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Macroeconomic and distributional consequences of net zero policies in the United Kingdom

Jon Pareliussen,
Aurelien Saussay,
Josh Burke

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MACROECONOMIC AND DISTRIBUTIONAL CONSEQUENCES OF NET ZERO POLICIES IN THE UNITED KINGDOM

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By Jon Pareliussen, Aurelien Saussay and Josh Burke

Authorised for publication by Isabell Koske, Acting Director, Country Studies Branch, Economics Department.

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ABSTRACT/RÉSUMÉ

Macroeconomic and distributional consequences of net zero policies in the United Kingdom

This paper presents new simulation results for the UK combining macroeconomic simulations in ThreeME, a computable general equilibrium model, with household-level micro-simulations with the aim to provide consistent estimates of macroeconomic and distributional consequences of policy action to curb greenhouse gas emissions. One main and overarching result is that if an economy-wide and significant carbon price is introduced it leads to large emission reductions. Macroeconomic and distributional consequences are very limited in comparison. Redistributing 30% of total tax revenue as a lump-sum transfer to households would ensure that a majority of income deciles in most regions increase their disposable income, with gains notably in the lower part of the income distribution.

This Working Paper relates to the 2022 Economic Survey of the United Kingdom
https://www.oecd.org/economy/united-kingdom-economic-snapshot/
Key words: Climate policy, general equilibrium, microsimulation, redistribution
JEL codes: H23, H31, H32, Q52, Q58

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Conséquences macroéconomiques et distributives des politiques de zéro émissions nettes au Royaume-Uni

Cet article présente de nouveaux résultats de simulation pour le Royaume-Uni combinant des simulations macroéconomiques dans ThreeME, un modèle d'équilibre général calculable, avec des micro-simulations au niveau des ménages dans le but de fournir des estimations cohérentes des conséquences macroéconomiques et distributives des politiques visant à réduire les émissions de gaz à effet de serre. L'un des principaux résultats est que si un prix du carbone significatif à l'échelle de l'économie est introduit, il conduit à d'importantes réductions d'émissions. Les conséquences macroéconomiques et distributives sont très limitées en comparaison. Redistribuer 30 % des recettes fiscales totales sous forme de transferts forfaitaires aux ménages garantirait que le revenu disponible augmente dans une majorité de déciles de la distribution des revenus dans la plupart des régions, avec des gains notamment dans la partie inférieure de la distribution.

Ce document de travail concerne l'Étude économique du Royaume-Uni de 2022
https://www.oecd.org/fr/economie/royaume-uni-en-un-coup-d-oeil/
Mots clés : Politique climatique, équilibre général, microsimulation, redistribution
Codes JEL : H23, H31, H32, Q52, Q58

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This paper presents new simulation results for the UK combining macroeconomic simulations in ThreeME, a computable general equilibrium model, with household-level micro-simulations with the aim to provide consistent estimates of macroeconomic and distributional consequences of policy action to curb greenhouse gas emissions. One main and overarching result is that if an economy-wide and significant carbon price is introduced it leads to large emission reductions. Macroeconomic and distributional consequences are very limited in comparison. Redistributing 30% of total tax revenue as a lump-sum transfer to households would ensure that a majority of income deciles in most regions increase their disposable income, with gains notably in the lower part of the income distribution.

Introduction and background

The United Kingdom reduced emissions by 40% from 1990 to 2019, among the largest reductions in the OECD and the largest among G20 countries, while GDP increased by 78%. Greenhouse gas emissions per unit of GDP were reduced by almost a factor of three since 1990, and emissions per capita have fallen considerably. In 2019, it was the first G7 country to create a legally binding target to bring net GHG emissions to zero by 2050 to deliver on the Paris Agreement. This ambition is supported by a strong institutional framework, which has inspired similar climate legislation across the world, and broad political and public support. In 2021, the UK was also the first among advanced economies to set a net zero strategy (BEIS, 2021[1]; OECD, 2022[2]; OECD, 2022[3]).

Continuing this success in the future will require considerable efforts. Electricity production has so far been the largest source of emission reductions, with the shift in electricity generation from coal to gas and, in the past decade, to renewable energy. Sectoral shifts away from heavy industry towards services and higher value-added, less polluting manufacturing have also contributed (Caselli, Ludwig and Van Der Ploeg, 2021[4]; OECD, 2022[2]).

Progress is slower in other sectors and projections show that without additional policies the UK is not yet on track to meet the fourth (2023 to 2027), the fifth (2028-2032) and the sixth legally binding carbon budget

[1]Jon Pareliussen works in the Economics Department of the OECD. Aurelien Saussay and Josh Burke work in the LSE Grantham Research Institute. The authors would like to thank Filippo Maria D'Arcangelo, Aida Caldera Sanchez, Daniela Glocker (Economics Department), Frédérique Zegel, Elisa Lanzi, Kilian Raiser, Enrico Botta (Environment Directorate), Herwig Immerwoll (Directorate for Employment and social affairs) as well as members of the OECD Economic Development Review Committee for their valuable comments and feedback at various stages of the process. Special thanks to Karimatou Diallo for editorial assistance, communication assistance by Nathalie Bienvenu and Steven Cassimon for preparing statistics and figures (Economics Department).

(2033-2037), as well as the net zero target (Climate Change Committee, 2021[5]). This trend largely reflects the uneven coverage of effective policy instruments. In the past, it was possible to successfully concentrate policy action and emission reductions on particular sectors while shielding others. Such differentiation is no longer an option with the target of reaching net zero emissions. All sectors will need to be covered by effective policies and early policy action will make the transition more gradual and less costly (OECD, 2022[2]).

Moving towards net zero is compatible with continued strong GDP growth and prudent fiscal policy, but will be challenging. Climate policies will change the sectoral composition of the economy, boost investment, inflation and interest rates. Some sectors are highly responsive to price signals, while various market failures such as coordination failures, asymmetric information, bounded rationality, liquidity constraints and underinvestment in research and development hold back action in others. Clean technologies are readily available and price competitive in some cases, but in others, they are unaffordable, on the testing stage, or not yet developed. Furthermore, the green transition will create winners and losers, and may challenge peoples' attitudes and beliefs. Energy security concerns and surging fossil fuel prices related to Russia's invasion of Ukraine add to the urgency of the transition, but also highlights the difficult political economy of adding to peoples' cost of living (D'Arcangelo et al., 2022[6]; OECD, 2022[2]).

Against this background, this paper presents new simulation results combining macroeconomic simulations in ThreeME, a computable general equilibrium model, with household-level micro-simulations. The aim of the combined simulation exercise is to provide internally consistent estimates of macroeconomic and distributional consequences of strong policy action to curb greenhouse gas emissions coupled with transfers to partially off-set distributional effects.

The paper adds to the existing literature by analysing different economic and distributional effects of introducing greenhouse gas mitigation policies, which can be better understood with simulations. Macroeconomic and microeconomic simulations are usually conducted in isolation, although there are studies combining the two. Merging these two approaches can give a fuller picture of potential consequences, including macroeconomic, sectoral and distributional effects of policy and the feasibility and effectiveness of redistribution packages.

Key findings from the simulations are:

- One main and overarching result of these simulations is that introducing a carbon price leads to large emission reductions across scenarios. Macroeconomic and distributional consequences are very limited in comparison.
- The ThreeME model points to double dividends, where stronger action on climate change also boosts GDP. Employment and output increase in most sectors, but notable output and employment losses are found in fuel supply and energy-intensive industries.
- Considerable investments are needed in the transition. Annual investments are set to increase to 5-10% above baseline by 2050, depending on scenario. Investments in major emitting sectors are set to increase considerably, from around 10% in buildings to around 40% in agriculture and land use. However, the simulations do not indicate a need for additional investments in the services sector, which accounts for two-thirds of UK output, but less than 10% of emissions.
- How carbon tax revenues are used matters for the GDP effects. The fiscal multiplier is higher if these revenues are distributed to households rather than firms. This redistribution has negligible effect on emission reductions.
- Carbon pricing is slightly regressive in the absence of additional redistribution, with a somewhat larger share of household income lost in lower income deciles. Multiple-person households are more exposed than single-person households, and working-age (head of household) households are more exposed than younger and older households.

- The effect of carbon pricing varies across regions, reflecting business structure, topography and climate. Scotland would be particularly affected, while Wales, the South East and South West would also be more affected than the national average.
- The carbon tax revenue is more than enough to offset negative income effects in the bottom half of the income distribution. Redistributing 30% of total tax revenue (in the medium carbon price scenario) would ensure that the population in a majority of income deciles in most regions increase their disposable income, with gains notably in the lower part of the income distribution. Even so, average income would fall in those regions most affected at the outset. Redistributing a larger share of revenues and/or supporting energy saving investments could further counteract negative income effects.

This paper is structured as follows: the second section presents the models, scenarios and how scenarios are linked across the two models. The third sections presents and explains a comprehensive selection of results, while the fourth section summarises and concludes.

The models and scenarios

The OECD and LSE's Grantham Research Institute modelled UK-specific policy scenarios to move towards net zero in an integrated macro-micro framework. Macroeconomic simulations feed into a microsimulation model to map macro-consistent distributional effects and redistribution packages.

Macroeconomic simulations in the ThreeME model

ThreeME (Multi-sector Macroeconomic Model for the Evaluation of Environmental and Energy policy) is a **country-generic and open source model** developed since 2008 by the French Environment and Energy Management Agency (ADEME), the French Economic Observatory (OFCE) and the Netherlands Economic Observatory (NEO). Initially developed to support the debate on energy, environment and climate debate in France, ThreeME has since been calibrated and applied to other regional contexts, including Mexican, Indonesian, Tunisian and Dutch studies (ThreeME, 2022[7]). The current study is the first time the model has been calibrated to the United Kingdom.

ThreeME is currently a country-level model designed for small open economies. As such, the evolution of the rest of the world is completely exogenous: world demand and world commodity prices are the same in the baseline and in each of the scenarios. No assumption is therefore made of any mitigation efforts outside the country considered. However, carbon leakage can and does happen: trade is modelled through a standard Armington approach, and terms of trade deteriorate when a country applies a carbon price. The scenarios presented in the paper are equivalent to a unilateral carbon tax implemented by the UK - thus carbon leakage impacts are if anything an upper bound of what they would be in a more cooperative scenario with foreign countries. Besides, the full redistribution of carbon tax proceeds mitigates this competitiveness effect (see below).

The UK baseline scenario is based on economic and population growth assumptions to 2050 aligned to that of the counterfactual used in the latest UK Climate Change Committee's (CCC) Net Zero Strategy assessment. Similarly, the baseline electricity mix is calibrated to reflect the same counterfactual evolution used by the CCC. World oil, and European natural gas and coal import prices are calibrated to IEA's World Energy Outlook projections to 2050.

An exogenous technological improvement trend in energy efficiency is assumed in both the baseline and the scenarios simulated. The annual rate of improvement is calibrated to that observed empirically over the 1990-2020 in the UK in both the baseline and carbon price scenarios. A form of endogenous technological change is taken into account in ThreeME, as the realized rate of energy efficiency improvement is a function of both the exogenous trend described above and the relative price of energy to the other factors of production (higher relative energy prices lead to an acceleration of energy efficiency improvements).

The model is especially designed to evaluate the medium and long-term impact of environmental and energy policies at the macroeconomic and sector levels. To do so ThreeME combines several important features:

Its **sectoral disaggregation** allows for analyzing the effect of transfers of activities from one sector to another in particular in terms of employment, investment, energy consumption and trade balance. These analyses reflect sectoral heterogeneity regarding labor, capital and energy intensity and their propensity to import and export.

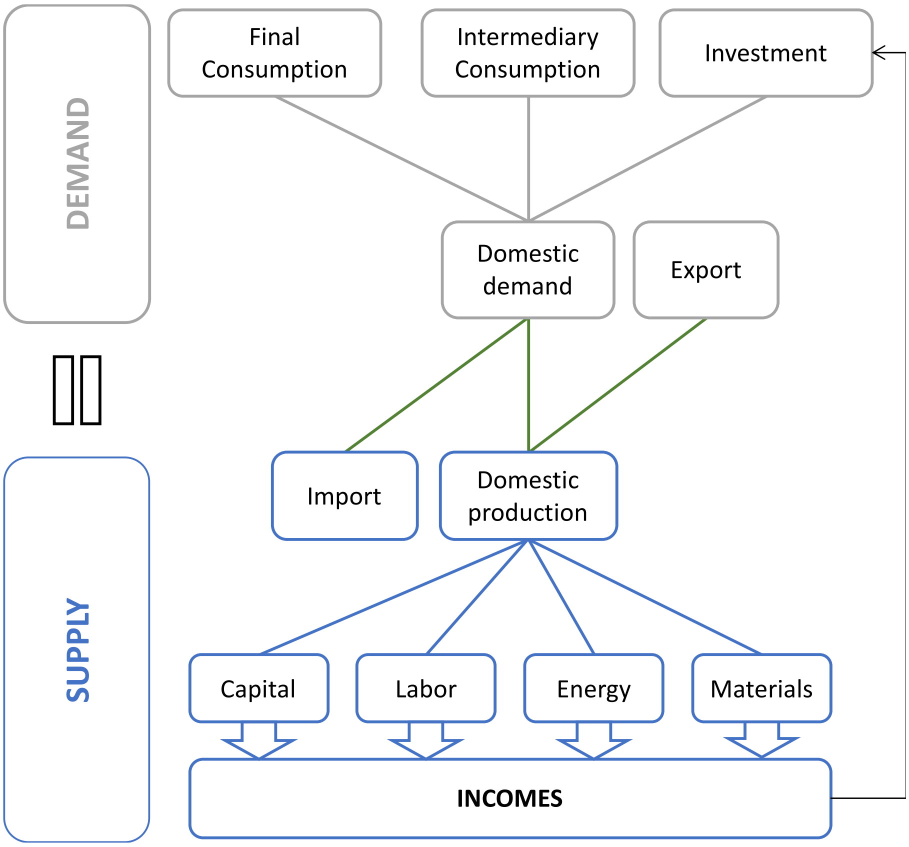
The **energy disaggregation** allows for analyzing the energy behavior of economic agents. Business sectors can arbitrate between different energy investments. They can substitute capital for energy when the relative energy price increases and they can substitute between energy sources. Furthermore, when the relative energy price increases, this incentivises more rapid technical progress (endogenous energy efficiency). Consumers can substitute between energy sources, between transport modes and between goods.

ThreeME is a **Computable General Equilibrium Model** (CGE). It therefore considers the interaction and feedbacks between supply and demand. The demand (consumption, investment) defines the supply (production). The supply defines in return the demand through the incomes generated by the production factors (labor, capital, etc.) (Figure 1). Compared to bottom-up energy models such MARKAL or EFFECT (IEA-ETSAP, 2022[8]), ThreeME goes beyond the mere description of the sectorial/technological dimension by linking those with the global economic system.

ThreeME is a **neo-Keynesian model**. This has the advantage over standard Walrasian-type CGE Models that it allows for disequilibrium between supply and demand and for the existence of sub-optimal equilibria, such as the presence of involuntary unemployment. This framework is better suited to analyze the transition phase of a particular policy and to address the questions relevant to social and political acceptability (e.g. identifying the agents and the sectors that are going to experience a net loss and thus to test the possibility of compensation mechanisms). The main neo-Keynesian characteristics are:

- *Slow adjustment of prices and quantities* to their notional (optimal) level. This reflects adjustment costs. Under imperfect competition, firms maximize their profit by adjusting production to demand rather than adjusting their price.
- *Prices* are defined as a mark-up over the firm's production costs. Production costs integrate intermediary consumption (material and energy), labor and capital costs.
- *Wages* are determined by a Wage Setting (WS) curve or a Phillips curve: wages increase with inflation and decrease with unemployment. Therefore, wages do not adjust instantly to supply and demand for labor. This allows for an equilibrium with permanent unemployment in line with the theory of an equilibrium rate of unemployment (NAIRU).
- The *interest rate* does not equilibrate instantaneously savings and investments. It is defined by the Central Bank according to a "Taylor" reaction function: the interest rate increases with inflation and decreases with unemployment.

Figure 1. Diagram of the ThreeME model



Source: ThreeME (2022[7]).

- Being a neo-keynesian CGE model, Three-ME considers:
- *General equilibrium effects*: supply influences demand and vice versa
- *Direct and indirect effects* of the energy transition. The direct effects are the impacts for the energy, building, transport sectors whereas the indirect effects (or rebound effects) are the impacts for the rest of the economy (in particular the other sectors, the government, households).
- *Limited eviction effects*. Investments are not only defined by savings. The financing through bank credit does not necessary lead to an increase of the interest rate. Increasing investment in one sector is not necessary achieved through decreasing investment in other sectors.
- *A double dividend (environmental and economic) is possible* through the improvement of the trade balance caused by the substitution of imported fossil fuels for domestic renewable production, and the full redistribution of tax revenue in the model which improves fiscal efficiency (e.g. reduction of the taxation of labor and capital financed by a tax on carbon), and increases demand (fiscal multiplier effect). This neo-keynesian feature of the model would not be considered in classical CGE models.

ThreeME has the limitation (as any CGE model) that net emissions will never reach zero in the model. Residual emissions will remain because of three important features of the ThreeME model:

- *Elasticities of substitution calibrated on historical data* determine the rigidity of demand for carbon intensive goods in the model. The marginal cost of abatement moves towards infinity. These elasticities may underestimate the potential for future adjustments, since emissions in the model converge towards low levels but never actually reach zero in any sector. However, a number of the changes needed to reach net zero are not incremental in terms of emission reductions. For example, substituting fossil fuels from electricity in heating and transportation, thereby reducing emissions to zero in these sectors goes beyond the scope of the model. New technologies, for example substituting coal for hydrogen in steel production, could have the same effect.

- *The model does not consider negative emissions*, which will be needed to reach net zero. This also means that the macroeconomic outputs from the model are partial. While negative emissions from natural sinks may have co-benefits, negative emissions achieved by carbon capture and storage (CCS) will sink resources for the sole benefit of reducing emissions, and will therefore in macroeconomic terms represent a loss of productivity.
- *The model is built around carbon pricing*, which is a stylised representation of the UK's policy mix.

Microsimulations built on the ONS Living Costs and Food Survey

Households in ThreeME are modelled using a single representative household, as is common in the macroeconomic literature. However, carbon pricing affects different households heterogeneously, particularly along the income distribution. To better account for this heterogeneity, ThreeME is combined with a techno-economic micro-simulation model of household carbon footprint adapted from Owen, Burke and Serin (2022[9]). Using data from the Office of National Statistics' Living Costs and Food Survey (LCF), the consumption basket of British households is characterised by income decile. The LCF provides highly detailed consumption data for each product of the Classification of Individual Consumption by Purpose (COICOP) at the 6-digits level. This expenditure data is combined with carbon footprint estimates for each COICOP product, which is used to estimate the carbon intensity of households' spending along the income distribution. This allows an assessment of the incidence of carbon taxation across incomes.

The product classification provided in the LCF is subsequently matched to the 24 aggregate products used in the calibration of the ThreeME model to the UK economy. This matching allows the disaggregation of the impact of the carbon price trajectory simulated in the macroeconomic model over each of the ten income deciles for each year in the simulation. However, this combination of ThreeME and the micro-simulation model is a one-way model: there is no retroaction from the micro-simulation towards the macro-economic model. Distributional considerations have no macroeconomic implications in the results of the simulations presented.

Scenarios

Three carbon price scenarios (low, medium and high) are modelled with a uniform carbon price across the economy, converging over time towards the UK government's official shadow price trajectories ("carbon values") in their high, medium and low variants, with the following assumptions (BEIS, 2021[10]; HMT, 2020[11]; OECD, 2022[2]):

- Low carbon price: GBP 100 per ton of CO2 equivalent emissions (tCO2e) in 2030, GBP 189 in 2050.
- Medium carbon price: GBP 140 per tCO2e in 2030, GBP 378 in 2050.
- High carbon price: GBP 280 per tCO2e in 2030, GBP 568 in 2050.

The shadow price on emissions represents how much more profitable the sum of climate policies makes green production and consumption compared to polluting activities. It is modelled as a uniform carbon (equivalent) tax, but could in principle come from an emission trading scheme, regulations, subsidies or a combination of instruments. For reference, UK ETS allowances traded between GBP 68 and GBP 88 in the first three months of 2022, but is complemented by renewable energy subsidies and increasingly stringent environmental regulations.

One notable difference to price signals from regulations and subsidies is that the model operates with carbon tax revenues, which are redistributed to households and businesses according to different scenarios:

- “Standard” scenario: Redistribution to households and business sectors without transfers between firms and households. However, transfers can occur from carbon-intensive sectors to the rest of the economy.
- “Households” scenario: Total receipts are distributed to households.
- “Firms” scenario: Total receipts are distributed to firms.
- “Export exposure” scenario: As in the standard scenario, but the distribution of receipts among firms is adjusted to distribute more to sectors with high trade exposure (measured by the ratio of exports to output).
- “Neutral GDP” scenario: A share of revenue is withheld so that the overall GDP impact from 2040 to 2050 is zero. Remaining revenues are distributed as in the “Standard” scenario.

Microsimulations are built on the ONS household expenditure survey (the Living Costs and Food Survey). For each revenue redistribution and carbon tax scenario in the macro model, four distribution scenarios are explored:

- Unmitigated impacts of the carbon tax.
- Uniform lump-sum redistribution of all available carbon tax receipts across all households.
- Calibrating a lump-sum redistribution to all households equal to the average carbon tax paid by households in decile 4, measured at the national level. This translates into a net gain for deciles 1-3, who pay less carbon taxes (but a larger share of their income) than higher-income households. The majority of fuel poverty incidence has been found in deciles 1-3 (BEIS, 2022[12]).
- Calibrating a lump-sum redistribution so that not a single decile 4 household in any region experiences a loss.

Results

A selection of macroeconomic output variables from the ThreeME model simulation are presented below, including notably emissions, GDP, investments, fiscal balance, inflation and labour market outcomes. These outputs are available for the economy as a whole and by sector. Output variables describing distributional consequences are available by income level, household type and geography. Results are presented as differences to a baseline with unchanged climate policies.

Macroeconomic outputs

One main and overarching result of these simulations is that if a carbon price is introduced it leads to large emission reductions across scenarios. Emission reductions range from a 47% decrease compared to the unchanged policy baseline with a low carbon price to a 71% reduction with a high carbon price in the “Standard” revenue use scenario, where revenues are recycled back to households and firms based on their share of carbon tax paid. These reductions are larger than simple estimated elasticities such as in D’Arcangelo et al. (2022[13]), due to exogenous and endogenous technical progress. The model predicts double dividends, with GDP increasing with the carbon price. However, the difference to the baseline is negligible, ranging from 1.1% to 1.8% cumulative over a 30-year period. This feature of the results is also reflected in other key macroeconomic variables, with both employment increasing with the carbon price and public debt to GDP falling (Table 1).

Table 1. Macroeconomic outputs by carbon price scenario

Difference from baseline in % (*percentage points)

Carbon price scenario	Variable	2030	2040	2050
Low carbon price	GDP	0.7	0.8	1.1
	Emissions	-26.8	-38.0	-47.2
	Employment	0.7	0.7	1.0
	Wages	1.3	2.7	3.9
	Consumer price level	1.3	2.6	3.7
	Unemployment rate*	-0.5	-0.5	-0.7
	Debt to GDP*	-3.2	-6.1	-9.0
	Investment	1.4	3.2	4.8
	Interest rate*	0.09	0.09	0.11
Mid carbon price	GDP	0.8	1.1	1.5
	Emissions	-33.2	-50.3	-62.8
	Employment	0.8	1.0	1.3
	Wages	1.6	3.6	5.4
	Consumer price level	1.7	3.5	5.1
	Unemployment rate*	-0.6	-0.7	-1.0
	Debt to GDP*	-4.0	-8.2	-12.6
	Investment	1.8	4.5	7.1
	Interest rate*	0.12	0.13	0.15
High carbon price	GDP	1.2	1.3	1.8
	Emissions	-49.3	-62.5	-71.2
	Employment	1.3	1.3	1.8
	Wages	2.6	5.4	7.2
	Consumer price level	2.8	5.2	6.8
	Unemployment rate*	-0.9	-0.9	-1.3
	Debt to GDP*	-6.8	-12.4	-17.8
	Investment	3.4	7.5	10.7
	Interest rate*	0.19	0.16	0.18

Note: “Standard” scenario: Redistribution to households and business sectors without transfers between firms and households.
Source: Authors’ calculations.

A second main finding is that emissions are only marginally affected by how proceeds are distributed, generating rebound effects from changing GDP level and composition. With a medium carbon price, emission reductions round to 63% below baseline regardless of revenue use scenario. How proceeds are handled within the broader fiscal stance and how they are distributed does however play a role in offsetting undesired macroeconomic effects. Due to fiscal multiplier effects, the GDP boost increases if more revenue is distributed to households, with wages and inflation increasing as a consequence. Withholding a share of revenue, as in the “Neutral GDP scenario” reduces GDP growth and inflationary pressures, and reduces the debt to GDP ratio considerably. ThreeME's interest rates are set by a Taylor rule, under the assumption that the central bank tries to limit both inflation and unemployment. The inflationary effects of the green transition are the highest if all revenues are redistributed to households. In this case the consumer price level increases almost 10% above baseline over a 30-year time horizon, and interest rates increase to peak 22 basis points higher than the baseline in 2030 (Table 2).

Table 2. Macroeconomic outputs by revenue use scenario

Difference from baseline in % (*percentage points)

Variable	Revenue use scenario	2030	2040	2050
GDP	Standard	0.84	1.09	1.47
	Trade exposure	0.92	1.21	1.62
	All to households	1.33	1.48	1.83
	All to firms	0.63	0.91	1.32
	Neutral GDP impact	0.09	-0.05	0.06
Emissions	Standard	-33.22	-50.27	-62.80
	Trade exposure	-33.00	-50.03	-62.58
	All to households	-32.60	-49.96	-62.62
	All to firms	-33.49	-50.41	-62.87
	Neutral GDP impact	-33.78	-50.94	-63.42
Employment	Standard	0.85	1.01	1.35
	Trade exposure	0.88	1.08	1.43
	All to households	1.24	1.12	1.38
	All to firms	0.68	0.96	1.33
	Neutral GDP impact	0.11	-0.10	-0.03
Wages	Standard	1.58	3.56	5.35
	Trade exposure	1.60	3.63	5.46
	All to households	3.25	6.96	9.64
	All to firms	0.81	2.04	3.44
	Neutral GDP impact	1.61	3.62	5.49
Consumer price level	Standard	1.68	3.47	5.14
	Trade exposure	1.66	3.48	5.16
	All to households	3.65	6.94	9.47
	All to firms	0.79	1.92	3.21
	Neutral GDP impact	2.06	4.06	5.92
Unemployment rate	Standard	-0.60	-0.72	-0.96
	Trade exposure	-0.63	-0.77	-1.01
	All to households	-0.88	-0.79	-0.98
	All to firms	-0.49	-0.68	-0.95
	Neutral GDP impact	-0.06	0.06	0.01
Debt to GDP	Standard	-3.99	-8.24	-12.63
	Trade exposure	-3.50	-7.01	-10.44
	All to households	-6.46	-10.96	-14.36
	All to firms	-2.86	-6.98	-11.83
	Neutral GDP impact	-8.97	-29.98	-47.99
Investment	Standard	2.05	4.50	7.13
	Trade exposure	2.12	4.58	7.19
	All to households	2.34	4.68	7.12
	All to firms	1.93	4.41	7.13
	Neutral GDP impact	1.25	3.22	5.53
Interest rate	Standard	0.12%	0.13%	0.15%
	Trade exposure	0.12%	0.13%	0.16%
	All to households	0.22%	0.17%	0.17%
	All to firms	0.08%	0.11%	0.14%
	Neutral GDP impact	0.08%	0.05%	0.05%

Note: Medium carbon price: GBP 140 in 2030, GBP 378 in 2050.
Source: Authors' calculations.

Sectoral shifts

Even though the effects on GDP and other main macroeconomic aggregates are modest, the policies needed to reach net zero are set to trigger a large change in the industrial structure. These changes are illustrated in Table 3 A, within the overall neutral GDP scenario. Sectors of the economy will be affected differently, with notable output and employment losses in fuel supply and energy-intensive industries contrasting gains in employment and output in most other sectors. Increasing employment in transportation may seem counterintuitive, but in the version of ThreeME used in the present paper, the transportation sector can substitute from one energy vector to another as a function of relative energy prices. Increasing carbon taxation increases the price of fossil fuel relative to that of (decarbonized) electricity and therefore triggers a switch to electricity.

However, much of the structural change will take place within sectors. For example, construction, aviation and shipping are set to reduce emissions by 60-70% compared to the baseline while boosting output by 3-4%. This will require investments, notably in energy efficiency, zero emission energy and compatible equipment. In the GDP neutral scenario, annual investments within the scope of the model are set to increase to 6% above baseline by 2050. Investments in major emitting sectors are set to increase considerably, from 10% in buildings to 39% in agriculture and land use. The simulations do not point to a need for additional investments in the services sector, which accounts for two-thirds of UK output but less than 10% of emissions.

The green economy will change the composition of the labour market, with falling employment and wages in some sectors offset by increases in others and changing skill needs also within sectors. This will only translate into a durable net employment gain to the extent labour supply meets demand in terms of both skills and location. There is a risk that unemployment increases throughout the transition if skills supply does not match demand. The United Kingdom has a resilient economy with flexible regulations in labour- and product markets that are likely to limit the pain of the transition.

The “pollution haven” hypothesis is a term describing cases when climate policies in one country result in production and investment moving to other more lax jurisdictions. This will lower prices on emission-intensive products in both importing and exporting countries and spur excessive consumption, with increasing global emissions as a result (“carbon leakage”) (OECD, 2021[14]). Real or perceived carbon leakage and competitiveness concerns are often met, in the United Kingdom and elsewhere, by lowering policy ambition and by subsidies such as tax rebates on energy inputs or free allowances for emissions covered by emissions trading schemes.

Compensating these industries by means of subsidies, tax rebates and free allowances would benefit shareholders at the expense of the taxpayer, but would come with very limited positive effects. This point is illustrated by comparing the “Standard” scenario (Table 3 B) with the “Export exposure” scenario where tax revenue is targeted to companies according to their export exposure (Table 3 C). These subsidies only yield marginal improvements in output and employment in fuel supply and energy intensive industry, the industry most affected by stringent climate policies. This is because climate policies aim to trigger structural change. A monetary incentive designed to block such structural change would imply compensation according to the carbon tax bill or a close proxy thereof, and would blunt the incentives to reduce emissions.

Table 3. Sectors of the economy will be affected differently by net zero

A. Neutral GDP scenario (% difference from baseline, 2050)

Sector	Emissions	Output	Investment	Employment	Wages
Agriculture and land use	-42.1%	-3.1%	38.6%	1.2%	5.6%
Aviation and shipping	-63.1%	3.3%	27.2%	4.7%	5.6%
Construction	-69.7%	3.7%	9.6%	4.0%	5.6%
Fuels	-60.0%	-35.5%	33.1%	-7.6%	-8.1%
Industry-energy intensive	-50.6%	-6.9%	22.2%	-3.6%	7.1%
Industry-non-energy-intensive	-64.5%	-1.8%	27.8%	-0.3%	5.7%
Services	-63.2%	-1.7%	0.3%	-0.3%	5.6%
Surface transport	-58.0%	0.9%	23.9%	1.6%	5.7%
Economy-wide	-63.4%	0.1%	5.5%	0.0%	5.5%

B. Standard scenario (% difference from baseline, 2050)

Sector	Emissions	Output	Investment	Employment	Wages
Agriculture and land use	-41.2%	-2.1%	39.6%	2.3%	5.4%
Aviation and shipping	-62.3%	4.5%	28.4%	6.0%	5.4%
Construction	-68.9%	5.3%	11.5%	5.6%	5.5%
Fuels	-59.5%	-34.9%	33.9%	-6.8%	-8.3%
Industry-energy intensive	-49.9%	-6.1%	22.8%	-2.8%	6.9%
Industry-non-energy-intensive	-63.7%	-0.8%	28.8%	0.8%	5.5%
Services	-62.2%	-0.2%	2.0%	1.1%	5.5%
Surface transport	-57.0%	2.4%	25.8%	3.1%	5.6%
Economy-wide	-62.8%	1.5%	7.1%	1.3%	5.4%

C. Trade exposure scenario (% difference from baseline, 2050)

Sector	Emissions	Output	Investment	Employment	Wages
Agriculture and land use	-40.7%	-1.6%	39.9%	2.8%	5.5%
Aviation and shipping	-61.8%	5.8%	29.1%	7.7%	5.0%
Construction	-68.6%	5.4%	11.4%	5.7%	5.6%
Fuels	-59.1%	-34.3%	34.9%	-5.9%	-8.4%
Industry-energy intensive	-49.3%	-5.3%	23.7%	-1.9%	6.9%
Industry-non-energy-intensive	-63.2%	0.0%	29.7%	1.6%	5.6%
Services	-62.1%	-0.2%	2.0%	1.0%	5.6%
Surface transport	-56.8%	2.3%	25.2%	3.1%	5.6%
Economy-wide	-62.6%	1.6%	7.2%	1.4%	5.5%

Note: The carbon price signal is here modelled as uniform carbon (equivalent) tax, but could in principle come from an emissions trading scheme, regulations, subsidies or a combination of instruments. Results based on a "Medium carbon price" starting at GBP140 in 2030, rising to GBP378 in 2050. The "Neutral GDP" scenario holds back a share of revenue (45%) to achieve average GDP growth as in the baseline from 2040 to 2050. Remaining revenues are distributed proportionately to sectors as in the "Standard" scenario. "Standard" scenario: Redistribution to households and business sectors without transfers between firms and households. "Export exposure" scenario: As in the standard scenario, but the distribution of receipts among firms is adjusted to distribute more to sectors with high trade exposure (measured by the ratio of exports to output).
Source: Authors' calculations.

Distributional effects

Households directly produce greenhouse gas emissions from residential energy consumption and transport. Waste handling is also a complex task involving households and businesses, national, devolved and local authorities. Taken together, these sectors generate approximately half of UK greenhouse gas emissions. Explicit pricing instruments targeting these emissions tend to be regressive unless compensated. Although this is not universally true, the danger of triggering cost of living shocks can be a considerable hurdle to efficient policies (OECD, 2022[2]).

However, these first-order negative distributional effects do not capture that taxes and emission trading schemes also generate revenue to finance public services and transfers, which are overall progressive in the United Kingdom and across the OECD. Furthermore, households will be affected differently within each decile of the income distribution because of differences in occupation, housing and transport needs, but will also have opportunities to adapt their investments and consumption to minimise costs and maximise benefits of the transition (OECD, 2022[2]).

In order to assess the merits of carbon pricing targeted to households, it is useful to have an idea whether the tax revenue collected is sufficient to off-set the first order distributional impact. Three redistribution scenarios are considered, as described above. The first distributes a lump-sum redistribution of all available carbon tax receipts across all households, bearing in mind that a share of receipts is distributed to firms or to strengthen the budget balance in most scenarios. The second distributes a lump-sum calibrated to off-set the average losses in the fourth national income decile. The rationale behind this is that a lump-sum transfer calibrated so that households below the median are unaffected or gain from the combination of the tax and the transfer, the policy package will be progressive overall, and the most vulnerable households in terms of income and the incidence of fuel poverty will be protected. Under the third scenario a lump-sum calibrated to off-set the average losses in the fourth income decile of the region experiencing the highest income losses is distributed. The overall tax revenue is more than sufficient to finance each of these redistribution scenarios if all revenues are assigned to the household sector. In this case, off-setting average losses in the fourth income decile nationally would require approximately 30% of total revenue, while off-setting losses for the fourth decile in the region where these losses are the largest would require around 60% of total revenue. These revenue shares are stable over time and relatively insensitive to the carbon price (Table 4 A). The full revenues might not be available for redistribution for various reasons. Assuming that only revenue collected from the household sector is available for redistributions to households, revenues are still sufficient to off-set negative income effects in the bottom of the distribution nationally. However, a more expensive scenario where the lump-sum transfer is calibrated to off-set the losses in the fourth decile in the most affected region would require additional funding (Table 4 B). The revenue available for redistribution is similar in the “Neutral GDP impact” scenario (Table 4 C).

Table 4. Share of available revenues used for redistribution

A. Share of total revenue collected used for redistribution to households

	Low carbon price		Medium carbon price		High carbon price	
Year	**Off-set average losses national D4**	**Off-set highest regional D4 losses**	**Off-set average losses national D4**	**Off-set highest regional D4 losses**	**Off-set average losses national D4**	**Off-set highest regional D4 losses**
2030	32%	60%	31%	59%	29%	55%
2040	34%	63%	31%	60%	29%	56%
2050	34%	63%	30%	58%	27%	54%

B. Share of revenue collected from the household sector used for redistribution to households

	Low carbon price		Medium carbon price		High carbon price	
Year	Off-set average losses national D4	Off-set highest regional D4 losses	Off-set average losses national D4	Off-set highest regional D4 losses	Off-set average losses national D4	Off-set highest regional D4 losses
2030	77%	143%	77%	144%	76%	147%
2040	77%	144%	76%	146%	76%	149%
2050	77%	144%	76%	147%	76%	149%

C. Share of revenue collected from the household sector used for redistribution to households

	Low carbon price		Medium carbon price		High carbon price	
Year	Off-set average losses national D4	Off-set highest regional D4 losses	Off-set average losses national D4	Off-set highest regional D4 losses	Off-set average losses national D4	Off-set highest regional D4 losses
2030	77%	143%	77%	144%	76%	147%
2040	77%	144%	76%	146%	76%	148%
2050	77%	144%	76%	147%	76%	149%

Note: Table A shows the "All to households" scenario. Table B shows the "Standard" scenario. Table C shows the "Neutral GDP" scenario. The share of revenue available for redistribution in scenarios B and C amounts to approximately 45% of total revenues.
Source: Authors' calculations.

Looking at the actual distributional effects, the first-order effects of carbon pricing in a GDP neutral scenario with macroeconomic consequences as outlined above is regressive, with the largest % share of income lost in deciles one, four and six. Redistributing all available revenue (approximately 45% of total revenue from the carbon tax) as a lump-sum transfer equally to all households turns the combined policy package progressive, with minor income losses in the highest income deciles, and somewhat more substantial gains in the lower part of the distribution. The pattern is the same for the two other redistribution scenarios, with the size of the transfer dictating the extent of gains and losses (Table 5).

Table 5. Changes in income by income decile and redistribution scenario (%)

Medium carbon price, neutral GDP scenario, 2050

Decile	No redistribution	Full redistribution	Neutral impact on D4	Neutral on highest regional D4
1	-1.74	2.33	1.36	4.25
2	-1.25	1.62	0.93	2.97
3	-0.94	1.26	0.73	2.30
4	-1.33	0.42	0.00	1.24
5	-1.15	0.28	-0.06	0.96
6	-1.41	-0.22	-0.51	0.33
7	-0.97	0.01	-0.22	0.47
8	-0.96	-0.17	-0.36	0.21
9	-1.05	-0.44	-0.58	-0.15
10	-0.90	-0.46	-0.57	-0.26

Note: The share of total revenue used for redistribution is in this case about 30% of total carbon tax revenue.
Source: Authors' calculations.

There are also large variations within income deciles due to for example differences in housing size and transportation patterns. There is an age dimension, with a lower impact on young households who typically live in smaller houses and consume less transport fuels and household size, with larger households more affected (Table 6).

Table 6. Change in income by household size and age (of head of household), GBP

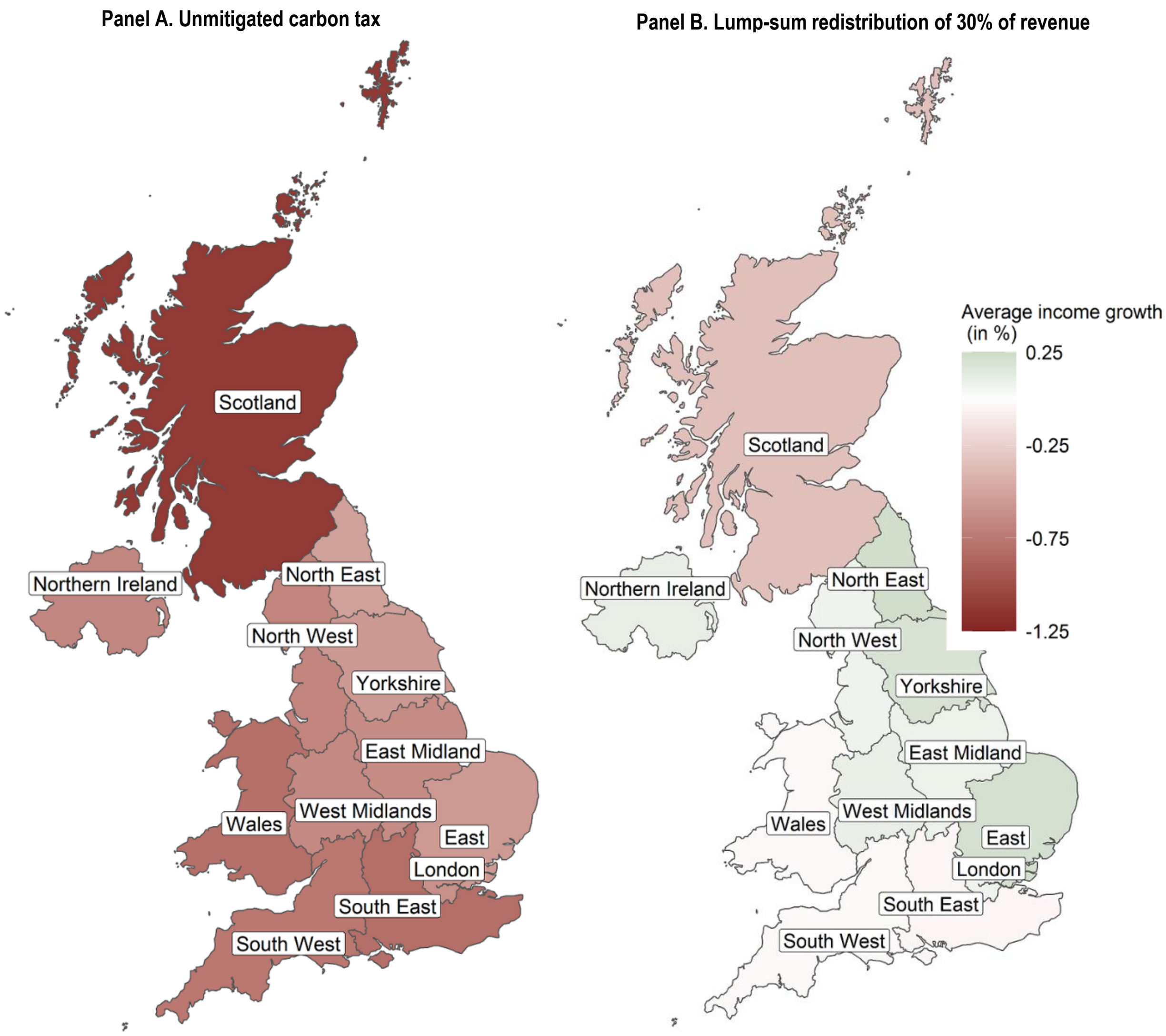
Medium carbon price, neutral GDP scenario, 2050

Gross carbon price					
Size/age	< 24	25-44	45-64	65+	Average
1	222.93	409.67	211.55	170.25	253.60
2	258.47	432.56	596.22	611.34	474.65
3+	329.03	427.86	630.73	394.55	445.54
Average	270.15	423.36	479.50	392.04	391.26
Uniform redistribution					
Size/age	< 24	25-44	45-64	65+	Average
1	-222.92	-36.19	-234.30	-275.61	-192.26
2	-187.39	-13.29	150.36	165.48	28.79
3+	-116.83	-18.00	184.88	-51.31	-0.31
Average	-175.71	-22.49	33.64	-53.81	-54.59
Neutral impact on two-person households					
Size/age	< 24	25-44	45-64	65+	Average
1	-328.96	-142.23	-340.34	-381.65	-298.30
2	-293.42	-119.33	44.32	59.44	-77.25
3+	-222.87	-124.04	78.84	-157.35	-106.35
Average	-281.75	-128.53	-72.40	-159.85	-160.63

Note: "Neutral GDP" scenario: A share of revenue is withheld so that the overall GDP impact from 2040 to 2050 is zero. Remaining revenues are distributed to firms and households according to their respective shares in carbon taxes paid. Medium carbon price: GBP 140 in 2030, GBP 378 in 2050.
Source: Authors' calculations.

The effect of carbon pricing also has geographical dimensions, reflecting business structure, topography and climate. Scotland would be particularly affected, and Wales, the South East and South West would also be more affected than the national average (Figure 2, Panel A). Redistributing 30% of total tax revenue as above would ensure that the population in a majority of income deciles in a majority of regions increased their disposable income, with gains notably in the lower part of the income distribution. Even so, negative income effects would remain on average in those regions most affected at the outset (Figure 2, Panel B).

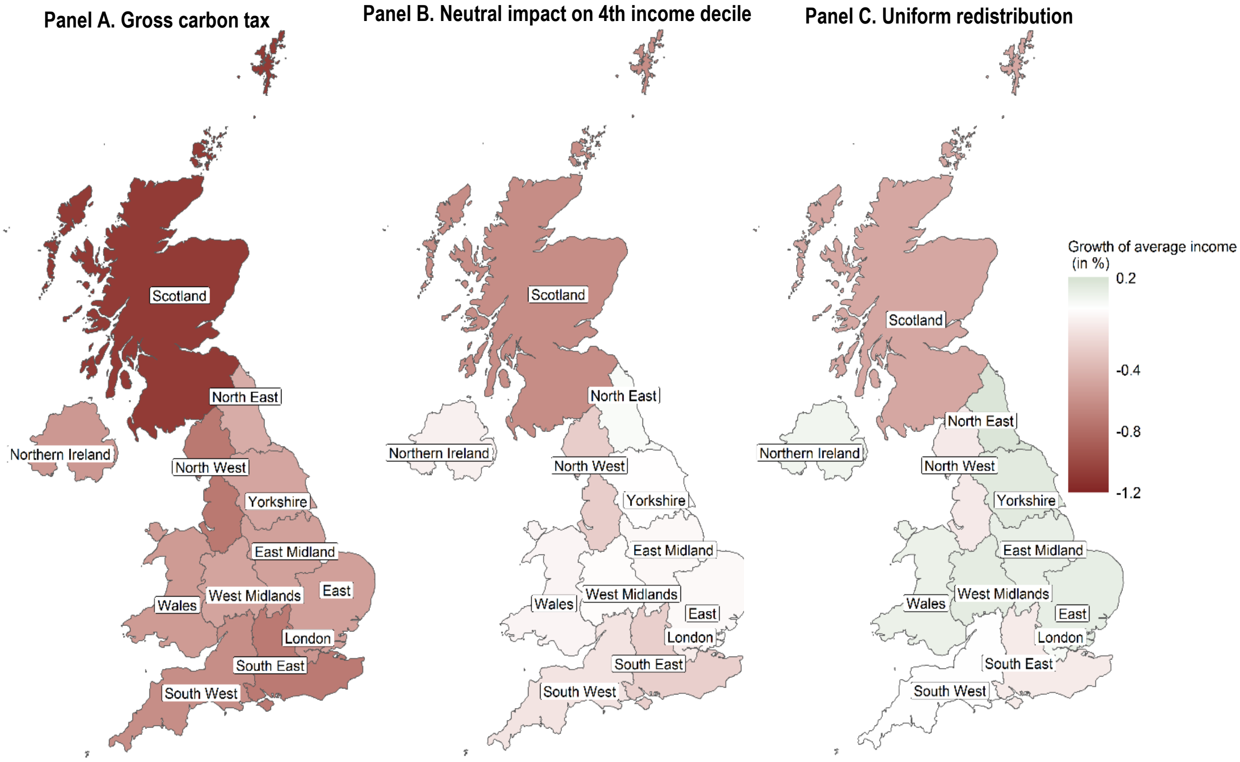
Figure 2. A carbon price affects regions differently



Note: GDP neutral scenario. The redistribution scenario implies a lump-sum redistribution scaled to offset the first-order income effect from a carbon tax for the 4th income decile at the national level. This implies a redistribution of 30% of total tax revenue. Income growth is defined as % income growth within each decile, averaged over deciles.
Source: Authors' calculations.

A second relevant question to ask is how the income distribution between regions would change. The regions experiencing the largest losses in average income are Scotland, the North West, the South East and Wales. As the redistribution is designed as a lump-sum transfer, these relative differences remain in all redistribution scenarios, and average incomes in these three regions remain below the baseline scenario even if 45% of carbon tax revenue would be redistributed (Figure 3). Other instruments than lump-sum transfers might counter these regional differences in sensitivity to carbon pricing more effectively. Targeted capital subsidies for housing energy efficiency improvements and electric vehicle charging infrastructure would for example benefit the most emission-intensive households and regions disproportionately. Burke et al (2020[15]) estimate that using 33% of the revenue from a GBP 50 tax per tonne of CO_2 for housing energy efficiency measures can ensure fuel-poor households are not adversely affected.

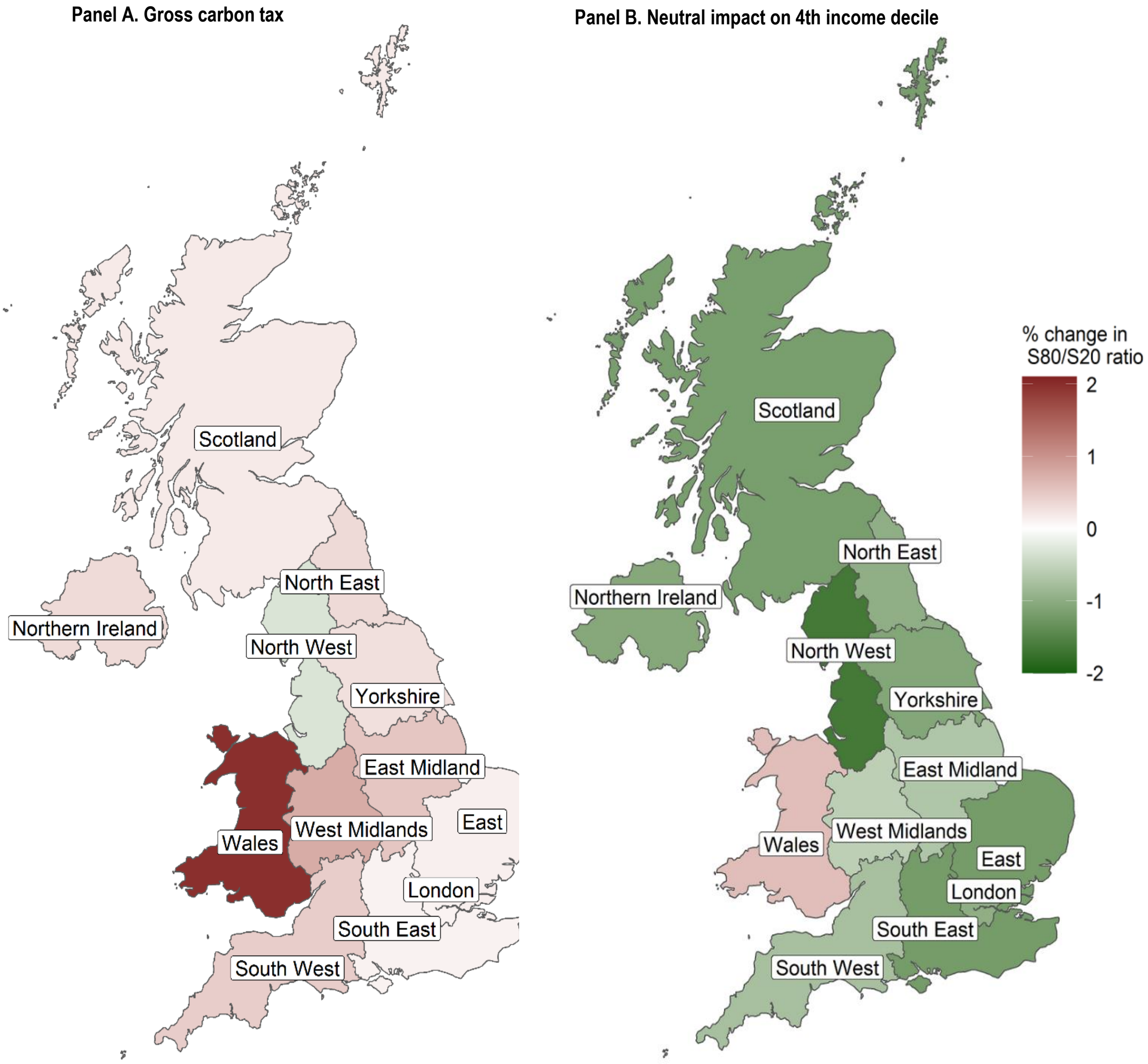
Figure 3. Change in average income by region, difference to baseline (2050)



Note: GDP neutral scenario. The "Neutral impact on 4th income decile" redistribution scenario implies a lump-sum redistribution scaled to offset the first-order income effect from a carbon tax for the 4th income decile at the national level. This implies a redistribution of 30% of total tax revenue. The "Uniform redistribution" redistribution scenario implies a lump-sum redistribution of all available revenue in the "Neutral GDP" revenue use scenario. This implies a redistribution of 45% of total tax revenue. Income growth is defined as % average income growth by region.
Source: Authors' calculations.

The simulations can also shed light on how income inequality would be affected within regions. To do this, the change in the S80/S20 ratio has been calculated. The S80/S20 ratio compares the mass of income held by 20 % of the richest persons to that held by 20% of the poorest persons. The largest widening of inequalities are found for Wales and the West Midlands. Redistributing 30% of revenue to off-set losses in the fourth decile at the national level, as outlined above, neutralises the initial widening of the income distribution in all regions but Wales (Figure 4).

Figure 4. Changes in income distribution within regions, difference to baseline (2050)



Note: GDP neutral scenario. The redistribution scenario implies a lump-sum redistribution scaled to offset the first-order income effect from a carbon tax for the 4th income decile at the national level. This implies a redistribution of 30% of total tax revenue. The S80/S20 ratio is the income held by 20 % of the richest persons divided by that held by 20% of the poorest persons.
Source: Authors' calculations.

Summary and conclusions

This paper presents new simulation results combining macroeconomic simulations in ThreeME, a computable general equilibrium model, with household-level micro-simulations. The aim is to provide internally consistent estimates of macroeconomic and distributional consequences of strong policy action to curb greenhouse gas emissions, coupled with possible compensatory policies.

One main and overarching result of these simulations is the strong negative link between carbon price and emissions. If a carbon price is introduced it leads to significant emission reductions, depending on the size of the carbon price. The model points to double dividends, where stronger action on climate change also boosts GDP and improves a number of macroeconomic outcomes. However, the magnitude of macroeconomic and distributional consequences are very limited over the 30-year time horizon of the modelling exercise.

Considerable investments are needed in the transition. In the GDP neutral scenario, annual investments are set to increase to 6% above baseline by 2050. Investments in major emitting sectors are set to increase considerably, from 10% in buildings to 39% in agriculture and land use, while the simulations do not point to a need for additional investments in the services sector, accounting for two-thirds of UK output, but less than 10% of emissions.

Carbon pricing is slightly regressive, with a somewhat larger share of household income lost in lower income deciles. Multiple-person households are more exposed than single-person households, and working-age (head of household) households are more exposed than younger and older households. However, the carbon tax revenue is more than enough to offset negative income effects in the bottom half of the income distribution.

Redistributing 30% of total tax revenue (in the medium carbon price scenario) would ensure that the population in a majority of income deciles in a majority of regions increased their disposable income. The first-order effect of carbon pricing varies across regions. Scotland would be particularly negatively affected by a tax, while Wales, the South East and South West would also be more affected than the national average. Average incomes in these regions would also fall relative to the national average. Furthermore, the first-order effect of carbon pricing would be to widen income inequality within regions. These effects are fairly limited over a 30-year horizon, and redistributing 30% of total tax revenue (in the medium carbon price scenario) would ensure that the population in a majority of income deciles in a majority of regions increased their disposable income, with gains notably in the lower part of the income distribution. Such a transfer would also largely off-set increased within-region inequality. Even so, negative income effects would remain on average in those regions most affected at the outset, and mitigating widening income differentials between regions would require more targeted policies than those covered in this paper.

In conclusion, recycling carbon revenues to make the overall policy package progressive means that low-income households will gain on average, but not that every low-income household will gain. Differences remain, and are driven by where people are in their life cycle in terms of age and family size, by where and in which kind of housing they live and their transportation needs and habits. Such differences are inevitable, as compensating households (or businesses) based on their actual exposure to carbon pricing would remove their incentives to reduce emissions. At the same time, a number of households and businesses will be able to seize new opportunities, as they have the time and opportunity to adapt and bring about the change, which is the purpose of carbon pricing policies.

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