

Could a new Scottish CO₂ transport and storage industry deliver employment multiplier and other wider economy benefits to the UK economy?

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Abstract

In 2021, the UK Government commenced a ‘cluster sequencing’ initiative to identify early movers in delivering carbon transport and storage (T&S) services to proximate regional industry clusters with capture potential. A Scottish proposition focussed primarily on linking the Grangemouth industry cluster to North Sea storage, and the potential to transition Oil and Gas industry capacity to deliver CO₂ T&S has devolved policy support. This is in terms of potential to transition and create new direct industry and supply chain jobs, set against risks of displacing jobs in different sectors and regions of the UK. We introduce a Scottish CO₂ T&S industry to a UK multi-sector economy-wide model, assessing the extent of potential expansion and job creation in the presence of supply-side and funding constraints. We find that large employment ‘multiplier’ gains registered in previous studies only apply over the very long term and in the absence of such constraints. Crucially, any need to recover demands on the public purse via socialisation of costs severely constrains possible gains, while imposing ‘polluter pays’ leads to net economy-wide contractions triggered by competitiveness losses concentrated in Scottish cluster industries, leading to offshoring of production and jobs, potentially skewed within the localities hosting the clusters.

Keywords

Computable general equilibrium models, carbon capture, CO₂ transport and storage, economy-wide impacts, employment multipliers, industrial decarbonisation, new industry development, regional industry clusters

Introduction

The evolving UK Industrial Decarbonisation and linked UK ‘green growth’ strategies [Department for Business, Energy & Industrial Strategy \(BEIS, 2021a\)](#); [HM Government, 2020](#); [HM Treasury,](#)

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2021) focus on the need to deliver deep emissions reductions in energy-intensive industries while sustaining the GDP and employment contributions of those industries and the domestic supply chains. Current policy activity centres on regional industry clusters across England, Scotland and Wales, where the national government's 'Industrial Clusters mission' (BEIS, 2019) aims to deliver one net zero and four low emissions clusters by 2030/2040 as a central part of meeting the UK's 'net zero' (territorial emissions generation) commitments (UK Legislation, 2019).

The UK Industrial Decarbonisation Strategy (BEIS, 2021a) identifies carbon capture (potential usage) and storage, CCS – involving the capture of carbon emissions in production processes to be piped and/or shipped to off-shore reservoirs previously containing oil and gas reserves – as one route to decarbonising regional manufacturing clusters in line with 'net zero carbon' ambitions. Crucially, extensive CO₂ transport and storage services (T&S) capability already exists in the nation's oil and gas (O&G) industry and supply chains. In 2021, a CCUS Infrastructure Fund (BEIS, 2021b) is being deployed to support the first stage of sequenced investment to develop CO₂ T&S capability and capacity in different sites off the Scottish (east) and English (east and west) coasts (BEIS, 2021c). This will link to proximate capture activity within the UK's regional industry clusters, primarily involving manufacturing industries such as iron and steel, chemicals, cement, lime and glass, along with oil refining. Ultimately, a UK-wide network may develop, linking T&S capacity to a range of point source emissions (potentially including power generation) in the three mainland nations, including the potential to ship CO₂ between different regional capture and T&S locations, and possibly to export T&S services (shipping in CO₂ from capture sites in other nations).

This paper focusses on the challenges of understanding the likely local and national wider economy impacts of, and the trade-offs involved in, supporting new T&S capacity as part of potential CCS systems, where direct

policy support in the UK context is likely to involve cost recovery from taxpayers and/or emitting regional cluster industries in different timeframes. We focus on the case of deploying T&S capacity to service capture activity in the Grangemouth industry cluster on the Firth of Forth in the eastern central belt of Scotland. This is a relatively specialised cluster with activity and emissions sources concentrated in petrochemical production and oil refining, with the largest firm directly employing more than 1,300 people on site and constituting around 8% of Scotland's manufacturing base.¹ Sequestration of industrial emissions captured at Grangemouth via the T&S network is likely to involve use of on-shore pipelines to St Fergus in the north east of Scotland linking to an offshore pipeline to the Goldeneye site in the North Sea.²

We identify two central policy-facing research questions. Will the adoption of T&S be a driver of 'green growth' at national UK and/or at the Scottish regional level where its deployment is aimed at helping decarbonising production activity at Grangemouth? How does the approach to funding the T&S activity affects key macroeconomic and sectoral indicators of concern to policymakers, including employment?

Crucially, T&S involves introducing new industry capacity in Scotland. We consider the conditions and timeframes under which employment 'multiplier' outcomes generated using the national 'input-output' (IO) frameworks that decompose the sectoral composition of existing economic activity but are commonly used by policy makers to consider 'what if' scenarios where activity levels may change. Specifically, we apply the more flexible multi-sector economy-wide computable general equilibrium (CGE) modelling methods that incorporate IO data but are more commonly used for policy-facing analyses of scenarios of changes in activity involving likely price effects.³ This is motivated by the need to investigate the impacts of new T&S activity in the context of constraints in the UK labour market and on public funding.

We consider key issues associated with the introduction of such a new sector; in particular,

the implications of its infrastructure intensity, with emphasis on the likely need for early/upfront investment and government action to guarantee demand for the initial capacity. Crucially, these are all issues of likely relevance in other decarbonisation contexts, such as the deployment of hydrogen networks. We examine the challenges of funding a new T&S sector, where the UK approach is likely to involve public/taxpayer support but with a move to a ‘polluter pays’ approach at least in the medium term (BEIS, 2021a). Our key conclusion is that where the direct cost burden is borne by cluster industries, the notion that T&S could contribute to UK ‘Green Growth’ and the ‘Just Transition’ that the Scottish Government is committed to may be undermined.⁴

Methods

The need for a multi-sector economy-wide modelling

CCS research and debate has traditionally focussed on project techno-economics and costs per tonne of CO₂ capture and sequestration (e.g. Budinis et al., 2018; IEA, 2016). However, international policy focus is shifting to understanding wider economy implications (IEAGHG, 2020). In the UK, the BEIS (2021c) ‘cluster sequencing’ initiative already includes consideration of an ‘economic benefits’ criterion in identifying Phase 1 CCS propositions. At the Scottish level, development of the Scottish Government’s Climate Change Plan (2020)⁵ highlights the role of the ACORN CCS (and hydrogen) project⁶ in the northeast of the devolved nation. The potential to link T&S capacity developed via ACORN to carbon capture in the Scottish Grangemouth industry clusters is the basis for a Scottish cluster sequencing bid, where a key source of perceived economic benefits is transitioning existing capacity and safeguarding employment linked to the current O&G industry. Here, the, (as yet) limited, evidence based on potential wider economy benefits builds largely on employment-related ‘multiplier’

analyses – based on national accounting of IO interactions across the economy – of the current contribution of O&G to the Scottish and UK economies commissioned by Crown Estate Scotland and Scottish Enterprise (Turner et al., 2019a, b).

However, in fully considering the potential for economic benefits associated with CCS development, the question arises as to whether multiplier methods (Miller and Blair, 2009) are the most appropriate approach to assess the likely employment outcomes of developing T&S industry capacity in any region or across the UK national economy. Multi-sector demand-driven modelling approaches using published IO matrices are widely deployed in assessing potential local/regional economy impacts of a range of activities and initiatives (e.g. see Bishop et al., 2000; Crawley and Munday, 2017; Gibb and Keoghan, 1998; Jones and Munday, 2004, in this journal). Moreover, they have already been applied on an international stage in making the economic and socio-economic case for CCS in nations such as China, the Netherlands, Norway, US and the UK (e.g. see Koelbl et al., 2016; Jiang et al., 2019; SINTEF, 2018; Singh et al., 2011; Swennenhuis et al., 2020; ZEP, 2018) and in developing initial policy narratives around the potential role of CCS in decarbonising the UK’s industrial clusters (Turner et al., 2020). This is consistent with an initial UK (BEIS, 2018) focus on understanding the levels of existing cluster and supply chain activity that policymakers wish to safeguard, rather than what the wider economy impacts may be of introducing new carbon capture or T&S activity to the UK economy and/or her regions.

However, the specific statement of the ‘economic benefits’ criterion in the current UK cluster sequencing exercise (BEIS, 2021c) demands that economy-wide impact evidence involve consideration of the potential for displacement of activity and associated jobs across sectors, both locally and across the national economy. Here, works such as McGregor et al. (1996) and Gillespie et al. (2001) have highlighted the limitations of IO multiplier approaches in terms

of a lack of attention to the impacts of short-term and sustained supply constraints, where the nature of these will differ at regional and national levels, and on the dynamic adjustment processes of the economy, in determining the nature, magnitude and distribution of economy-wide outcomes. While other economy-wide approaches such as macro-econometric modelling (e.g. [Dagoumas and Barker, 2010](#)) can incorporate such considerations, this is generally through how scenarios are specified, rather than capturing supply responses within the modelling framework. On this basis, the more flexible and theoretically consistent approach is generally considered to be the application of computable general equilibrium (CGE) methods (e.g. see [Babatunde et al., 2017](#); [Robson et al., 2018](#), for reviews) to systematically capture a range of potentially unanticipated effects and interactions, particularly those driven by a range of price and income effects in a constrained economy context.

[Turner et al. \(2021\)](#) take a first step in applying CGE methods to consider the potential wider economy impacts of the carbon capture element of CCS (focussing on the productivity and competitiveness implications of additional capital requirements) in a Scottish regional context. They also provide a comprehensive review of how a range of potential impacts of CCS have been previously estimated in the literature, particularly in the context of considering alternative policy options and/or justifying public support. CGE work is sparse in this context, and [Turner et al. \(2021\)](#) focus on the contributions of authors such as [Li et al. \(2017\)](#) and [Thephkhun et al. \(2013\)](#) in modelling the wider economy implications of additional ‘end-of-pipe’ equipment requirements for industries capturing CO₂.

Here, we focus on the other element of CCS, the transport and storage of captured CO₂, considering how this requires the introduction of entirely new industry activity, an aspect not commonly addressed in economy-wide analyses. Key contributions on introducing new low carbon/environmental protection activities

to IO and/or CGE frameworks are concentrated in studies such as [Leontief \(1970\)](#), [Schäfer and Stahmer \(1989\)](#), [Nestor and Pasurka \(1995\)](#) and [Phimister and Roberts \(2017\)](#). We make a novel contribution by addressing the need to focus new industry development in CGE frameworks in the context of questions around ‘who pays’ for CCS-related costs. Crucially, we consider how any consequent contraction in demand for the output of other sectors, combined with any price effects triggered by the presence of supply constraints, could drive potential gross or net negative employment outcomes at sectoral and wider economy levels.

The UKENVI CGE model

Given the current policy focus on national economy impacts, we employ UKENVI, a multi-sector economy-wide computable general equilibrium (CGE) model of the UK, calibrated on a UK social accounting matrix (SAM) incorporating the most recently published 2016 UK analytical input-output tables. [Alabi et al. \(2020\)](#) provide a detailed model listing. Here, we focus on explaining how UKENVI is customised to accommodate energy and climate policy actions involving large scale investments and their user uptake over different periods and labour market configurations under alternative public funding mechanisms.

We identify 34 commodities and activities, including the new CO₂ T&S industry.⁷ There are four main final demands – household consumption, investment, government expenditure and exports to an exogenous region, the rest of the world (ROW) – that respond to changes in relative prices.

While some key parameter values governing model outcomes (e.g. trade responses to changing prices in UK production) are imposed and adjusted through targeted sensitivity analyses in *Results and Analysis*, others are structural in nature – such as the initial size, trade and capital intensity of individual sectors – are given by the SAM database. Here, the first crucial model development is adjustment of the SAM to

include the new T&S sector, at this stage involving disaggregation of the existing O&G sector, with the implication that the imposed T&S sector initially has an identical cost (and supply chain) structure, starting at a scale of 0.2% of the original O&G sector. In the absence of survey or other concrete information on the input–output structure of a new T&S sector, the ‘as if’ O&G assumption is a useful benchmark for initial analysis and an appropriate one if sending CO₂ to offshore reservoirs involves similar processes and input requirements to extracting oil and gas from them. The pitfalls are potentially over- or under-estimating the positive supply chain impacts within the UK economy. For example, T&S sector is more/less dependent on UK manufacturing, on-shore equipment servicing, UK-based provision of financial and insurance services etc., or if there are differences in the labour intensity of the T&S sector, then we could observe different economy-wide impacts compared to the ‘as if’ O&G case we examine here.

We assume that the UK Government is the central consumer of T&S output with additional consumption costs being offset by an appropriate increase in the indirect business tax covered by other UK industries to re-balance the SAM. Otherwise, real government spending is determined exogenously (nominal spending adjusts with CPI changes). Where government recovers direct T&S expenditure costs from households or polluters, lump sum transfers to the public purse are exogenously imposed. Otherwise, the government budget balance is endogenous, with fixed tax rates.

The process of wage bargaining is a key element of model specification. We assume a fixed national labour force, thereby setting an upper limit to total employment, with some flexibility through an initial pool of unemployed workers. Our default wage setting closure involves an econometrically parameterised relationship where the bargaining power of workers, and therefore the level of the real wage, is inversely related to the unemployment rate (Blanchflower and Oswald, 2009). Alternatively,

we assume, primarily for benchmarking purposes, a fixed real wage where nominal wage adjusts to maintain the purchasing power of wages over time. This limits wage flexibility and its impact on competitiveness.

Investment in the T&S sector is determined exogenously on a period-by-period basis to simulate the initial oversizing of the sector, scaled to service Scottish industry only, before the supply of captured CO₂ builds up. In all other sectors, investment is endogenous, driven by a dynamic process, whereby sectoral capital stocks are updated on a year-on-year basis: annual investment covers depreciation of the existing sectoral capital and a fraction of the gap between the actual and required new capital stock, thereby adjusting gradually to a new equilibrium where gross investment is simply covering depreciation.

Scenario simulation strategy

Our analyses involve the introduction of T&S infrastructure in Scotland, with the new industry scaled to service the Scottish industry cluster, and becoming operational and sequestering emissions after an initial 4-year period of investment activity.⁸ The investment profile (£500 million in total) is based on required capital expenditure data generated by Calvillo et al. (2021), associated with the development of transportation infrastructure and the cost of storage in the Scottish North Sea required to provide T&S services to the Scottish cluster. This infrastructure is introduced via an exogenous investment shock to the T&S sector so that it reaches the appropriate capital stock level to service the Scottish cluster in year 5. Thereafter, there is a fixed level of ongoing investment to maintain capital stock at a specific level and cover for capital depreciation.

Following the creation of the necessary capital, we introduce a T&S output demand shock, in the form of UK government purchases, of sufficient size to fully utilise the Scottish capacity. The demand shock follows the development of T&S infrastructure, meaning that demand is introduced in year 5 when the

Table 1. Scottish regional cluster emissions sources and interventions/impacts of linked CO₂ Transport and Storage capacity.

Key T&S industry investment and operational characteristics	
Total capital stock created (£m)	430
Pre-operation investment (£m) - Staged 10/20/30/40% over 4 years to 2024	500
Ongoing additional annual investment (£m)	65
Annual output to demand (£m)	381
Direct employment (FTE)	929
Value-added (GDP) (£m)	131
Grangemouth cluster emission sources (tonnes CO₂)	
Chemical	1373
Coke and refined petroleum products	1638
Cement, lime and glass	731
Others	83

Scottish T&S sector becomes operational. The demand shock is introduced exogenously, not affecting government spending on other sectors, and is initially reflected in the public budget balance.

If government cannot run a deficit, the direct costs are recovered from UK households (socialising costs across the national economy) or Scottish emitters (imposing ‘polluter pays’ at regional level). These transfers are introduced in a simplified way to aid analyses of the trade-offs involved in different broad types of approaches rather than attempting to model precisely as-yet-unknown potential UK policy actions around CCS. The ‘households pay’ approach involves a payment, equal to the additional T&S government purchases, introduced to all UK households, thereby reducing their disposable income in the manner of a lump sum tax.⁹ The ‘polluter pays’ approach involves government recovering the cost of T&S via increases to the indirect business tax paid by the industries present at the Scottish cluster, impacting costs, prices and competitiveness. This almost exclusively involves the ‘Chemicals’ and ‘Coke and Refined Petroleum Products’ and ‘Cement, Lime and Glass’ industries (98% of source emissions at Grangemouth – see Table 1 above, where emissions and, thus, share of costs faced, based on information from the UK Pollution Inventory¹⁰).

We test the implications of our assumptions on the results of our central case by embedding key sensitivity analyses. First, across all scenarios, we consider the alternative wage setting specification of a fixed real wage. This is a benchmark in considering the importance of the response of the labour market where the labour force is fixed. Second, for the ‘polluter pays’ scenarios only, we vary the sensitivity of export price responses, via the value of a set of sectoral ‘trade elasticities’. We vary these between low (1.1), medium (2.0) and high (3.0) settings to explore the importance of external market responsiveness to competitiveness losses associated with greater output prices.

Results and analysis

Scottish T&S industry outcomes

Our scenario involves the required £500m total investment building incrementally for 4 years (2021–2024) in annual amounts of £50 m/£100 m/£150 m/£200 m until the additional capital stock is £430 m (covering annual depreciation) (see Table 1). The direct T&S industry employment and value-added/GDP associated with the full operation of the capacity generated in this first phase is 929 full-time equivalent (FTE) workers and £131 m per annum, respectively.

Subsequent annual T&S investment simply comprises maintenance and repair.

The simulations ensure that long-run capacity in the T&S industry is reached once the exogenously determined staged investment is complete. We assume that government commits to buying the output and introduce an accompanying demand shock from 2025 involving demand for the total annual output (£381 m) on a year-by-year basis financed by a budget deficit, a lump sum transfer from UK households or increased indirect business taxes on potential capture industries in the Scottish cluster. This allows us to focus on the introduction of the T&S industry in isolation (see [Turner et al., 2021](#), for analysis of the challenges around industrial demand via carbon capture).

The T&S industry outcomes in [Table 1](#) are therefore determined exogenously. That is, they will not vary in response to any changes in model scenarios or configurations, or the endogenous wider economy responses captured therein. Rather, we are primarily concerned here with tracking the endogenous effect of this stimulus on activity in the other sectors of the UK economy. Will the adoption of T&S be a driver of ‘green growth’? How does the approach to funding the T&S activity affect key macroeconomic indicators of concern to policymakers, including employment? Further, while the analytical framework is a UK-wide one (and in the absence of appropriate data to inform a more sophisticated and granular interregional analysis for the UK), can we impute anything regarding how national effects may feedback to those industries located in the Scottish Grangemouth regional cluster that the new T&S industry services?

Economy-wide implications – unconstrained multipliers at the national level?

As discussed earlier, previous policy attention and narratives within Scotland and beyond around the potential economic impact of CCS have focussed on the value of the appropriate

input–output (IO) employment multipliers, typically adopting the benchmark of oil and gas (O&G) industry activity in considering the impacts of T&S. We similarly assume that the new T&S industry has an identical input structure to O&G. Previous works drawing on UK Office for National Statistics data (e.g. [Turner et al., 2019b](#)) have shown that each direct FTE job in the UK O&G sector supports up to 10 jobs associated with supply chain (indirect) and further spending of income from employment (induced) jobs across the wider economy. Will such a relatively high multiplier value be replicated in CGE simulation scenarios?

Two key model characteristics are central to the simulation results here: the nature of the labour market and the way in which increased government expenditure is to be funded. We adopt two alternative wage setting closures: either a fixed or bargained real wage, where the former is more consistent with a fixed price IO system (though we note that there will be nominal price changes for as long as any derived or direct shock on the supply side of the economy persists). We also employ three funding options to support UK Government in guaranteeing demand for all T&S output as set out above. The impacts on a range of aggregate UK economic variables over the long run are given in [Table 2](#). Period-by-period total employment changes are reported in [Figure 1](#) (sectoral results for selected scenarios are considered below). All results are reported in terms of changes relative to values given by the 2016 SAM database, taken to represent a 2020 baseline where there are no other changes in the real economy.

[Figure 1](#) is a useful starting point in terms of the question of whether employment multipliers similar in size to those previous IO estimates may be expected to emerge over time. First, a new long-run equilibrium is only achieved over an extended timeframe (to 2060 in [Figure 1](#)). The only rapid adjustment is in direct T&S employment. Endogenous capacity adjustment is required in all other sectors, triggering further indirect and induced ripple

Table 2. Long-run key UK macroeconomic impacts of introducing the Scottish T & S industry-alternative funding and wage assumptions.

	Base values (2016)	Fixed Real Wage			Bargained Real Wage		
		Public funding approach			Public funding approach		
		Deficit	Household Transfer	Polluter pays	Deficit	Household Transfer	Polluter pays
Government demand for T & S (£million)	21	402	402	402	402	402	402
Government budget balance (£million)	-517	-188	48	-254	-292	36	-150
GDP (£million)	1,751,690	672	165	-559	295	121	-185
GDP (% change)	1,751,690	0.038	0.009	-0.032	0.017	0.007	-0.011
Employment (FTE)	29,300,731	9483	1105	-9421	2736	319	-2724
Employment (% change)	29,300,731	0.032	0.004	-0.032	0.009	0.001	-0.009
Employment multiplier (Total/ T&S industry employment)	1	10.2	1.2	-10.1	2.9	0.3	-2.9
Unemployment (% change)	5%	-0.615	-0.072	0.255	-0.177	-0.021	0.093
Nominal wage - index to 1 (% change)	1	0.000	0.000	0.048	0.040	0.005	0.008
Real wage - index to 1 (% change)	1	0.000	0.000	0.000	0.020	0.002	-0.020
CPI - index to 1 (% change)	1	0.000	0.000	0.048	0.020	0.002	0.028
Exports (% change)	477,563	0.000	0.000	-0.129	-0.038	-0.005	-0.092
Imports (% change)	515,335	0.040	0.001	0.050	0.048	0.002	0.042
Household consumption (% change)	1,185,745	0.033	-0.021	-0.015	0.028	-0.021	-0.011
Total investment (% change)	310,036	0.044	0.012	-0.030	0.025	0.010	-0.011

effects in upstream supply chains and household spending funded by wage income, with outcomes bounded in some, or all, timeframes by price and income adjustments. Second, relatively large positive multiplier values of around 10 (i.e. comparable to what may be derived from IO data for the UK O&G industry) are only achieved in the 'deficit' and '100% export' cases under the fixed real wage (FRW) assumption. We can consider these outcomes more fully by considering the long-run results in Table 2.

Begin with the results in the second data column of Table 2. These are for deficit financing case, the key reference case where there is a domestic funding requirement for T&S: the UK Government simply runs a deficit to purchase (guarantee) the demand for T&S output.

However, by imposing a fixed real wage (FRW) case, we force a long-run outcome where UK labour market constraints do not impact, coupled with the simplest form of demand shock, here the one that effectively involves no domestic financing requirement. Crucially, there is no lasting impact on prices, meaning that the cost minimising technical production coefficients show almost no change so that the model operates much like an extended (investment endogenous) IO system.¹¹ Note that the net outcome on the budget is negative; however, while government expenditure on the T&S sector is £402 million the additional borrowing requirement is eroded by more than 50% (to £188 m) due to the expansion in activity generating additional tax revenues.

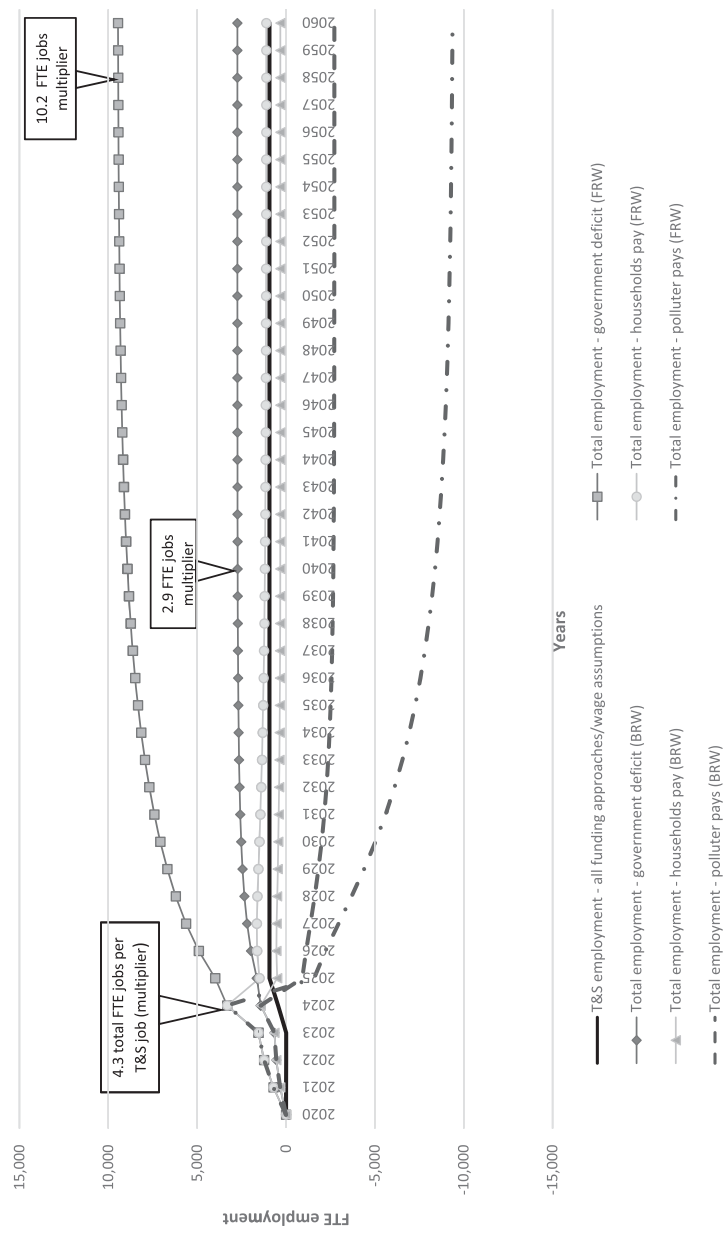


Figure 1. Direct (T&S industry) and total economy FTE employment impacts of introducing the new Scottish T&S industry-central bargained real wage (BRW) and alternative fixed real wage (FRW) assumptions.

That there is no lasting impact on the CPI reflects the fact that under the deficit funding option, there are no impacts on labour costs (the nominal wage) or competitiveness where the real wage is fixed, so that there is no crowding out of exports. However, there are relatively substantial increases in UK household consumption (0.033%), investment (0.044%) and GDP (0.038%). Total employment increases by 9,483 FTE jobs, equating to an employment multiplier of 10.2. Thus, the results in this case suggest that T&S would be a very effective source of 'green growth'. However, it involves effectively removing all supply-side and funding constraints. What happens if these do in fact persist and impact outcomes?

Adding labour market and financing constraints

The impact of simply introducing an active labour market, in the form of a wage curve, to the simulation results can be observed by comparing the 'deficit' case figures in data column 2 in [Table 2](#) with the corresponding bargained real wage (BRW) ones in column 5. Note that the wage curve is our preferred labour market closure as it reflects the impacts of the lasting UK labour supply constraint on labour costs faced by all sectors. By introducing the wage curve, even the limited 0.009% increase in employment is enough to increase the real wage 0.02% with knock implications for prices in general and a corresponding long-run impact on the CPI. The fall in competitiveness limits the increase in GDP and employment to less than half and a third respectively of their values with FRW. However, the impact may still be considered substantial given the relatively small scale of the initial shock to the UK economy, with GDP increasing by almost 0.02%, positive changes in household expenditure and investment, and the employment multiplier takes a value of 2.9. What really restricts the expansion is the 0.038% reduction in exports and the 0.0483% increase in imports. Thus, the domestic expansion concentrated in the T&S supply chain

(including net positive impacts in service sectors) now acts to crowd out activity in other UK sectors.

The more constrained outcomes are reflected in a quicker adjustment to the long-run equilibrium than is shown in the FRW case. This is apparent from [Figure 1](#). Crowding out effects are apparent from the, albeit small, negative changes in employment experienced by a limited number of sectors in [Figure 2](#). Note also from [Table 2](#) the additional tax income associated with the expansion equates to around 19% of the T&S expenditure so that the net government deficit change is still less than the direct spending requirement, increases by only £326 m, though now the increased tax take is only just over one third of that under FRW.

However, we have not yet introduced an active form of financing for the public expenditure on T&S. A straightforward way of doing this is to socialise the cost by introducing a non-distortive lump sum tax on consumption. Essentially in this case all UK households directly pay for the Scottish T&S industry with the implication that the increase in expenditure on the output of the T&S sector will be matched by an equal reduction in income available for consumption across the UK.

Introducing financing through taxing households under the BRW setting gives the results reported in the sixth data column in [Table 2](#). A net demand stimulus is observed, due to T&S expenditure being less import intensive than household consumption. However, introducing this form of financing limits the increase in GDP to 0.007%, less than a half of the value with deficit financing, but with one trade-off emerging in that the limited expansion delivers a net positive change in the public budget. Nonetheless, the IO-type employment multiplier is further eroded, falling by nearly 90% to 0.3. As would be anticipated, UK household consumption falls in this case (−0.02%). [Figure 2](#) demonstrates that most sectors of the economy do still experience net gains in employment. However, the main 'winners' are those involved in servicing the T&S supply chain and

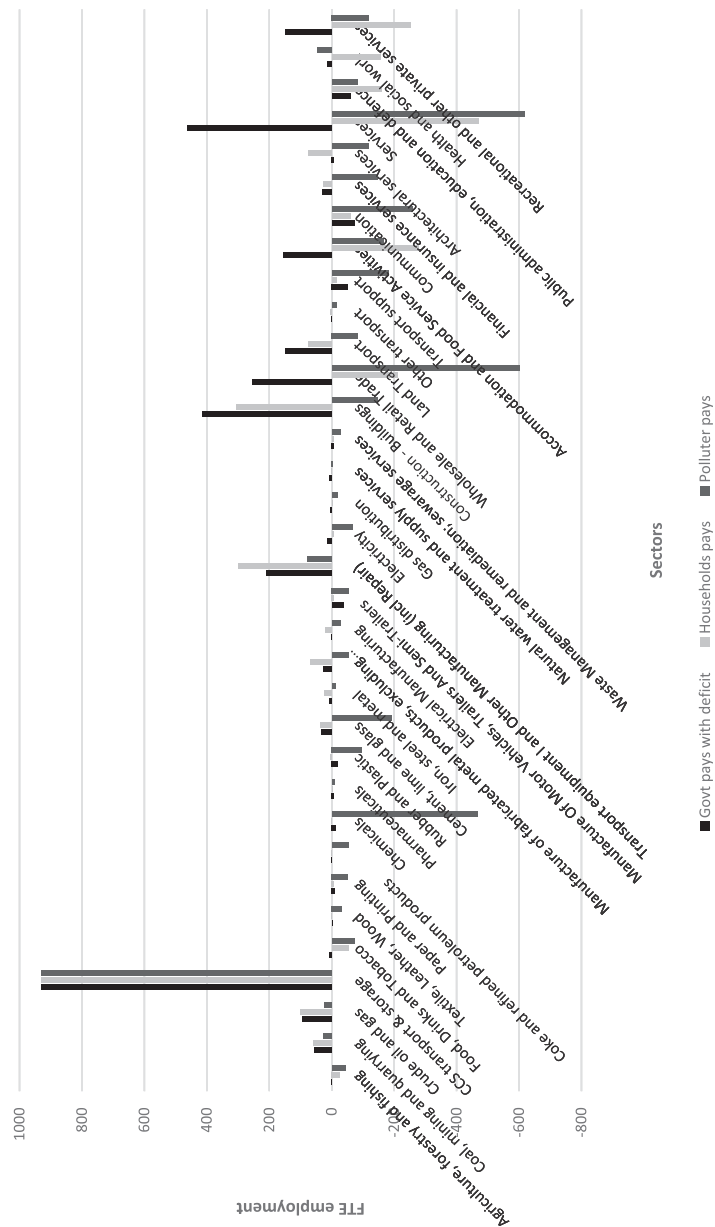


Figure 2. Long-run sectoral distribution of total economy FTE employment impacts of introducing new Scottish T&S industry under alternative funding options – central bargained real wage (BRW) wage setting assumption.

its construction needs, while the main ‘losers’ are those sectors predominately servicing export or household demand, including more labour and/or wage intensive domestic service sectors.

The same comparison can be made to consider the impact of socialising the T&S costs through household taxation where the real wage is fixed. The key point to note from the results in the third data column of [Table 2](#) is that the scale of the aggregate adjustments will be larger where wage bargaining process do not cushion any expansion or contraction.

National and regional impacts if government imposes a ‘polluter pays’ approach

However, it is unlikely that the UK Government would support T&S – or CCS more generally – in any or all regions through deficit financing or socialisation of costs over the medium term. This motivates consideration of a simple ‘polluter pays’ model, the implications of which are likely to have particular resonance at regional and local levels (where the polluters in question are located). As set out in *Methods*, in this approach we assume UK Government still guarantees demand for T&S output but passes the annual direct costs to emitters/capture firms in line with emissions sequestered. Crucially, in the current analysis this involves firms in the Scottish regional cluster. The deficit and socialisation (‘households pay’) cases register gross T&S industry (and supply chain) gains – much of which may accrue within Scotland in line with the location of current UK O&G industry supply chain activity. These have been only partly offset by crowding out and/or socialisation costs that may be expected to fall in a more dispersed geographical pattern. However, the ‘polluter pays’ outcomes in [Figure 1](#) and [Table 2](#) (fourth and seventh data columns) involve a net contraction of the UK economy and one associated with net negative public budget outcomes that erode the benefits of recovering those direct costs.

This reflects a crucial shift in the driver of outcomes triggered by the fact that the ‘polluter pays’ funding mechanism has both direct demand and supply-side implications. It directly changes the cost structure and, therefore, the price of the outputs of the Scottish capture industries, some of which are heavily internationally traded. Thus, imposing a ‘polluter pays’ approach triggers a 0.092% reduction in UK exports under our central BRW labour market closure. This is accompanied by a fall in GDP of 0.011% and employment of 0.009%, with investment and household consumption also declining. [Figure 1](#) indicates that total employment begins to fall as soon as the pollution payments are imposed, and the employment multiplier becomes increasingly negative.

Thus, with the polluter pays and default model parameter values, the notion that T&S can form the basis for ‘green growth’ is clearly difficult to maintain. Once the construction stage is completed, activity in the wider economy begins to fall. Moreover, if we adopt the FRW labour market closure, there is an even larger negative impact on all aggregate economic variables, including GDP, employment, exports, investment and household consumption. This can be seen from comparing the results data columns 4 and 7 in [Table 2](#) and the corresponding employment timelines in [Figure 1](#). Again, the real wage flexibility offered under BRW cushions the negative impact on competitiveness.

On the one hand, this represents a relatively marginal contraction in terms of the wider UK economy. On the other, the funding burden falls on firms in the Scottish cluster. While our UK model is not set up to fully consider regional impacts, some important regional implications can be imputed (and would be worthy of future research). This is reflected in the sectoral employment results reported in [Figure 2](#). The geographic spread of sectoral impacts under the ‘households pay’ case will be primarily driven by the distribution of the population across the whole of the UK. However, under ‘polluter pays’ negative impacts are likely to be concentrated in the Scottish cluster where the main

Table 3. Long-run key UK macroeconomic impacts of introducing the Scottish T & S industry under polluter pays with alternative wage setting and trade sensitivities (import/export, domestic/external).

	Base values (2016)	Fixed real wage			Bargained real wage		
		Trade 1.1	Trade 2.0	Trade 3.0	Trade 1.1	Trade 2.0	Trade 3.0
Government demand for T & S (£ million)	21	402	402	402	402	402	402
Government budget balance (£ million)	-517	-147	-254	-372	-112	-150	-179
GDP (£ million)	1,751,690	-197	-559	-963	-65	-185	-277
GDP (% change)	1,751,690	-0.01	-0.03	-0.05	-0.004	-0.011	-0.016
Employment (FTE)	29,300,731	-3,927	-9,421	-15,539	-1,430	-2,724	-3,657
Employment (% change)	29,300,731	-0.01	-0.03	-0.05	-0.005	-0.009	-0.012
Employment multiplier (Total/T & S industry employment)	1	-4.22	-10.13	-16.71	-1.538	-2.930	-3.933
Unemployment (% changes)	0	0.000	0.000	0.000	0.236	0.093	0.177
Nominal wage - index to 1 (% change)	1	0.048	0.048	0.048	0.027	0.008	-0.005
Real wage - index to 1 (% change)	1	0.000	0.000	0.000	-0.010	-0.020	-0.027
CPI - index to 1 (% change)	1	0.048	0.048	0.048	0.038	0.028	0.022
Exports (% change)	477,563	-0.071	-0.129	-0.194	-0.060	-0.092	-0.118
Imports (% change)	515,335	0.000	0.000	0.000	-0.011	0.042	0.013
Household consumptions (% change)	1,185,745	0.000	-0.015	-0.032	0.000	-0.011	-0.018
Total investment (% change)	310,036	-0.009	-0.030	-0.055	-0.003	-0.011	-0.018

capture industries identified in Table 1 are located. These are the industries bearing the cost of guaranteeing demand for T&S output, but with net outcomes depending on the structure, and destination, of output in each industry. For example, being a larger emitter ‘Coke and Refined Petroleum Products’ faces a greater percentage output loss (-0.92%) compared to ‘Chemicals’ (-0.64%) and ‘Cement, Lime and Glass’ (-0.43%). This is also reflected in the percentage losses of sectoral employment. However, ‘Chemicals’ and ‘Cement, Lime and Glass’ are more labour intensive and therefore lose more FTE jobs, 467 and 194 respectively (see Figure 2). Reduced competitiveness due to higher prices, is a key factor contributing to export-intensive ‘Chemicals’ industry output and employment losses. On the other hand,

‘Cement, Lime and Glass’ mainly services domestic users, but is adversely affected by the economy-wide disinvestment, as it is one of the key contributors to the ‘Construction’ industry’s supply chain.

Crucially, we know that it is only the Scotland-based elements of these industries that directly meet these costs, with the implication that the bulk of the 917 FTE jobs and £94.8 million value-added losses will be in terms of ‘offshoring’ of Scottish operations. Moreover, when employment is shed in Scottish cluster industries, the contraction in total UK household spending is likely to be skewed towards the Scottish economy. In turn, this means that the (more labour and household spending-intensive) service sector industry losses reported in Figure 2 are also likely to be more concentrated in within the regional

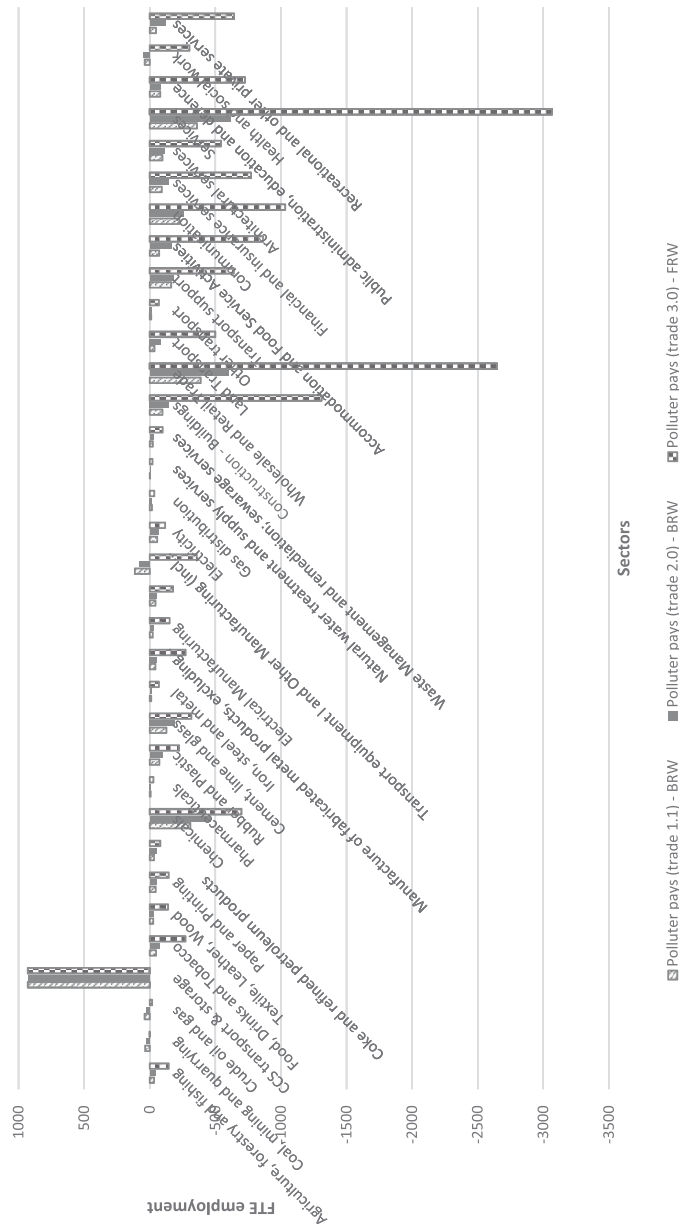


Figure 3. Long-run sectoral distribution of total economy FTE employment impacts of introducing new Scottish T&S industry polluter pays, central case compared with 'best' and 'worse' cases determined by wage setting and trade response assumptions.

economies, and local areas therein, where those suffering the most job losses reside.

Sensitivity of ‘polluter pays’ results to price sensitivity in trade

These likely more regionally skewed outcomes under the polluter pays are dependent on what we assume about the sensitivity of import and export demands to changes in UK industry prices – these are the ‘trade elasticities’, which have a default value of 2.0 in all scenarios so far. These trade response parameters are crucial in determining the impact of the fall in competitiveness that drives the economic contraction. Note that we implicitly assume that competitors in other nations are not bearing similar T&S (or other comparable decarbonisation) costs and/or that their own governments are somehow cushioning the price impact. Moreover, the outcomes within the UK will ultimately be dependent on which other regions are involved in CO₂ capture and/or T&S activity. Regionally focussed analysis should therefore ideally be conducted using a regional or interregional national CGE modelling framework (Turner et al., 2021), potentially augmented with more localised impact analyses to drill down to firm and community level impacts that cannot be captured using models dependent on national accounting input–output accounting of inter-sectoral interactions. However, it is still useful here to extend our sensitivity analysis to consider the nature of stronger or weaker international competitiveness effects on what are likely to be regionally skewed outcomes.

In Table 3 we report the long-run results of rerunning both the FRW and BRW ‘polluter pays’ scenarios with higher (3.0) and lower (1.1) values on all trade elasticities, while Figure 3 reports sectoral employment outcomes under the central (BRW – 2.0), ‘best’ (BRW – 1.1) and ‘worse’ (FRW – 3.0) cases from Table 3. Universally higher elasticity values are motivated by the likelihood that many capture firms in the Scottish industry cluster (certainly ‘Chemicals’ and ‘Rubber and Plastic’) are largely selling

intermediate or process outputs into complex global supply chains. They are thereby most at risk of investment/carbon leakage (European Commission, 2018).

The key point to note is that even where the price sensitivity of trade responses is limited, the impact of introducing the T&S sector on total UK GDP, employment, exports and investment, and employment in most other sectors, is negative, though the net impact on total UK household consumption may be relatively benign even where real wage incomes fall. However, as trade becomes more price sensitive, the net change in household consumption becomes negative and the fall in the other aggregate and sectoral activity measures increases. From the final data column in Table 3, under BRW with trade elasticities of 3.0, exports fall by 0.118%. This generates reductions of 0.018% in UK investment and household consumption, around 0.016% in GDP and 0.012% in employment.

While it is not our central assumption, we note that where there is downward rigidity in wages (FRW) the most extreme negative aggregate and sectoral outcomes are observed. Crucially, if such rigidity did indeed exist the greatest impact here would be felt in those Scottish firms that need to try to limit competitiveness loss through reductions in other costs in the face of additional T&S costs.

Conclusions

Employment ‘multiplier’ metrics have been commonly used to indicate how the deployment of the CO₂ transport and storage (T&S) element of CCS in Scotland and elsewhere may impact across the wider economy. We have considered whether and under what conditions relative high employment multiplier values and associated ‘green growth’ expansionary processes may hold if T&S is deployed to decarbonise Scotland’s main industry cluster. This involves introducing a new sector to a dynamic UK CGE model to consider the national economic impacts of concern in the planned sequenced roll

out of T&S provision to enable carbon capture in regional industry clusters. We acknowledge the early stage of our analysis, with a lack of region-specific model specification and detail on specific policy funding instruments. Nonetheless, our analysis provides valuable initial insight in demonstrating the importance of the UK's national labour supply constraint and funding challenges in considering what type of 'multiplier' impacts may in fact be anticipated.

We find that the type of employment multiplier outcomes predicted by previous IO analysis are only likely to transpire (a) over the very long term, (b) under conditions where UK labour supply constraints do not cause sustained impacts on wages and other prices, (c) where there are no domestic funding constraints that lead to demand for Scottish T&S industry services effectively having to be paid for through reduced consumption in other parts of the economy. Crucially, our results challenge the extent to which the role of CCS in delivering sustained wider economy benefits at regional and national levels will in fact be unequivocally positive. Potentially of concern to policy makers is the finding that if a Scottish T&S industry is introduced on a basic 'polluter pays' basis, costs to emitting industries in the Scottish cluster are ultimately likely to generate substantial activity loss and offshoring of production therein. Moreover, our results relate only to the T&S element of CCS and would in fact compound industry and wider economy costs of the capture element of CCS already considered in the Scottish context by [Turner et al. \(2021\)](#). CCS may well be necessary to deliver the deep decarbonisation required to meet the UK's 'net zero' and other climate change commitments. Also, it would do so in ways that help transition the oil and gas industry capacity and jobs that have historically been so important to the Scottish and wider UK economy. However, its deployment will not necessarily lead to wider 'green growth' outcomes at a national level and particularly, where an 'polluter pays' approach is imposed on industries operating in regional clusters, for the hosting local areas and regional

economies where substantial wage income and associated household expenditure may depend on activity therein. Fully quantifying the latter merits further research that may draw insight from but will require more granular focus on localised effects than can be achieved with the economy-wide scenario simulation approach employed here.

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Availability of data and materials

The CGE model used in this study is calibrated using a 2016 UK Social Accounting Matrix (SAM) developed for aforementioned Bellona Foundation project. The SAM is publically Available at: this address: <https://doi.org/10.15129/ad64a94c-152d-4ec7-a3a5-4e4a13576a3a>

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Notes

1. For example, see industry data of the main operator, INEOS, at <https://www.ineos.com/sites/grangemouth/about/>.
2. For example, see <https://www.hydrocarbons-technology.com/news/ineos-petroineos-acom-ccs-project/>.

3. For example, see an example of CGE analysis by UK Government itself in [HMRC/HMT \(2014\)](#).
 4. In 2019, the Scottish Government set up a Just Transition Commission, which made recommendations to Ministers in 2021: see <https://www.gov.scot/groups/just-transition-commission/> and [JTC \(2021\)](#).
 5. The Scottish Climate Change Plan sets out delivery of the Climate Change (Emissions Reduction Targets) (Scotland) Act 2019 – see <https://www.legislation.gov.uk/asp/2019/15/contents/enacted>
 6. See <https://theacornproject.uk/>
 7. See [Figures 2 and 3](#) in *Results and Analysis* for industry breakdown and the SAM database at <https://doi.org/10.15129/ad64a94c-152d-4ec7-a3a5-4e4a13576a3a> for sector details.
 8. Future analyses will scale the T&S sector up ultimately to service all UK regional clusters using the approach set out here. Here, we model the introduction of Scottish capacity to enable regional focus in interpreting particularly the ‘polluter pays’ results in *National and Regional Impacts if Government Imposes a ‘Polluter Pays’ Approach* and *Sensitivity of ‘Polluter Pays’ Results to Price Sensitivity in Trade*.
 9. This equates to a non-distortionary tax, though we note that the UK has no such ‘lump sum’ transfer instruments of the type specified here since the ‘poll tax’ model of local household taxation in the late 1980s/early 1990s.
 10. Available at: <https://www.gov.uk/government/statistics/uk-local-authority-and-regional-carbon-dioxide-emissions-national-statistics-2005-to-2018>
 11. In sensitivity analyses not reported here, we found that a similar demand-driven IO outcome is achieved if an exogenous export demand shock is introduced.
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