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Policy trade-offs in introducing a CO_2 transport and storage industry to service the UK's regional manufacturing clusters

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ABSTRACT

Government and industry in oil and gas producing nations are increasingly considering development of carbon capture and storage (CCS) as both a deep emissions reduction solution and route to transitioning extraction supply chains. We develop a computable general equilibrium model of the UK economy to investigate the economy-wide impacts of introducing a new carbon dioxide (CO_2) transport and storage sector supplying national capacity to support decarbonisation of four of the main mainland industrial clusters, located in the North England and Scotland. We consider key issues including the implications of the new sector's infrastructure intensity and the need for both upfront investment and action to guarantee demand for the initial capacity. We examine the challenges of funding the sector, particularly the UK Government's stated preference to move to a 'polluter pays' approach in the medium term. We find that such an additional cost burden could impact the international competitiveness of industries concentrated in the four regional clusters, with consequent offshoring of industry demand and activity. The associated job losses bring potential conflicts with the UK Government's regional 'levelling up' agenda, triggering reconsideration of what policymakers should anticipate in terms of the 'green growth' potential of CCS in an industrial decarbonisation context.

1. Introduction

A number of nations, such as the Netherlands, Norway and the UK, have the potential to repurpose skills and infrastructure developed through existing oil and gas (O&G) industries to sequester CO_2 in offshore geological storage sites, particularly in the North Sea. These countries are currently exploring the development of carbon capture and storage (CCS) to enable deep emissions reductions and transition solutions for extraction supply chains. In the UK and the Netherlands, this aligns with large-scale domestic capture demand residing within regional manufacturing clusters. Norway has a smaller industry capture base but capacity to develop an export-intensive CO_2 transport and storage (T&S) sector (SINTEF, 2018), potentially servicing the decarbonisation needs of regional industry clusters in various European nations (European Commission, 2021).

The UK currently has a more domestic focus for CCS, with Government's 'Industrial Clusters Mission' (Business Energy and Industrial Strategy (BEIS) (Department for), 2019) focussing on decarbonising six regional industry clusters across England, Scotland and Wales (Business Energy and Industrial Strategy (BEIS) (Department for), 2017, 2018, 2021a, 2021b; HM Government, 2020; HM Treasury, 2021a). Here, delivery of one net zero and four low carbon clusters between 2030 and 2040 is considered necessary to be consistent with the UK's 'net zero' (territorial emissions generation) commitments (UK Legislation, 2019).

The current UK CCS roll-out involves front-loading of public support for projects linking industrial capture of CO_2 emissions within industry cluster sites with transport (via pipelines and/or shipping) to offshore storage capacity in the North and Irish Seas via a 'cluster sequencing' process (Business Energy and Industrial Strategy (BEIS) (Department for), 2021a, 2021c). A staged deployment of operational CCS is anticipated between 2025 and 2030. This process, triggered in 2021, involves two 'Phase 1' clusters in the North of England (involving collaborations across the physical sites on North and South Humberside, Merseyside and Teeside) and one reserve/potential 'Phase 2' cluster in eastern

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Scotland (including the Grangemouth on the Firth of Forth, where deployment activity also involves the ongoing ACORN CCS project[1]).

The UK Government has dual aims with this action. First, to help deliver deep emissions reduction in line with the Industrial Decarbonisation Mission's 2030/40 targets. Second, to not only transition oil and gas supply chain employment but also to sustain jobs and GDP within the clusters and their regional and national supply chains. Here, the wider UK Industrial Strategy (Business Energy and Industrial Strategy (BEIS) (Department for), 2017), the Government's 2018 'action plan' on CCS (Business Energy and Industrial Strategy (BEIS) (Department for), 2018) sets out the need to sustain the GDP and employment contributions of currently emissions-intensive manufacturing industries operating in the regional cluster sites and supporting extensive supply chain linkages across the wider economy.

This remains the central framing for UK CCS deployment in a regional industry cluster context. Here, analysis of data provided by the UK Office for National Statistics[2] shows that around 38% of all UK manufacturing is located at the four regional industry clusters that the initial CCS deployment will service. However, crucially, two of the UK-based industries with the largest presence at these clusters – iron and steel production and chemicals manufacturing - currently generate around 50% of their total CO_2 emissions on UK soil across the northern England and Scottish sites. Producers of cement, lime and glass have a smaller presence across the four sites (only around 10% of their UK emissions) but also constitute major emitters that could link into the clustered CCS capacity.

Actual deployment of the initial CCS capacity brings two specific policy challenges. First, how can demand for new T&S industry output be guaranteed to ensure the required infrastructure investment? Second, where government acts to provide such a guarantee, how will the costs of doing so ultimately be recovered? Addressing such questions requires insights and evidence that move earlier focus on CCS research from project-specific techno- economics and costs per tonne of CO_2 capture and sequestration analyses (Budinis et al., 2018; International Energy Agency (IEA), 2016) to focussing on the wider economic and industrial policy challenges (International Energy Agency Greenhouse Gas (IEAGHG) R&D Programme, 2020). Moreover, the challenge is made even more complex in the UK context with increasing political framing for CCS and industrial decarbonisation involving narratives around a 'green growth' and a 'green industrial revolution' (Prime Minister's Office (PMO), 2021) and links to the regional 'levelling up' agenda (HM Government, 2022).

The latter focusses on addressing the longstanding problem of regional economic disparities in the UK, where some of the regions identified as having 'levelling up' needs are those northern England and Scottish ones that host both clustered industrial production and the Phase 1 and reserve/Phase 2 CCS projects. This brings an increased focus on maximising the gross and net economic benefits that may emerge for host regions as well as the wider UK economy, while maintaining and growing industrial capacity, competitiveness and jobs (avoiding offshoring). In Scotland, where much of the UK's O&G extraction and supply chain activity is located, there is also particular political focus on the potential to transition industrial capacity and employment through the roll-out of T&S industry activity.

The complexity of the policy challenge leads us to identify three fundamental research questions concerning the trade-offs involved in the development of national CCS capacity via a build-up servicing regional sequestration needs. First, what distribution of impacts on employment and other aspects of economic activity across sectors (particularly those that are regionally concentrated within the clusters involved in CCS rollout) might emerge in different timeframes from establishing and operating a new T&S industry? Second, what are the macroeconomic and distributional impacts of government guaranteeing demand for an initially over-sized sector under different funding approaches? Third, how might the outcomes impact across different economic, regional, industry, and climate policy (and political) agendas?

In responding to these research questions, we build on studies exploring the difficulties encountered in introducing new sectors providing emissions reducing services, including simple input-output general equilibrium frameworks (Leontief, 1970; Schäfer and Stahmer, 1989) and extending to computable general equilibrium (CGE) modelling frameworks (e.g., Nestor and Pasurka, 1995; Phimister and Roberts, 2017) where endogenous price, supply constraint and/or funding issues require consideration. We also draw on an extensive literature that considers the economic problems posed by CCS as a decarbonisation solution, including studies with particular focus on the challenges of enabling the carbon capture element of CCS within polluting industries (e.g., Liang et al., 2010), which are reviewed in previous work in this journal applying CGE methods to the analysis of industrial CO_2 capture (Turner et al., 2021).

There is, however, a gap in the literature around economy-wide modelling of the impacts of new sectors servicing decarbonisation agendas characterised by the need to invest in initially over-sized industry capacity. This need is only partly driven by the indivisible nature of the infrastructure involved. Policy and modelling challenges arise through the need to create new capacity in contexts where demand levels and sources, production conditions and costs/prices for new 'low carbon' industry across different geographical locations and timeframes are unknown and/or challenging, and where significant public support may be required to ensure utilisation of capacity and reduce risk for private actors. Such issues may apply in a wide range of decarbonisation contexts – including, for example, hydrogen networks – but we focus here on the challenge of CCS and introduction of new industry activity servicing the CO_2 transport and storage element thereof.

We do so by developing an existing CGE model of the UK economy (UKENVI) to specify scenarios for investment in, and the operation of, a new T&S industry where capacity is linked to emissions in several industries which dominate activity at four of the nation's regional industry clusters. We consider this new sector as sharing characteristics of the nation's existing O&G industry, but requiring investment in new, and potentially initially oversized, capacity to deliver T&S services to industrial emitters (four of the largest regional industry clusters). The illustrative investment scenarios we consider also include key clusters that are part of the Phase 1 rollout of the UK Government's current 'cluster sequencing' approach (Business Energy and Industrial Strategy (BEIS) (Department for), 2021a).

We investigate the sectoral and economy-wide impacts of delivering an initially publicly supported T&S industry. We consider how public funding involving government either running a budget deficit or socialising costs through a lump sum transfer from UK households compares with adopting a user or 'polluter pays' model, where the latter is the preferred UK Government approach, at least in the medium term. We explore how wage flexibility in labour markets limits both the possible positive and negative impacts of the introduction of the T&S industry. International trade responses to changes in the competitiveness of capture industries, largely based in the regional clusters linked to the new T&S industry, are the key drivers of the outcomes of using the 'polluter pays' option. Our findings lead us to consider how, on the one hand, this may equate to a potential source of tension between the UK Government's 'green growth' and regional 'levelling up' agendas, set against the longer term environmental and economic sustainability benefits of delivering deep emissions cuts through industrial decarbonisation enabled by early investment in CCS.

[1] See https://theacornproject.uk/.

[2] See the ONS data set on 'JOBS05: Workforce Jobs by Region and Industry' at https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/employmentandemployeetypes/datasets/workforcejobsbyregionandindustryjobs05

2. Developing our UKENVI CGE model to incorporate a new T&S industry

2.1. Basic CGE model configuration and calibration

2.1.1. The model and database

We conduct our analyses using UKENVI, a multi-sector economy wide CGE model of the UK, designed to accommodate policy actions involving large scale investments and their user uptake. Here, we give a broad account of the model set up and configuration, with fuller detail provided in Appendix A. This section focusses on the central issues of how we simulate the dynamic adjustments made by the UK economy in response to a series of investments to first enable and then maintain T&S capacity for CCS, and the alternative labour market closures and public funding mechanisms that play a key role governing outcomes.

The UK economy is modelled as small open economy that interacts with a single exogenous region, the rest of the world (ROW). We identify thirty-four production sectors (see Appendix B) including the new CO_2 T&S industry and the same number of commodities, which (apart from T&S) can be domestically produced or imported. There are four main components of final demand: household consumption, investment, government expenditure and exports to the ROW, all of which can be shocked exogenously, but also respond endogenously to changes in relative prices.

The basic dataset for the model is a UK social accounting matrix (SAM) incorporating the most recently published UK analytical input-output tables for 2016. In the absence of more recent base line data, we treat these data as reflecting the real economy in the effective policy base year of 2021 and report all results in Section 3 in terms of changes from this otherwise unchanging baseline in order to isolate the impacts of introducing the T&S sector.[3]

The SAM provides the values for key structural model parameters, such as the initial size, trade and capital intensity of individual sectors. Other parameter values, such as trade elasticities, wage bargaining function parameters and elasticities of substitution in production, are imposed exogenously, drawing from existing econometric studies (providing annual data, consistent with the SAM and interpretation of time periods as years) and informed judgement. A final set of parameter values is determined through calibration where the economy can be assumed to be in long-run equilibrium in the base-year period.

The SAM data are adjusted in creating the new T&S sector. Based on consultation with industry experts, our starting assumption is that the introduction of the T&S sector, will initially involve utilising existing the O&G industry and supply chain capacity. This is done by disaggregating the O&G extraction sector, which means that the imposed T&S sector initially has a cost structure identical to that of O&G. The starting size of T&S is set at 0.2% of the original O&G sector. A key difference is that government becomes the central consumer, with purchases offset by an appropriate increase in the indirect business tax paid by other UK industries. This balances the SAM with the base year data adjusted to include the T&S sector whilst maintaining key control totals. Crucially, through ongoing research, we aim to develop on this starting assumption as further information emerges regarding distinctions in how T&S services may be supplied, as well as how UK O&G supply chain activity itself continues to change and evolve. Here, factors, such as changes in global oil and gas prices, may have already changed the level of production in the UK, while the structure of the upstream supply chain applied to T&S will also be sensitive to shifts in absolute and relative prices within the UK and internationally. This will be a focus of future research (see Section 4).

[3] We acknowledge that the current supply chain structures by way of inputs and domestic/import content may have changed for a wide range of reasons, impacting the structure and/or size of underlying economic multipliers and may deviate from those generated by the 2016 dataset.

2.1.2. Production sectors

In each production sector, local intermediate inputs are combined with imports via an Armington link (Armington, 1969). This composite input is then combined with labour and capital (value-added) to determine each sector's gross output via a nested constant elasticity of transformation (CES) function. The shares of output going to export, or domestic demand, are determined via a constant elasticity of transformation (CET) function, which takes a central value of 2.0 but is subject to sensitivity analysis. Only in the new T&S industry, introduced here to service domestic demand only, do we limit the possible export response (via the lowest possible CET value of 0.1).

In terms of meeting changing sectoral and total labour demand, the total UK labour force is assumed fixed, with a pool of unemployed labour allowing some increase in labour supply. We consider the most likely central case, wages adjust through a bargaining process where the real wage rate is inversely related to the unemployment rate (Blanchflower and Oswald, 2009). This compares, for analytical and useful benchmarking purposes, to an alternative fixed real wage assumption. Here, the nominal wage adjusts only to sustain the purchasing power of wages but crucially limits wage flexibility and its impact on firms' costs and competitiveness.

Capital changes through investment. Here annual investment in the new T&S industry is exogenously simulated to introduce the initial oversizing of the sector before the supply of captured CO_2 builds up. In all other sectors investment is driven by a recursive dynamic procedure where the required capital stock (a function of demand for output and input prices) is updated between periods through a simple capital stock adjustment procedure. Here, investment covers depreciation of the existing sectoral capital stock and a fraction of the gap between the actual and required capital stock. Where these are equalised, capital stocks are in equilibrium and net investment is zero, with gross investment simply covering depreciation.

2.1.3. Domestic consumption

Household consumption decisions are also determined through a nested CES function, with total demand linear in real income and homogenous of degree zero in all nominal variables. Real government spending is determined exogenously, with focus here on government's spending on T&S industry output. In turn, where government recovers these direct expenditure costs from households or polluters, lump sum transfers to the public purse are also exogenously imposed. Otherwise, the government budget balance is endogenous, with fixed tax rates.

2.2. Scenario simulation strategy

The main premise of our analyses involves the introduction of the necessary infrastructure in four industrial clusters so that they become operational and sequester emissions within a 10-year period. We stage this investment on a two-by-two basis based on capital expenditure (CAPEX) data generated by Calvillo et al. (2021), associated with the development cost of transportation infrastructure and estimates on the cost of storage facilities required to provide T&S services to each cluster.[4] This infrastructure is introduced via an exogenous investment shock to the T&S sector so that it reaches the appropriate capital stock level for the first two clusters in year 5, and the second two in year 10. Thereafter, there is a fixed level of ongoing investment maintaining capital stock at specific levels and covering the depreciation of capital.

[4] Calvillo et al. (2021) provide CAPEX information for the Grangemouth cluster in Table 6, Humber cluster in Table 8, Teesside cluster in Table 9 and Merseyside cluster in Table 10. Here, to smooth the scale in sequencing investment, we divide the Humber cluster into 'North' and 'South' and link the former with Teesside. We summarise the data drawn from the study to inform our scenarios in Appendix C. However, the sequencing of investment spending does not impact the long-run outcomes.

Following the creation of the necessary capital stock, we introduce a demand shock for the output of the T&S sector of sufficient size to fully utilise the capacity. This involves the government providing demand for all T&S output. The direct costs of doing so are financed through borrowing or from UK households (socialising costs) or regional emitters (imposing 'polluter pays'). The demand shock follows the cluster sequencing example we used for investment, meaning that a certain level of demand is introduced in year 5 when the first two clusters (A and B, assumed to be those in Scotland and Teesside/North Humberside – see Table 1 below) become operational, which is then expanded when all 4 clusters become operational in year 10. The demand shock is introduced exogenously as additional purchases from the government, without affecting the government spending on other sectors. The impact of these additional government purchases is therefore reflected in the government budget balance.[5]

We explore two ways in which the government could pass the T&S cost to other parts of the economy. These 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 first is a 'households pay' approach where a payment, equal to the cost of the government's T&S purchases, is introduced to all UK households, reducing their disposable income in the way that a lump sum tax would do.[6]

The second is a 'polluter pays' approach where the government recovers the cost of T&S via increases to the indirect business tax paid by the industries present at the clusters. This impacts the output price, and therefore the competitiveness, of these industries. Here, we focus only on those manufacturing industries identified as emitters in the regional clusters that T&S would service. This excludes sectors, such as 'Food, beverages and tobacco' that may be more likely to capture CO_2 for use in production processes. The share of the cost faced by each industry is based on information from the UK Pollution Inventory,[7] linking to the summary breakdown of industry emissions sources in each regional cluster provided in Table 1.

To test the implications of our assumptions on the results of our central case, we conduct a series of sensitivity analyses. First, across all scenarios, we use the alternative wage setting specification of fixed real wage as a benchmark to subsequently explore the importance of labour market response where the labour force is fixed so that variation in employment occurs through adjustments in the unemployment rate. Second, for the 'polluter pays' scenarios only, we vary the export price elasticities between low (1.1), medium (2.0) and high (3.0) values to explore the importance of the external markets responsiveness to the competitiveness losses associated with greater output prices in the sectors using T&S services.

3. Results and analysis

3.1. T&S industry investment and capacity breakdown

As set out in Section 2.2, we smooth the introduction of T&S capacity through two phases, first to service Clusters A and B (respectively Grangemouth in Scotland and Teesside/North Humber in North East England). The investment builds incrementally for four years (2021–2024) until the combined additional capital stock is just over £1.2billion (see Table 1). Thereafter, additional annual investment just maintains this capacity intact. Then, from 2026, capacity is introduced to service Clusters C and D (South Humber and Merseyside in North East and West England respectively). By 2030, T&S capacity to service all four regional industry clusters are online, with a total additional capital stock of just over £2.3billion and enabling potential removal of the almost twenty thousand (19,827) kilotonnes of CO_2 currently generated across these four sites. Additional annual investment required to cover depreciation settles at £352million and total direct T&S employment is 5,630 FTEs.

The simulations are devised so that for the T&S industry itself, long-run capacity is reached once the exogenously determined staged investment is complete. However, the policy and CGE modelling challenge lies in ensuring that this is in operation at the planned capacity output. We introduce an accompanying demand shock whereby from 2025 the government purchases the output of the sector on a year-by-year basis. This is at an annual level of just over £2.2billion from 2030 when capacity is in place to sequester all emissions (almost twenty thousand kilotonnes) across the four clusters (where the level of sectoral emissions in each cluster in Table 1 determines the distribution of cost recovery under 'polluter pays').

3.2. Economy-wide implications with public funding

From the discussion above, we identify two key model characteristics as being central to simulated outcomes. These are the nature of the labour market and the way in which the increased government expenditure is to be funded. We adopt two alternative wage-setting closures: (A) fixed real wage; (B) bargained real wage. For each, we also employ three funding options: (1) deficit funding, (2) socialising the cost through household taxation, and (3) 'polluter pays'. The impacts (in terms of percentage and/or value changes relative to the unchanging baseline) on a range of aggregate UK economic variables for 2040 are given in Table 2 for all six cases. This is the key timeframe for outcomes of the UK Government's Industrial Clusters Mission (Business Energy and Industrial Strategy (BEIS) (Department for), 2019) and one in which our model is almost entirely adjusted to a new long-run equilibrium. Corresponding sectoral employment changes (for the central wage bargaining case) are reported in Fig. 1.

As a useful benchmark, let us begin by considering the results in the second data column of Table 2. These are for a fixed real wage (labour market case A) and deficit financing (funding option 1). These results reflect an outcome with no effective labour market constraints coupled with the simplest form of financing in which the government simply runs a deficit so as to purchase the demand for T&S output. The model is also close to long-run equilibrium with only very small changes in prices.

The small (0.029%) increase in Consumer Price Index (CPI), which has a similarly small impact on the nominal wage and competitiveness, means that there is some crowding out of exports, which fall by 0.057%. But note the more substantial increase in household consumption, investment, and GDP, all of which increase by over 0.2%. Total employment increases by almost 54,000 jobs. Although government expenditure on the T&S sector is £2,193million, the expansion in activity generates additional taxes covering over 50% of this, so that the additional borrowing is only £1,064million. However, almost all supply side and funding constraints are removed in this particular simulation.

3.3. Adding a labour market and financing constraints

The impact of simply introducing an active labour market, through the introduction of wage bargaining as labour demand increases, can be seen from comparing the figures in data column 2 in Table 2 (scenario A.1) with those in column 5 (scenario B.1), i.e., retaining the

[5] Targeted deficit financing for net zero actions has emerged in the UK with the UK Government's new Sovereign Green Bond issue (HMT/DMO, 2021b). This will support a range of investment and operational activities, where the former may focus on front-loading public investment to support creation of high return assets, thereby incentivising sustained expansion in private investment (Stern, 2021).

[6] This equates to a non-distortionary tax, though 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. The ear-marking of tax revenues for specific purposes beyond a few examples, such as the Climate Change Levy, is also resisted by HM Treasury.

[7] Available at https://www.gov.uk/government/statistics/uk-local-authority-and-regional-carbon-dioxide-emissions-national-statistics-2005-to-2018.

Table 1
Investment costs in T&S capacity to enable sequestration of existing regional cluster emissions

	T&S operational from 2025		T&S operational from 2030		
	A (Scotland - Grangemouth)	B (NE England - North Humber/ Teeside)	C (NE England - South Humber)	D (NW England - Merseyside)	TOTALS (all 4 clusters)
Investment costs					
Additional capital stock introduced (£m)	430	813	659	442	2344
Total pre-operation investment (£m)	500	940	864	540	2844
Ongoing annual investment (£m)	65	122	99	66	352
Baseline emissions sources (KT CO_2)					
Chemicals	1373	3523	54	865	5816
Coke and refined petroleum products	1638	0	3596	2053	7287
Iron, steel and metal	0	109	5032	54	5195
Cement, lime and glass	731	41	0	509	1281
Others	83	0	26	139	248
Total baseline emissions	*3826*	*3673*	*8707*	*3620*	*19,827*

Table 2
Key UK macroeconomic impacts by 2040 of introducing the T&S industry (alternative funding and wage assumptions)

		A. Fixed Real Wage			B. Bargained Real Wage		
		Public funding approach			Public funding approach		
	Base values (2016)	1. Deficit	2. House-hold Transfer	3. Polluter pays	1. Deficit	2. House-hold Transfer	3. Polluter pays
Government demand to T&S (£million)	21	2193	2193	2193	2193	2193	2193
Government budget balance (£million)	−517	−1064	432	−1165	−1586	320	−766
GDP (£million)	1,751,690	3685	1187	−2554	1739	773	−977
GDP (% change)	1,751,690	0.210	0.068	−0.146	0.099	0.044	−0.056
T&S industry employment (FTE)		5630	5630	5630	5630	5630	5630
Employment (FTE)	29,300,731	53,873	11,181	−44,621	17,037	3464	−14,912
Employment multiplier		9.6	2.0	−7.9	3.0	0.6	−2.6
Employment (% change)	29,300,731	0.184	0.038	−0.152	0.058	0.012	−0.051
Unemployment (% change)	5%	−3.493	−0.725	2.893	−1.105	−0.225	0.967
Nominal wage - index to 1 (% change)	1	0.029	0.005	0.228	0.255	0.052	0.050
Real wage - index to 1 (% change)	1	0.000	0.000	0.000	0.126	0.025	−0.109
CPI - index to 1 (% change)	1	0.029	0.005	0.228	0.129	0.026	0.159
Exports (% change)	477,563	−0.057	−0.010	−0.661	−0.248	−0.051	−0.505
Imports (% change)	515,335	0.270	0.035	0.149	0.311	0.044	0.122
Household consumption (% change)	1,185,745	0.208	−0.091	−0.055	0.185	−0.095	−0.038
Total investment (% change)	310,036	0.275	0.089	−0.181	0.153	0.064	−0.070

government deficit assumption but varying the labour market response. Note that the wage curve is what we would assume to be the more likely labour market closure for the (labour supply constrained) UK economy.

With the introduction of the wage curve, the 0.058% expansion in employment is enough to increase the real wage 0.126% with knock implications for the prices in general, with the CPI rising by 0.125%. The fall in competitiveness limits the increase in GDP and employment to less than half and a third respectively of their values with the fixed real wage. However, the impact is still substantial. The GDP increases by almost 0.1%, and there are still positive changes in household expenditure and investment, and a substantially limited (relative to scenario A.1) but still positive employment impact of just over 17,000 additional FTE jobs. What is really restricting the expansion is the 0.248% reduction in exports, and the 0.311% increase in imports.

The more constrained outcomes are reflected in a quicker adjustment to the long-run equilibrium than is shown in the fixed real wage case (A.1). Also, increased amounts of crowding out are apparent from the negative change in employment experienced by a limited number of sectors, as indicated in Fig. 1 (where we report employment impacts in those sectors that experience changes of more than 500 FTE jobs by 2040 in at least one of the scenarios reported). Note also from Table 2 that the additional tax income equals just over 27% of the T&S expenditure so that the government deficit only increases by £1,586million (but with this increased tax take only around one half that with the fixed real wage (A.1)).

Recall that we have not yet introduced an active form of financing for the public expenditure on T&S. A very straightforward way of doing this is to socialise the cost by introducing a non-distortive lump sum tax on consumption. Essentially, in this case households directly pay for the T&S industry. The increase in expenditure on the output of the T&S sector is now matched by an equal reduction in income available for consumption. However, there is still a net demand stimulus because T&S expenditure is less import intensive than household consumption.

Introducing financing through taxing households in a model where the wage is set by wage bargaining gives the results reported in the sixth data column in Table 2 (scenario B.2). Note that adding this form of financing limits the increase in GDP to 0.044%, less than a half of the value with deficit financing, but now with the limited expansion delivering a net positive change in the public budget. The net employment gain is further reduced to 3,464 FTE jobs. As expected, household consumption in this case falls, by 0.095%. Fig. 1 demonstrates that most sectors of the economy still experience net gains in employment, with the main ‘winners’ being those involved in servicing the T&S supply chain and its construction needs. Most sectors do not experience much

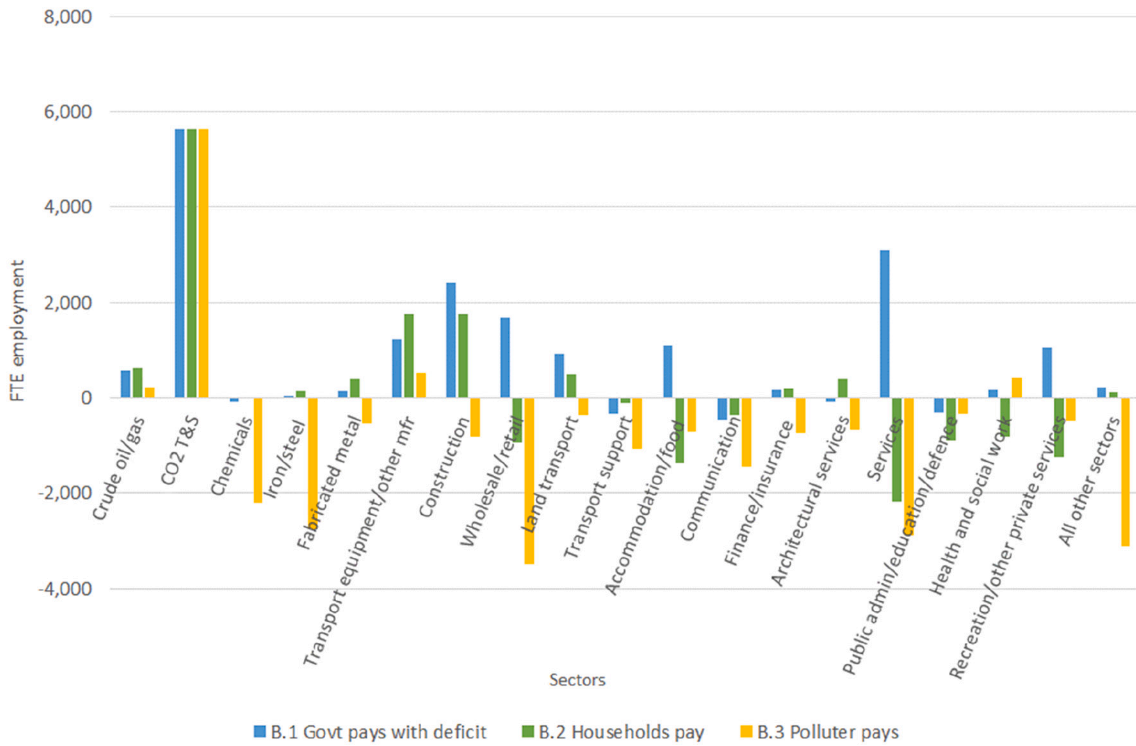

Fig. 1. Sectoral distribution of total economy FTE employment impacts by 2040 of introducing the new T&S industry under alternative funding options 1–3 with wage bargaining (B scenarios – reporting for sectors with changes of 500 FTE or more).

impact. However, 12 of 34 sectors modelled do now register employment reductions, with the main 'losers" being sectors predominately servicing export or household demand, including more labour/wage intensive domestic service sectors. Across the sectors in which employment falls, there is a gross loss of 1,802 jobs.

A similar comparison can be made to identify the impact of socialising the T&S costs through household taxation where the real wage is fixed. This involves comparing the results for scenarios A.1 and A.2. The scale of the aggregate adjustments with the fixed real wage are larger because the wage bargaining process cushions any expansion *or* contraction in output that is accompanied by corresponding changes in employment.

3.4. Impacts under a 'polluter pays' approach

Beyond 2040, it is unlikely that the UK Government would support T&S – or CCS more generally - through deficit financing or socialisation of costs. This motivates consideration of a simple 'polluter pays' model. Under this approach, we assume the government still guarantees demand for T&S output but passes the direct costs to emitters/capture firms in the regional clusters in each time period, in line with emissions sequestered. However, while the intention may be to transfer costs to the consumption of the goods produced by the industries that need to reduce emissions, the results for scenario B.3 in the final column of Table 2 show that the costs are more widely spread through a contraction of the UK economy. Moreover, in all cases, despite recovering direct T&S expenditure costs, the contraction delivers net negative public budget outcomes that substantially erode the benefits of recovering those direct costs.

These results reflect a crucial shift in the driver of outcomes because this funding mechanism has both direct demand and supply side implications. It directly changes the cost structure, and therefore the price of the heavily internationally traded outputs of capture industries. With the wage curve labour market closure, imposing a 'polluter pays' approach triggers a 0.505% reduction in exports. This is accompanied by a fall in GDP and employment of just over 0.05%, with investment and household consumption also declining. The results in Fig. 2 (in Section 3.5 below) indicate that total employment begins to fall as soon as the pollution payments are imposed and there is a consistent net loss in total UK employment under this funding option (under all the sensitivity analyses considered below). Fig. 1 shows that only the new T&S industry and linked extraction sector activity enjoy gross employment gains.

With the 'polluter pays' and the default model (labour market B) parameter values it is clearly difficult to maintain the notion that T&S can form the basis for 'green growth' in the form that delivers net GDP and employment gains alongside deep decarbonisation to support sustainable industry activity going forward. Once the construction stage is completed, activity in the wider economy begins to fall. Moreover, if we adopt the fixed real wage (labour market A) closure, there is an even larger negative impact on all aggregate economic variables (GDP, employment, exports, investment, and household consumption). This can be seen from comparing the results data columns 4 and 7 (scenarios A.3 and B.3) in Table 2. Again, the real wage flexibility offered by the wage curve cushions the negative impact on competitiveness in scenario B.3, where employment falls by just under 15,000 FTE jobs, around one-third of the almost 45,000 in A.3.

In the UK, the role of T&S (and CCS in general) has been explicitly linked to the 'levelling up' agenda seen as central to the national Government's economic strategy. An element of this strategy is the stimulation of the so-called 'left behind' parts of the country. In this narrative, it might be thought that even if the UK economy as a whole were negatively affected, those areas in which T&S development took place would benefit, so that a degree of 'levelling up' would occur.

While our UK model is not set up to fully consider regional impacts, some important regional implications can be imputed and identified (and would be worthy of future research). This is reflected most in the sectoral employment results reported in Fig. 1. The geographic spread of sectoral impacts under the 'households pay' case will be primarily driven by the distribution of the population across the whole country. However, under 'polluter pays' negative impacts are likely to be

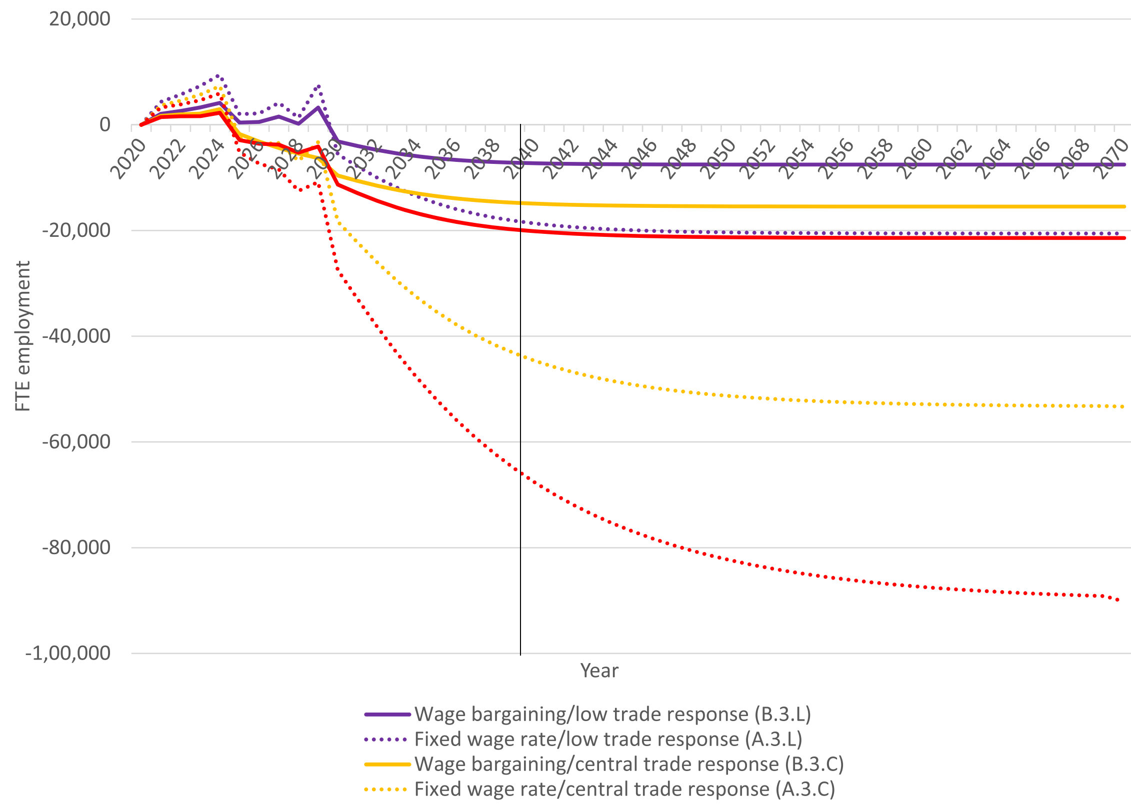

Fig. 2. Employment impacts of introducing the new T&S industry - polluter pays case under alternative wage setting and trade response assumptions.

concentrated in those cluster regions where the main capture industries identified in Table 1 are located. These are the industries bearing the cost of guaranteeing demand for T&S output.

Fig. 1 shows that some of the main sectoral losers under 'polluter pays' are those emitting/capture industries (particularly 'Chemicals' and 'Iron, Steel and Metal') largely located in the regional clusters now directly meeting the costs of guaranteeing demand for T&S industry output. That is, the wider economy contraction observed involves 'off-shoring' of these industries, where the loss in international competitiveness means that demand within the UK for those industry outputs might still be met, but now by overseas producers.

Moreover, when employment is shed in cluster industries, the contraction in total UK household spending is likely to be skewed towards the host regions. In turn, this means that the (more labour- and household spending-intensive) service sector industry losses reported in Fig. 1 are also likely to be more concentrated in the localities where those suffering the most job losses reside. Essentially, T&S combined with 'polluter pays' is not a positive contributor to the Government's industrial strategy, either on a 'green growth' or 'levelling up' basis.

3.5. Sensitivity of 'polluter pays' results to varying export elasticities

The above 'polluter pays' outcomes are dependent on the imposed value of the export elasticities, which have been given a default value of 2.0 in all scenarios so far. These elasticities determine the impact of the competitiveness reduction that drives the economic contraction. Note that we implicitly assume that competitors in other nations are not similarly bearing T&S (or other comparable decarbonisation) costs, and/or that their own governments are somehow cushioning the price impact. That is, we focus on the export elasticities to consider the impact of stronger or weaker competitiveness effects.

We rerun both the 'polluter pays' scenarios with higher (3.0) and lower (1.1) values on export price elasticities, indicated by 'H' and 'L' respectively in the labelling of scenarios to indicate high and low values compared to the central cases for A3 and B3, now distinguished as central by 'C' (i.e., the central case already reported in Table 2 is now shaded in Table 3).

Universally higher elasticity values are motivated by the likelihood that the capture firms in the regional industry clusters 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). In Table 3 we report sensitivity analyses for the 2040 results for the fixed real wage (A) and wage bargaining (B) closures under the 'polluter pays' funding option (3). For each labour market option, we report figures for the low (L), central (C) and high (H) export elasticity simulations. The corresponding employment time paths are given in Fig. 2, with sectoral outcomes presented in Fig. 3 The latter highlights results from the extreme 'worst' (fixed real wage with greatest export response, scenario A.3.H) and 'best' (bargained real wage with most limited export response, scenario B.3.L) cases from Table 3.

The first point to note from Table 3 is that even where export elasticities are low (1.1), the impact of introducing the T&S sector on the aggregate variables GDP, employment, exports, and investment, is negative. There is a small increase in household consumption but because wage income falls, this is likely to be accompanied by negative distributional effects (not addressed here) across households. As the export elasticities are raised, the change in household consumption becomes negative and the fall in the other aggregate activity measures is increased. From the data column seven (scenario B.3.H) in Table 3, with the bargained real wage and export elasticities equal to 3.0, exports now fall by 0.65%. This generates reductions of 0.12% in investment, around 0.085% in GDP and household consumption and nearly 0.069% in employment.

With the fixed real wage labour market closure, much more extreme results are observed. This is clearly reflected in the time path of employment outcomes shown in Fig. 2 (again reporting for individual sectors that experience changes of more than 500 FTE jobs by 2040 in at least one of the scenarios reported). Here, where the export elasticity is

Table 3
Sensitivity of key UK macroeconomic impacts in 2040 of introducing the T&S industry under polluter pays (alternative wage setting and export price elasticities)

	Base values (2016)	A. Fixed Real Wage			B. Bargained Real Wage		
		3 L	3C	3H	3 L	3C	3H
Government demand to T&S (£million)	21	2193	2193	2193	2193	2193	2193
Government budget balance (£million)	−517	−687	−1165	−1582	−543	−766	−920
GDP (£million)	1,751,690	−902	−2554	−4004	−343	−977	−1527
GDP (% change)	1,751,690	−0.052	−0.146	−0.229	−0.020	−0.056	−0.087
Employment (FTE)	29,300,731	−18,659	−44,621	−67,616	−7275	−14,912	−20,142
Employment (% change)	29,300,731	−0.064	−0.152	−0.231	−0.025	−0.051	−0.069
Unemployment (% change)	5%	1.210	2.893	4.385	0.472	0.967	1.306
Nominal wage - index to 1 (% change)	1	0.249	0.228	0.202	0.152	0.050	−0.038
Real wage - index to 1 (% change)	1	0.000	0.000	0.000	−0.053	−0.109	−0.147
CPI - index to 1 (% change)	1	0.249	0.228	0.202	0.206	0.159	0.109
Exports (% change)	477,563	−0.387	−0.661	−0.914	−0.342	−0.505	−0.650
Imports (% change)	515,334.82	0.312	0.149	−0.014	0.279	0.122	−0.013
Household consumption (% change)	1,185,745	0.023	−0.055	−0.127	0.021	−0.038	−0.083
Total investment (% change)	310,036	−0.054	−0.181	−0.302	−0.019	−0.070	−0.120

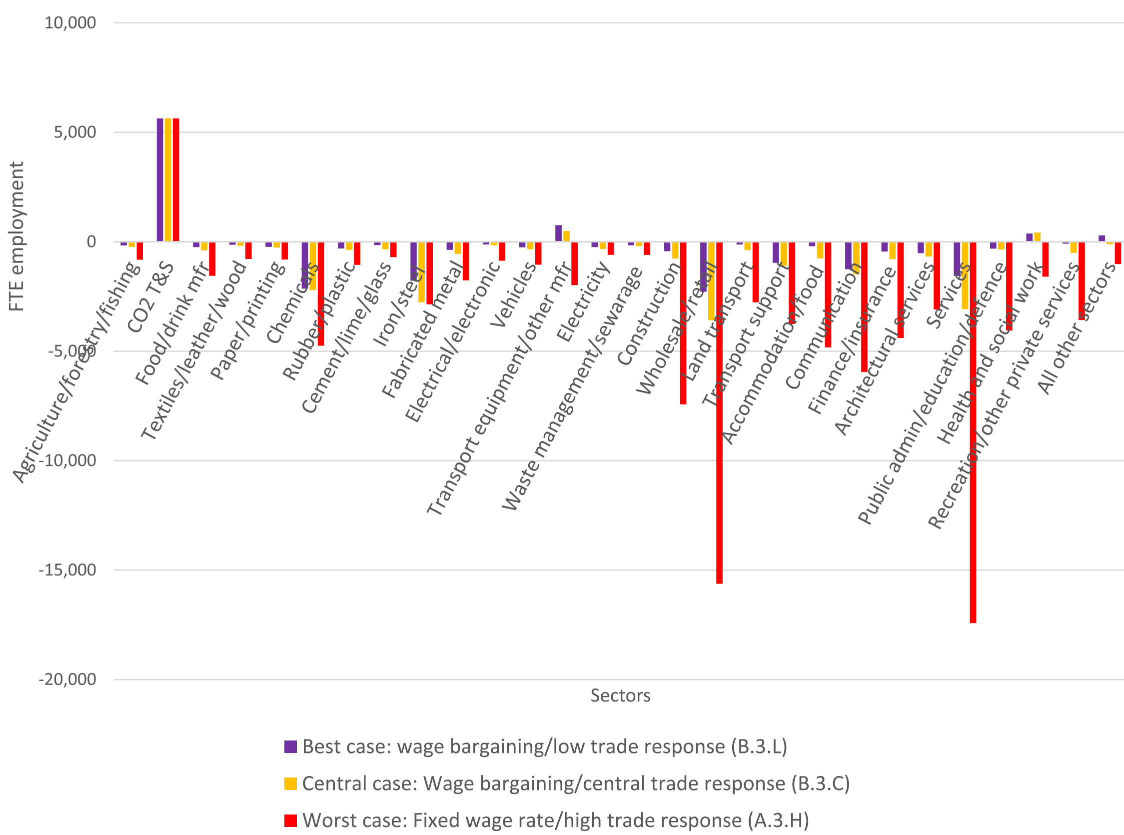

Fig. 3. Long run sectoral distribution of total economy FTE employment impacts of introducing the new T&S industry - 'best' and 'worst' cases under polluter pays (reporting for sectors with changes of 500 FTE or more).

3.0, not only is the total employment decline large, but by 2040 it is only around 75% of its full long-run negative change.

Crucially, Fig. 3 highlights the outcome that negative impacts across both capture industries and local service sectors increase both with international trade response to losses in UK competitiveness, which would be expected, and with downward wage rigidity (i.e., comparing the 'worst case' scenario A.3.H with the central and 'best' case with wage bargaining and more limited export price responsiveness). This latter point is important, given that policymakers might consider falling wage rates as much of a problem as falling employment in regions of concern under the stated 'levelling up' agenda (HM Government, 2022). But this downward flexibility in the real wage stems activity loss in our scenarios, particularly in cluster regions.

This suggests that policymakers need to reconsider the view and perspective that CCS can automatically deliver 'levelling up' outcomes: the role of this decarbonisation solution is to deliver and secure deep decarbonisation solutions and support the sustainability of cluster industries over the long-term. Focussed and timely policy intervention in deploying CCS is likely to be required to ensure that regional industries do not move production out of the UK where decarbonisation costs rise potentially ahead of those of competitors in other nations. However, where real wage rates are a 'levelling up' concern, this will require focussed (albeit potentially coordinated) intervention in that policy context.

4. Conclusions

Our analysis of the potential impacts of introducing a new national CO_2 T&S industry to service CCS in a regional industry context for a nation like the UK is intended as an initial contribution to stimulate further research on what is likely to be an important issue in other countries considering how fossil fuel extraction industries can be repurposed to service 'net zero' transition requirements. We focus on identifying the nature of trade-offs involved in different broad funding approaches for T&S, which is crucial to informing and supporting policy on identifying ways to managing the costs vs benefits if the real returns and overriding deep emissions reduction benefits are to materialise. Moving forward, among other things, fuller (and updated) information is required on the extent to which T&S supply chains are similar to O&G industry ones (and how these have adjusted and evolved over time). Crucially, however, our initial analysis does demonstrate that the presence of a national labour supply constraint (which is a real current policy concern) coupled with the UK Government's preferred 'polluter pays' funding option, has important macroeconomic and distributional implications, particularly in the context of the prevailing wider public policy context.

In particular, the UK Government has cited CCS as an integral part of not only climate and industry policy strategies but also its wider 'green growth' and regional 'levelling up' agendas. Our results challenge such a view and perspective. We find that if a T&S industry is introduced under a 'polluter pays' scenario, positive impacts are only assured in the initial periods of infrastructure construction. Subsequently, costs to emitting industries are likely to generate substantial activity loss and 'offshoring' of production and the resulting wider economy losses are likely to be largely concentrated in host regions. This constitutes a key policy challenge. Our analysis suggests that ultimately adopting a 'polluter pays' approach to guaranteeing demand for T&S industry output is likely to generate negative outcomes in the very regional cluster activity that Government aims to safeguard. Moreover, Turner et al. (2021) suggests such outcomes will be exacerbated by capture costs.

Thus, perhaps the key message emerging for policymakers is to focus on CCS as a deep decarbonisation solution that could remove otherwise quite intractable industrial emissions, which (as set out in the UK Government's earlier CCUS Action Plan (Business Energy and Industrial Strategy (BEIS) (Department for), 2018) is a key first step in sustaining regionally clustered industries. Moreover, with domestic delivery of CO_2 T&S services, this could help transition (non-regionally clustered) O&G industry capacity and jobs. This is quite different to the argument that CCS could somehow constitute a broader 'green growth' solution capable of delivering regional 'levelling up' outcomes without further focussed and timely policy intervention to that end, where decarbonisation can be expected to increase production costs and a need to prevent offshoring of current industry activity.

Data statement

The CGE model used in this study is calibrated using a 2016 UK Social Accounting Matrix (SAM) developed for this project, publicly available at: https://doi.org/10.15129/ad64a94c-152d-4ec7-a3a5-4e4a13576a3a.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

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Appendix A. The UKENVI CGE model

For this paper, we use a recursive dynamic specification of our economy-wide multi-sector CGE model of the UK, UKENVI. The sectors of the UK economy are aggregated to 34 groups (see Appendix B) and captures the links between the sectors and the effects that relative price changes may have across the entire economy. The model we use here is based on the model used previously by Turner (2009) and Alabi et al. (2020), with the latter detailing the model. This Appendix details the key elements of the specification required to run the scenarios reported in Section 4 of the paper.

Production

We model $i = 1, \ldots, N = 34$ industries, including the newly introduced CCS Transport and Storage (T&S) sector. Production in each industry is determined through a nested constant elasticity of substitution (CES) production function. The key nest for the present scenarios is where labour, L, and capital, K, combine to produce value added, Y:

$$Y_{i,t} = A\left(\xi_{i,t}\right) \bullet \left[\delta_i^k \bullet K_{i,t}^{\rho_i} + \delta_i^l \bullet L_{i,t}^{\rho_i}\right]^{\frac{1}{\rho_i}} \quad [A.1]$$

In eq. [A.1] A, δ^k, δ^l, ζ and ρ are parameters. As in this paper we do not consider the effects of carbon capture, the efficiency parameters $\delta_i^k$and δ_i^l, for capital and labour respectively, remain unchanged. Furthermore, we assume no other factor productivity changes in the scenarios we simulate. The default value of the elasticity of substitution between capital and labour in all sectors is set at 0.3.

Investment

The level of investment is endogenous for most sectors, with the capital stock adjusting between periods via a simple adjustment process. We assume a fixed depreciation of physical capital throughout the periods at 15% and the level of investment is determined to be such that it covers the depreciation of capital and a fraction of the difference between the actual and the desired capital stock. This fraction is also fixed and set for all sectors, where investment is endogenous, at 0.5. The desired capital is a function of the output of each sector and the input prices, while we assume that the economy has reached its long-run equilibrium when the actual and the desired capital stock are equal and by which point the annual investment only covers the depreciation of capital.

A notable exception to the aforementioned treatment of investment is the T&S sector. Here, due to the need to oversize the sector before the demand for its services are in place, we introduce an exogenous investment approach. We implement a series of investment shocks in periods 1 to 9 so that the capital stock, that does not adjust instantaneously to additional investment, reaches the desired levels discussed in Section 3.2, and also summarised in Appendix C, by period 10. Thereafter, we exogenously introduce an additional investment, above the base year level, so that the capital stock remains at the desired levels for the remainder of the simulations. The key implication of this treatment is that the T&S capital stock does not adjust to changes in demand in the same way that it does for the other UK sectors where investment is endogenous.

Labour market

Across all our simulations we assume a fixed labour supply, a common assumption across national CGE models. This implies no migration and no natural population changes. For our central case, wages are determined by a regional wage bargaining (wage curve) approach (Blanchflower and Oswald, 2009) in which:

$$ln\left[\frac{w_t}{cpi_t}\right] = \omega - \varepsilon ln(u_t) \quad \text{[A.2]}$$

where w_t is the nominal wage, cpi_t is the consumer price index, ω is a parameter calibrated to the steady state and u_t is the regional unemployment rate, which is assumed to start from a base value of 5%. ε is the elasticity of wages related to the level of unemployment rate and in our model takes the value of 0.113 (Layard et al., 1991).

As an alternative labour market specification, we assume a fixed real wage meaning that nominal wage is adjusting to maintain the purchasing power of wages constant over time. This limit, but does not eliminate, the wage flexibility in the economy and therefore its impact on the price of output of UK sectors and their competitiveness in global markets.

Trade

In our model, all producers and consumers can choose between domestically and imported goods and services, where imports are combined with domestic goods under the Armington assumption of imperfect substitution (Armington, 1969). The UK trades with the rest of the world (ROW), with the nominal price of ROW goods and services remaining fixed across all periods. Thus, the demand for UK exports and imports responds to changes in relative prices between (endogenous) UK and (exogenous) ROW prices (Armington, 1969). The set the default value of trade substitution elasticities at 2.0 in line with Turner (2009). As discussed in Section 3.2 though, for the ‘polluter pays’ scenarios we conduct sensitivity analyses where we explore the impact of low (1.1) and high (3.0) export price elasticities, with the default value (2.0) constituting the medium option.

Household consumption

Households in our model make their consumption decisions based on their current income rather than future discounted utility. We model a single representative household, which in each time period makes consumption decisions based on the following general form:

$$C_t = Y_t - S_t - HTAX_t - CTAX_t - SUBSIDY_t \quad \text{[A.3]}$$

where *C* represents the total consumption, *Y* is the income, *S* are the savings, *CTAX* is the direct tax on consumption, and *HTAX* is the income tax, all for period t. *SUBSIDY* is relevant for our ‘households pay’ scenarios, where it is set at a value equal to the cost of the additional government purchases from the T&S sector. This effectively limits the disposable income of households and by extension household consumption. In all other scenarios the value of *SUBSIDY* is set at zero.

Government

In our model, we adopt a generic setting where the government budget (*GB*) is derived by the government revenue (*GY*) minus the government expenditure (*GEXP*):

$$GB_t = GY_t - GEXP_t \quad \text{[A.4]}$$

$$GY_t = d^g \sum_i rk_{i,t} \bullet K_{i,t} + \sum_i IBT_{i,t} + \overline{\tau}_t \sum_i L_{i,t} \bullet w_t + \overline{FE} \bullet \varepsilon_t + SUBSIDY_t \quad \text{[A.5]}$$

$$GEXP_t = \sum_i \overline{G}_{i,t} \bullet Pg_t + \sum_{dngins} \overline{TRG}_{dngins,t} \bullet Pc_t \quad \text{[A.6]}$$

In [A.5], *GY* is the sum of share d^g of capital revenue transferred to the government, *IBT* is indirect business tax (part of which includes the *CTAX* above), *L* is revenue from taxing labour income (i.e. the income tax, *HTAX*, above) at fixed rate τ, *FE* are the payments/transfers from abroad converted using fixed exchange rate ε and *SUBSIDY* corresponds to the payments made by households to cover the cost of T&S purchases (when applicable). Note that the tax rate used in our model does not capture the different tax scales in the UK tax system, meaning that it is best to be considered as a representation of the average income tax paid by UK households. For the ‘polluter pays’ scenario an additional component is introduced to the indirect business tax of the industries liable to cover the cost of T&S, in line with the emissions breakdown presented in Table 1. The additional tax payments of these industries are reflected in the IBT component of [A.5], increasing the government revenue.

GEXP includes spending on goods and services *G* and transfers *TRG* to non-governmental domestic institutions *dngins*, with the latter assumed fixed. Here we assume that government expenditure on goods and services *G* is also fixed, while we exogenously introduce additional demand for the output of the T&S sector. As we do not require a balanced budget in any of our simulations, the additional revenue or expenditure of the UK government are reflected in the overall government budget as calculated in [A.4].

Data

The model in our study is calibrated using a 2016 Social Accounting Matrix for the UK, which uses as its core element the 2016 UK Input Output (IO) tables published by the UK Office for National Statistics (ONS). These are the latest UK IO tables currently available. To facilitate our analyses, the 64 industrial sectors reported in the UK IO have been re-organised into 34 sectors. Table B.1 in Appendix B details the sectors in our model and what are the matching SIC2007 codes. The process of re-organising the UK IO tables, apart from the aggregation of certain sectors, involves the disaggregation of certain sectors that are key for this work and the model more broadly. This includes disaggregating the 'Mining and quarrying' sector of the IO tables into 'Coal, Mining and Quarrying' and 'Crude Oil and Gas'. The latter is especially important because this is the sector we further disaggregate to introduce the 'CCS transport & storage' sector. Furthermore, we disaggregate the 'Electricity, gas, steam and air conditioning supply' sector into 'Electricity' and 'Gas Distribution' sectors, with the latter also including the steam and air conditioning supply activities.

The disaggregation of sectors in the UK IO tables have been done using the UK Supply-Use tables, also published by the ONS, which contain information on the volume of output of the new disaggregated sectors, as well as information on their labour and capital requirements. Overall, we use this aggregation level so that we can study the impact at economic sectors that we have identified as important for this specific work. At the same time, a smaller number of sectors, 34 rather than 64, allows a more comprehensive sense-checking of the results to avoid any potential black-box effects. Our objective is to ensure that the results we report are accurate and that we can trace the drivers behind the impacts we observe.

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Appendix B. The sectors in our CGE model

Table B.1
Sector aggregation in CGE model and link to SIC2007 codes.

Sector Number	Sector Name	SIC code
S1	Agriculture/Forestry/Fishing	01–03
S2	Coal/mining/quarrying	05 & 08–09
S3	Crude oil/gas	06–07
S4	CCS transport & storage	new sector
S5	Food/drinks mfr	10–12
S6	Textile/leather/wood	13–16
S7	Paper/printing	17–18
S8	Refined petroleum products	19
S9	Chemicals	20
S10	Pharmaceuticals	21
S11	Rubber/plastic	22
S12	Cement/lime/glass	23
S13	Iron/Steel/Metal	24 & 25.4
S14	Fabricated metal	25.1–3 & 25.5–9
S15	Electrical/electronic	26–28
S16	Vehicles	29
S17	Transport Equipment and other mfr	30–33
S18	Electricity	35.1
S19	Gas distribution	35.2–3
S20	Water treatment/supply	36
S21	Waste management/sewerage	37–39
S22	Construction	41–43
S23	Wholesale/retail trade	45–47
S24	Land transport	49
S25	Other transport	50–51
S26	Transport support	52–53
S27	Accommodation/food service	55–56
S28	Communication	58–63
S29	Financial/insurance services	64–66
S30	Architectural services	71
S31	Services	68–70 & 72–82
S32	Public admin/education/defence	84–85
S33	Health and Social Work	86–88
S34	Recreational/other private services	90–98

Appendix C. Summary of CAPEX of different industrial clusters

Table C.1
Summary of CAPEX per industrial Cluster (in £million)

Cluster name	Onshore pipeline CAPEX	Offshore pipeline and storage CAPEX	Total
Cluster A: Grangemouth	115.61	314.12	**429.73**
Teesside	42.11	111.33	**153.44**
Humber	437.22	881.12	**1318.34**
North Humber	218.61	440.56	**659.17**
Cluster B: North Humber and Teesside	260.72	551.89	**812.61**
Cluster C: South Humber	218.61	440.56	**659.17**
Cluster D: Merseyside	150.78	291.44	**442.22**
Note:	Values taken from Calvillo et al. (2021)		

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