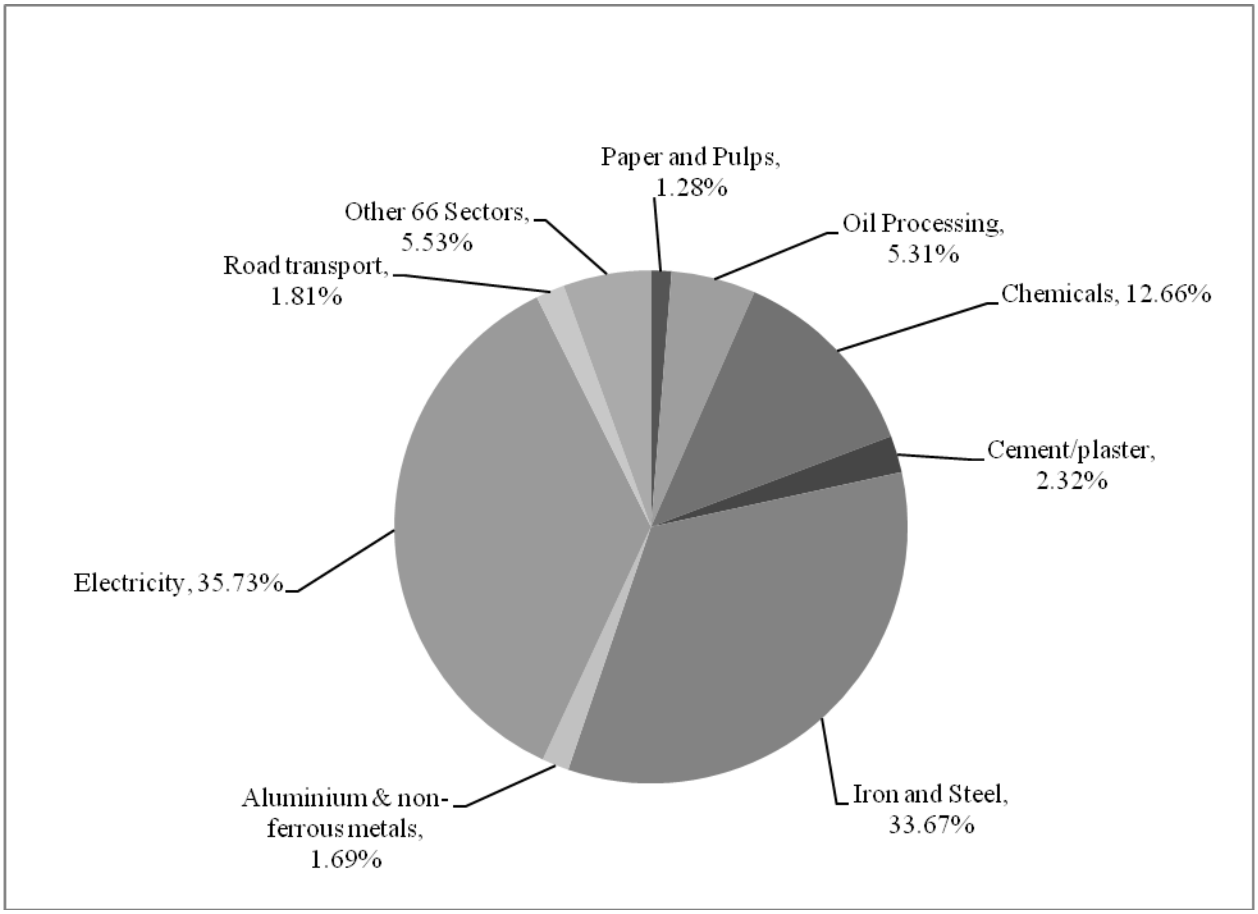


Figure 4: Region Supporting Welsh Sectoral CO2 Generation (8 sectors with highest CO2 generation to meet export demand)

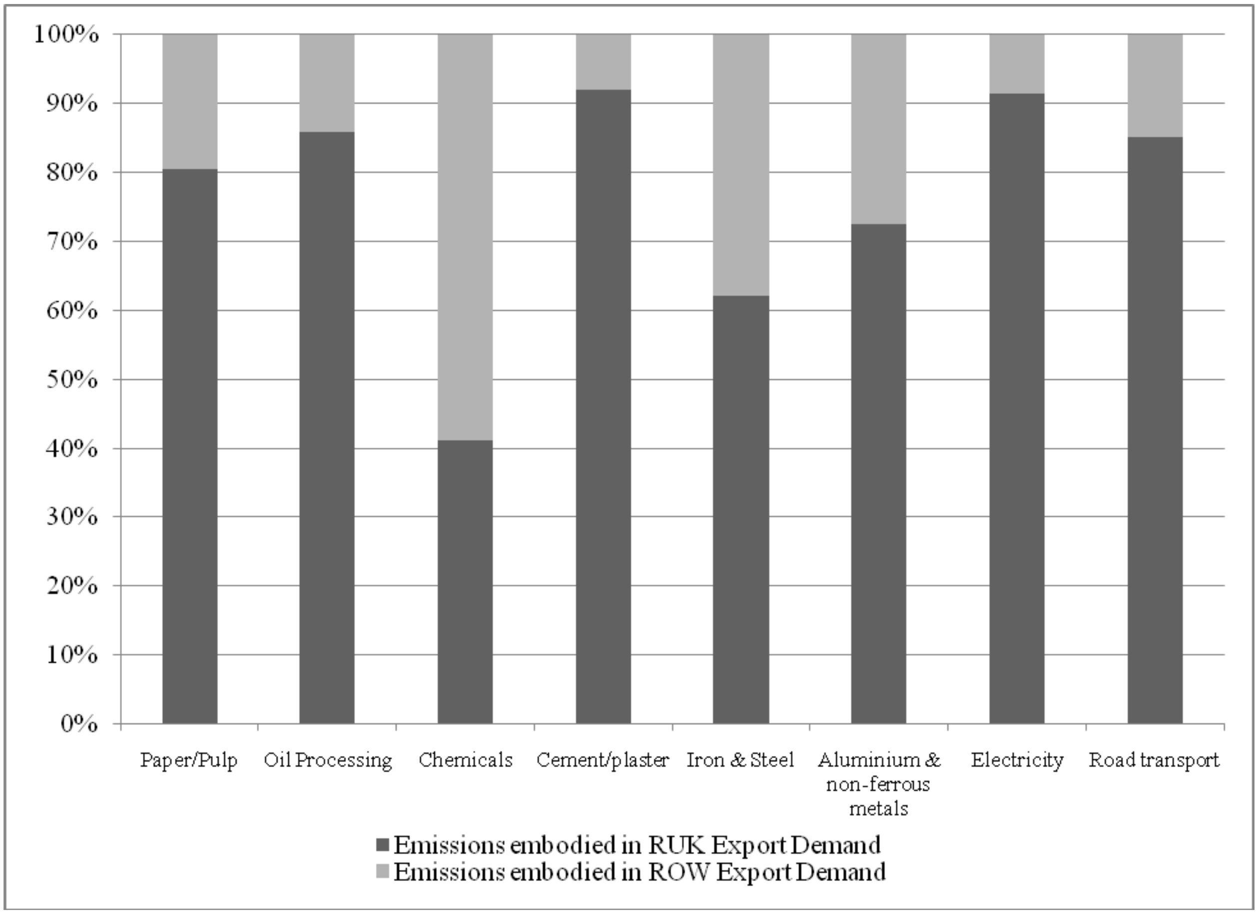


Figure 5: TELAS multipliers for sample low CO2 intensity sectors (tonnes of CO2 as carbon per £1m output production to meet final demand)