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The importance of labour market responses, competitiveness impacts, and revenue recycling in determining the political economy costs of broad carbon taxation in the UK

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ABSTRACT

Despite broad acceptance of the need to drastically reduce carbon emissions and limit global warming, political debates persist regarding the acceptability of actions to internalise carbon costs given potential impacts on the cost-of-living and income generation. We present fundamental macroeconomic and more complex computable general equilibrium analyses to consider how introducing broad carbon taxation might impact key macroeconomic indicators, taking the UK as an applied example. One key insight is that, with no other policy intervention, such a move introduces contractionary pressure through increases in consumer prices that reduces GDP, employment, and household spending, and erodes government revenue gains. The extent of contraction depends on the degree of resistance in labour markets to real wage rate reductions alongside substitutability away from taxed energy in determining prices, and on consequent export demand responses. A second is that where government prioritises balancing its budget, partial recycling of carbon tax revenues aimed at moderating negative impacts on firm costs and household real spending power can reduce wider economy losses. However, this is limited by wage bargaining and domestic consumption responses in a labour supply constrained and very open economy, with income tax recycling minimising macroeconomic losses at the cost of increasingly regressive outcomes.

1. Introduction

The United Nations Framework Convention on Climate Change (UNFCCC, 2015, 2021) now reflects general acceptance of the need to limit climate change through 'net zero' carbon targets. Economists typically argue that putting a price on carbon serves as an appropriate and effective basis for achieving such targets. This price should be set to 'internalise' the external cost imposed on the environment and to correct the market failure that otherwise leads to the allocative inefficiency. Taxes or similar market-based mechanisms are the main methods identified to impose such a price (Pigou, 1920).

It is likely that reasoning from these economic 'first principles' has motivated governmental bodies, such as HM Treasury (2021), to recommend an extension of carbon pricing beyond the current UK Emissions Trading Scheme. Thus, in the 2019 amendment of the UK Climate Change Act, carbon pricing is the central pillar of policy action to achieve the 'net zero' targets (HM Government, 2019). Carbon pricing schemes include both tax and tradable permits mechanisms, although Pigou's demonstration of their equivalence in principle may not be so straightforward in practice (e.g., see Goulder and Schein, 2013; Mideksa and Weitzman, 2019).

Imposing a carbon price is expected to activate three broad mechanisms for reducing the level of emissions. First, it encourages the substitution of other inputs for fossil fuels in production, typically delivered through investment in less energy intensive techniques. Second, it incentivises households to shift their consumption away from energy intensive goods and services. Finally, it stimulates research and development into energy saving technologies. However, additional policy actions are likely to be required to enable producers and consumers to respond to the tax in an optimal emissions-reducing way and to minimise the negative impacts across the economy of internalising the cost of carbon.

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The arguments for pricing carbon emissions are soundly based but rely primarily on a micro-economic perfectly competitive framework, including focus on agent responses (e.g., see Green, 2021; Stiglitz, 2019; Tvinnereim and Mehling, 2018). Here, following authors such as Carbone et al. (2020) and Metcalf and Stock (2020), we take a more macroeconomic perspective that stresses the wider economy drivers and implications of internalising carbon costs. In doing so, we introduce a novel focus on the likely, and possibly dominant, role of labour market responses in determining outcomes of political and public concern. Here, we focus on wage determination, specifically the likelihood of worker resistance to reductions in real wage rates as activity contracts, but the cost-of-living rises, as new taxation forces the internalisation of carbon costs. In taking this fuller economy-wide perspective, our analysis generates new insights into household distributional effects.

This approach allows the identification of political economy concerns that may arise, particularly where the wider policy framework is not yet in place to ensure that emissions-reducing outcomes will be delivered. These concerns add to the wider range of factors that drive and/or influence political support and public acceptability for carbon pricing interventions (Baranzini et al., 2017; Carattini et al., 2018; Fullerton, 2011; Huang et al., 2022; Levi et al., 2020; Klenert et al., 2018).

In this paper we investigate how the introduction of broad carbon taxation, linked to energy use, impacts key policy variables, such as GDP, the cost-of-living (as given by consumer price index, CPI), employment, real wage incomes and competitiveness. For pedagogic reasons we follow Allan et al. (2014) in considering the new tax as a single policy introduced in isolation. The focus is therefore on the causal processes directly triggered by the carbon tax itself. This is in contrast to the more common practice in the computable general equilibrium or macro-econometric modelling literature, where a business as usual (BAU) scenario is compared to the macroeconomic outcomes when a set of climate policy instruments, including a carbon tax, are deployed (e.g., see Best et al., 2020; Cunha Montenegro et al., 2019; Dolphin et al., 2020; Guo et al., 2014; Lin and Jia, 2018; Pradhan and Ghosh, 2022; Zhao et al., 2018).

We first introduce an economy-wide (carbon-based) tax on fossil fuels in a simple analytical model, set out in Section 2. Results from this model help to interpret the simulation outcomes produced by our more complex computable general equilibrium (CGE) approach (Sections 3 and 4) and to inform the conclusions drawn in Section 5. Three key economic factors play specific roles in driving or mitigating the types of negative macroeconomic and household impacts of meeting the net-zero commitment. We present these in the context of a range of economic and fiscal policy constraints, including, but not limited to, labour supply, cost-of-living and government budget pressures. The first is price pressures associated with the introduction of a carbon tax, with particular emphasis on the impact on labour costs, which depend on the degree to which workers may resist reductions in real wage rates in the face of increases in the cost-of-living. The second is the vulnerability of the economy to the competitiveness challenge of price responsive export demand. The third is the sensitivity of macroeconomic outcomes to government priorities regarding balancing the public budget, and the extent and way carbon tax revenues are recycled.

With no further policy intervention, decarbonisation action(s) or change in international trade conditions, we find that a unilateral carbon tax introduced across the UK economy will induce negative impacts on key political economy variables. These are a sustained wider-economy contraction, an increase in the consumer price index (CPI), and a loss in producer competitiveness. The main determinant of the nature, magnitude, and distribution of these negative effects is the extent to which workers resist reductions in their real wage rate in the face of cost-of-living pressures. This holds for both for the introduction of broad carbon taxation and how outcomes are affected by revenue recycling.

2. Fundamental insights from a simple analytical model

We begin by using a stripped-down macroeconomic model to illustrate the range of possible impacts of imposing a carbon price in the form of an energy tax. This shows how different macroeconomic conditions can affect energy use and other key economic variables of political concern. It also demonstrates that the economic and environmental implications depend on more than just technological issues over the ease of adoption of less energy intensive techniques. Whilst this very basic model aids comprehension, it abstracts from many key aspects of a modern developed economy. These we attempt to capture via simulation with a more detailed CGE approach in Section 4.

2.1. Basic equations

There are a set of basic equations that apply to all the variants of the analytical model used here. For simplicity, domestic output, Q, is produced using a Cobb-Douglas production function with labour and energy, L and E, as the sole inputs. The Cobb-Douglas production function imposes a unitary elasticity of substitution between energy and labour so that a proportionate change in output can be expressed as the weighted sum of the proportionate change in the two inputs. Using the dot notation to represent proportionate change:

$$\dot{Q} = \alpha\dot{L} + (1-\alpha)\dot{E} \tag{1}$$

The parameter α is the share of output paid to labour, so that $1 > \alpha > 0$. Here, we assume that: energy is the only import, and all energy is imported; that energy is only used in production; and that the foreign price of energy (the only import) is taken to be fixed and is used as the system's numeraire.[1] In all cases we introduce a proportionate energy tax of t_E. This means that the change in the price of domestic output, p_Q, can be expressed as a function of the energy tax and the price of labour to the firm, w^F.

$$\dot{p_Q} = \alpha\dot{w^F} + (1-\alpha)t_E \tag{2}$$

A third key characteristic of the Cobb-Douglas production function is that the share of output going to each input does not vary as the price of the inputs vary. This means that:

$$\dot{L} + \dot{w^F} = \dot{E} + t_E = \dot{Q} + \dot{p_Q} \tag{3}$$

It is also useful, for the labour market and welfare analyses, to track the change in the worker's real wage, $\dot{w}_R$, which is the proportionate change in the nominal wage received by the worker, w, minus the proportionate change in the domestic price level. Using Eq. (2), this means that:

$$\dot{w_R} = \dot{w} - \left(\alpha\dot{w^F} + (1-\alpha)t_E\right) \tag{4}$$

A key aspect of the model is the impact of the change in price competitiveness on the value of exports, X, which, again using Eq. (2), is given as:

$$\dot{X} = (1-\eta)\left(\alpha\dot{w^F} + (1-\alpha)t_E\right) \tag{5}$$

In eq. (5), the parameter η is the price elasticity of demand for exports. Where $\eta < 1$, so that export demand is inelastic, the total revenue from exports increases as the price of exports, which solely comprise domestic production, rises. If $\eta > 1$ total export revenue will fall as domestic prices rise.

If an energy tax is introduced and the price of labour remains unchanged, labour will be substituted for energy in domestic production.

[1] The choice of the energy price as numeraire is purely for analytical convenience. The labour market analysis is always presented in terms of the real wage.

There will also be an increase in the price of domestic output which affects the ability to export and therefore also to import energy. This typically requires adjustments in the labour market to bring the demand and supply of energy back into equilibrium. But such changes will impact the real wage and/or employment and therefore real household income, generating potential labour market and ballot box pushback. It is this set of inter-related issues we tackle here.

2.2. Labour market

We investigate three recycling options, and a labour demand curve can be derived for each using the basic equations outlined in Section 2.1. For a given energy tax, these curves show the relationship between the change in employment and the change in the real wage. However, their construction requires the specification of two additional conditions that differ across the three recycling scenarios. One is the link between the change in wage paid by the firm (the cost of labour to the firm), $\dot{w}^F$, and the wage received by the worker, $\dot{w}$. The second is the relationship between the change in value of exports and energy imports, $\dot{X}$ and $\dot{E}$. These alternatives are shown in Table 1, together with the three recycling options that we analyse.

For the non-domestic recycling there is no distinction between the wage paid to the worker and the cost of labour to the firm; $\dot{w}=\dot{w}^F$. Also, if the tax is not recycled domestically, then the change in domestic exports must equal not only the change in energy imports but also the energy tax rate, so that $\dot{X} = \dot{E} + t_E$. This is most straightforward if the tax revenue is recycled externally; for example, if the income were donated as aid or as reparations for previous emissions. But even if the revenue is simply not spent, then this equation still must hold given that exports are the only income injection employed in this analytical model.

There are two options for domestic recycling. One involves returning the revenue through lump sum payments to households; the second to recycle through a labour subsidy paid to firms.[2] In both cases the proportionate change in the value of exports simply equals the proportionate increase in energy imports, implying $\dot{X} = \dot{E}$. For the household payments, the wage paid by the firm is the same as that received by the worker but with the labour subsidy the cost of labour to the firm is reduced by a proportionate amount equal to $\frac{1-\alpha}{\alpha}t_E$. This ensures that the aggregate payment to the labour subsidy just equals the revenue raised by the energy tax.

Using eqs. (2), (3), (4) and (5), together with the relationships given in Table 1, we can construct a labour demand curve which gives the change in the level of employment associated with a given change in the real wage. Setting $t_E = 0$ gives the initial labour demand curve, which is:

$$\dot{L} = -\frac{(1-\alpha(1-\eta))}{1-\alpha}\dot{w}_R \tag{6}$$

The term $\frac{(1-\alpha(1-\eta))}{1-\alpha} > 1$ is the elasticity of labour demand with respect to the real wage, given a positive sign. Note that the demand curve is relatively elastic so that a proportionate reduction in the real wage leads to a greater proportionate increase in employment. This implies that a reduction in the real wage produces not only an increase in employment but also in the total real wage income.

Table 1
Recycling assumptions.

$\dot{X} =$		
$\dot{w}^F =$	$\dot{E}$	$\dot{E} + t_E$
$\dot{w}$	Domestic household recycling (DHR)	No domestic recycling (NDR)
$\dot{w} - \frac{1-\alpha}{\alpha}t_E$	Domestic labour subsidy (DLS)	

[2] There are no other taxes in this analytical model so that the change in tax take is solely the revenue raised by the carbon tax. There is also only one form of domestic expenditure, which is household consumption.

The labour market relationships are presented in Fig. 1. The proportionate changes in the employment and real wage are shown on the horizontal and vertical axes respectively. The initial labour demand curve would be represented by a downward sloping straight line, D_0, through the origin. The introduction of the energy tax generates a horizontal shift in this curve. The direction and size of the shift depends on the form of recycling and the size of the tax. For recycling mechanism, R, the generic labour demand curve is therefore:

$$\dot{L}_R = -\frac{(1-\alpha(1-\eta))}{1-\alpha}\dot{w}_R + k_R \tag{7}$$

The constant term, k_R, identifies the intercept with the $\dot{L}$ axis in Fig. 1. The relevant values for the non-domestic recycling (NDR), domestic recycling to households (DRH) and domestic recycling through a labour subsidy (DLS) are:

$$k_{NDR} = -\eta t_E; k_{DRH} = (1-\eta)t_E; k_{DLS} = \frac{t_E}{\alpha} \tag{8}$$

These intercept values represent the proportionate change in employment where the real wage is held constant and are associated with corresponding labour demand curves D_{NDR}, D_{DRH} and D_{DLS}. The accompanying intercepts on the vertical ($\dot{w}_R$) axis are:

$$m_{NDR} = -\frac{(1-\propto)\eta t_E}{(1-\propto(1-\eta))}; m_{DRH} = \frac{(1-\propto)(1-\eta)t_E}{(1-\propto(1-\eta))}; m_{DLS} = \frac{(1-\propto)t_E}{\alpha(1-\propto(1-\eta))} \tag{9}$$

These intercepts give the changes in the real wage where employment is held fixed.

Expressions (7) and (8) identify the labour demand functions which are represented by curves D_{NDR}, D_{DRH} and D_{DLS} in Fig. 1. To complete the labour market analysis, we incorporate a bargained real wage function of the form:

$$\dot{w}_R = \beta\dot{L}_R \tag{10}$$

where $\beta \geq 0$.In this formulation, the proportionate change in the bargained real wage is a linear function of the proportionate change in the employment rate (given a fixed labour force).

In Fig. 1, the wage curve, B, is indicated by a straight line through the origin with a slope of β which represents the elasticity of the real wage

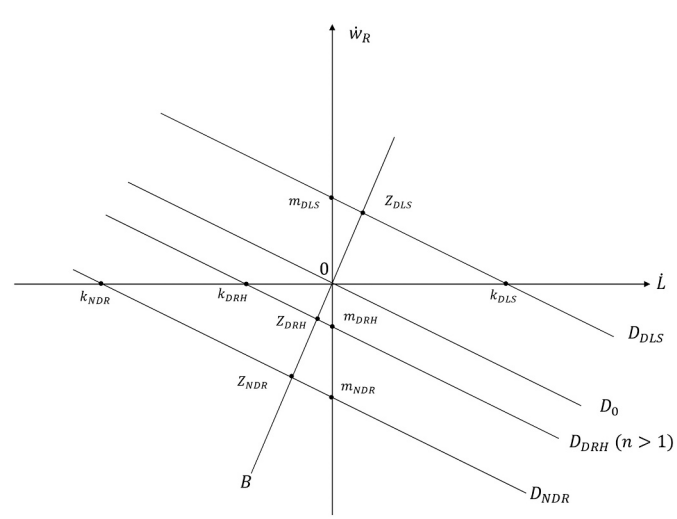

Fig. 1. Labour market outcomes with various recycling options.

with respect to the employment rate. This bargained function (wage curve) is unaffected by the carbon tax. Where $\beta = 0$ the bargaining function is a horizontal straight line; in this case the real wage is fixed at its initial value and workers can resist any reduction in the real wage resulting from the carbon tax. Where $\beta \to \infty$, the bargaining function is vertical, so that the real wage is flexible enough to reinstate the initial employment level after the introduction of the tax. Typically, we expect the β value to lie somewhere between these two extremes.

Combining Eqs. (7) and (10), gives the equilibrium generic changes in employment and real wage after the introduction of the energy tax.

$$\dot{L_R} = \frac{k_R(1-\alpha)}{(1-\alpha)(1+\beta)+\alpha\beta\eta}, \quad \dot{w_R} = \frac{\beta k_R(1-\alpha)}{(1-\alpha)(1+\beta)+\alpha\beta\eta} \tag{11}$$

Note that changes in both the real wage and employment have the same sign as k_R, the shift in the labour demand curve. For pedagogic reasons, for the analytical model we only discuss in any detail results from these two fixed real wage and fixed employment labour market closures.

2.3. No domestic recycling

In this model, the introduction of an energy tax with no domestic recycling always has a depressing effect on the labour market with the labour demand function shifting to the left, as can be seen in Fig. 1. The equilibrium is given as $Z_{NDR,}$ with a reduction in both employment and the real wage.

It is most straightforward to give the analytical results for the fixed real wage case, where price effects are easiest to identify. Competitiveness is reduced, so that the volume of exports falls, and the export revenues here must cover both the imports of energy and the extra tax. In this case, the qualitative responses to the energy tax are not determined by the elasticity of demand for exports but the absolute size of the effects is. Exports, output, employment, and energy use all decline by an equal percentage amount. Real household income, H^Y, which in this case simply comprises wage income, also falls. Although energy use is reduced, this is only through the fall in output; the energy intensity of production does not change. The increase in the nominal wage required to maintain its real value negates any substitution effects on energy use.

If we introduce a wage curve with a positive slope, so that $\beta > 0$, the real wage will fall, so that the labour market moves towards the initial employment level. This results in a more limited decline in economic activity and household income, though these are still below their original values. There is now some substitution towards labour so that energy use and intensity are below their initial levels.

2.4. Domestic household recycling

The results with domestic recycling to households differ from those with no domestic recycling in two ways. First, the income of households now comprises not only income from labour but also the recycled tax revenue. Second, domestic exports only need to finance energy imports valued at external (pre-tax) prices. This second condition means that many of the results now depend qualitatively on the value of the elasticity of demand for exports.

If we again begin by analysing the fixed real wage case, full pass through of the energy tax occurs. Nominal wages and the price of domestic output increase by the same proportionate amount as the price of energy to the firm. As domestic prices rise, if export demand is inelastic (that is, less than unity), total revenue from exports, and therefore total energy imports, will increase. The increased supply of energy then drives a similar proportionate change in output and employment, as there is no substitution of labour for energy in production. However, if export demand is elastic, the reverse occurs. The export revenues, energy imports, domestic output and employment all fall.

If the wage curve takes a positive value, where the export demand is inelastic the nominal wage will now increase by more than domestic prices, there will be some substitution of energy for labour and total real wage income will rise. If export demand is elastic, the real wage will fall and there will be substitution of labour for energy; but even where the initial employment is returned to its original level, domestic output and total wage income will fall. However, the change in real household income is no longer simply the change in total real wage income. It also includes the recycled tax revenues. It is calculated as:

$$\dot{H^Y} = \dot{w_R} + \dot{L} + \frac{1-\alpha}{\alpha} t_E \tag{12}$$

With fixed employment, real household income increases, even where labour income falls. With the fixed real wage, the change in household income is positive if $\eta < \frac{1+\beta}{\alpha\beta}$.

2.5. Domestic labour subsidy

Finally, with the labour subsidy, the real wage and employment both move in a non-negative way so that household income rises. Where the real wage is fixed, the subsidy to labour just offsets the tax on energy in the cost structure of the firm so that the price of domestic output is unchanged. This implies that export revenues are constant so that the use of energy does not change. However, the price of labour to the firm has fallen relative to the price of energy, so that employment, output, and household (labour) income all rise, with a corresponding fall in the energy intensity of production. If the wage curve has a positive slope (again $\beta > 0$), the price of domestic output will also increase. In this case, if export demand is elastic, export revenue and therefore energy use, output and energy intensity all fall, but if it is inelastic, they all rise.

3. CGE modelling approach

3.1. The UKENVI CGE model

We employ UKENVI, a multi-sector economy-wide computable general equilibrium (CGE) model of the UK, calibrated on the 2016 UK social accounting matrix (SAM) incorporating the 2016 UK input-output (IO) tables, the most recently available at the time of the study.[3] We simulate the long-run adjustment of the economy to the introduction of the carbon tax in the form of a tax on the fossil fuel supply sectors assuming no other exogenous changes. To isolate the impacts of introducing the carbon tax, no other changes to exogenous variables or parameters are imposed. Results are generally reported as percentage changes on the initial SAM values.

Our analysis proceeds under various assumptions regarding; the labour market; trade and production substitution responses; whether government prioritises balancing the public budget; and how any additional revenues may be recycled. This section gives a brief overview of the key characteristics, parameter values and closure rules of the model. Section 3.2 outlines the simulation strategy for this paper, including the way the model is adapted to facilitate the introduction of the carbon tax and the various recycling options.

3.1.1. Sectoral/commodity detail

We identify 34 production sectors producing 34 commodities detailed in the Appendix. These include four energy supply sectors: 'Refined Petroleum Products', 'Gas Distribution', 'Coal Extraction' and

[3] See link to the SAM database in the Data Statement. The UK analytical input-output is available at https://www.ons.gov.uk/economy/nationalaccounts/supplyandusetables/datasets/ukinputoutputanalyticaltablesindustrybyindustry.

'Electricity'. The first two are the suppliers of the main fossil fuels, which are subject to the carbon tax.[4]

3.1.2. Production

Each UK industrial sector produces output at minimum costs using a nested constant elasticity of substitution (CES) production function as shown in Fig. 2. The dual cost function determines the price of output, where the carbon tax is applied to the price of domestically produced and imported fossil fuels (basically the non-electricity inputs), which then affects the costs of all production sectors.

Crucially, this enables relaxation of the universal Cobb-Douglas assumption made in the analytical model outlined in Section 2, with inelastic values of 0.3 for the elasticity of substitution between domestically produced and non-produced inputs, and more elastic values (2.0) in the combinations of imported and domestically produced variants of each of the 34 commodities (Armington, 1969). Our simulations abstract from any technological progress so that all substitutions are driven by changes in relative input prices. Going forward, it will be important to investigate the impact of potentially greater elasticities when substituting away from taxed energy use, towards ideally low-carbon electricity (which currently does involve a significant amount of gas use in thermal generation), within the energy nest. However, to deliver real insight this would require policy scenarios regarding (a) how increased substitutability towards electricity would be achieved; (b) how a lower carbon mix of electricity generation may evolve. In the absence of information to inform such scenarios, we do not include this is in the sensitivity analysis in Section 4.

3.1.3. Labour market

We impose a fixed national labour force which comprises the sum of the employed and unemployed workers in the base year data. We do not model skills or sector-specific competencies and assume perfect mobility between sectors. In our central (reference) labour market closure the real take-home wage is determined by a bargaining function, where the post-tax wage rate is inversely related to the unemployment rate (Blanchflower and Oswald, 2009):

$$ln(w_R) = \omega - \varepsilon ln(u_t) \tag{13}$$

In our model, the starting unemployment rate is 5% while ε, the elasticity of wages related to the unemployment, is set at 0.113 (Layard et al., 1991). Under our fixed labour force assumption, the bargaining function can be reformulated so that it links the changes in real wage to the changes in employment:

$$\dot{w_R} = 2.1\,\dot{L} \tag{14}$$

We also model a key alternative case in which we enforce a fixed post-tax real wage. This implies 100% pushback by workers against any price increases resulting from the energy tax. Long-run conditions do not require full employment with the level of unemployment adjusting to ensure labour market equilibrium.[5] Thus, in all our scenarios there can be long-run overall job gains or losses, with the implication that employment will typically vary as labour demand varies.

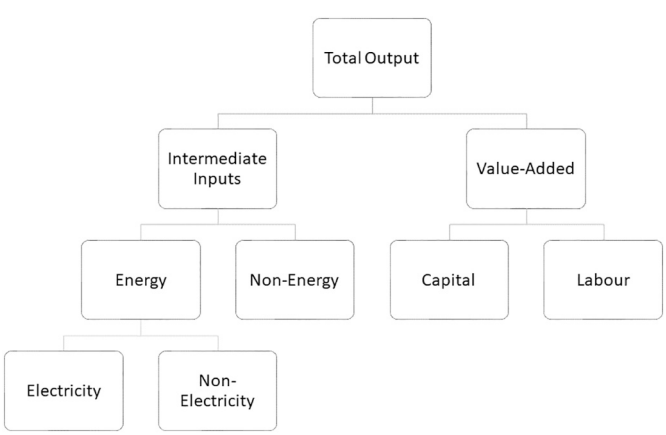

Fig. 2. Representative CES production function.

3.1.4. Savings and investment

Domestic savings rates are given as an exogenous share of household income. Investment is forward-looking, depending on exogenous depreciation and interest rates, set in exogenous markets, and quadratic adjustment costs. Thus, in each sector the actual capital stock gradually adjusts to its desired level, which is a function of sectoral output and relative input prices. Specifically, we follow Hayashi (1982) treatment of investment, meaning that producers anticipate demands and prices across all timeframes, determining the optimal investment pattern to maximise the value of the firms. We present results from running the dynamic model forward and focussing on the resulting long-run equilibrium outcomes when gross investment in each sector just covers depreciation.

3.1.5. Trade

UK exports to an exogenous rest of the world (ROW) region are sensitive to changes in relative domestic and foreign prices and are modelled through a constant elasticity of transformation (CET) function on the output of each production sector. A default, relatively elastic, value of 2.0 is used and reduced in sensitivity analyses to broadly consider the implications of any reduction in the relative competitiveness impacts of higher UK prices. Domestically produced commodities and imports are assumed to be imperfect substitutes, with producers and consumers choosing between and using a combination of both under an Armington (1969) assumption, imposed at commodity level. The initial price of foreign commodities effectively gives the model numeraire. Imports prices are fixed for most sectors/commodities, apart from imported energy, which is subject to the carbon tax.

3.1.6. Household consumption

Household expenditure is determined after deducting taxes and savings from household income. In our scenarios, the key drivers of changes in household real incomes and purchasing power are earnings from employment and taxes paid to government. Household income also includes income from capital and transfers, where transfers from the government are fixed in real terms so that their nominal values adjust with changes in the CPI. We identify five household quintiles based on their gross income. Both the composition of income sources and the pattern of spending vary across the income quintiles.

Households consume (domestic and imported) goods and services using a nested consumption function in a similar manner to that in production. See Fig. 3.

Again, default values are relatively inelastic and, as in the production case, we do not explore the implications of the sensitivity of results to these values in the absence of information on policy scenarios that may increase substitutability in favour of lower carbon electricity options.

[4] The 'Coal Extraction' sector directly supplies both intermediate and final users, but the quantities involved are extremely small. We do not apply the carbon tax to coal production or its use. This is due to the distortive effects when this industry's activity is very quickly driven to zero.

[5] The base-year unemployment rate is 5%, in line with ONS data, where annual unemployment data are reported at: https://www.ons.gov.uk/employmentandlabourmarket/peoplenotinwork/unemployment/timeseries/mgsx/lms

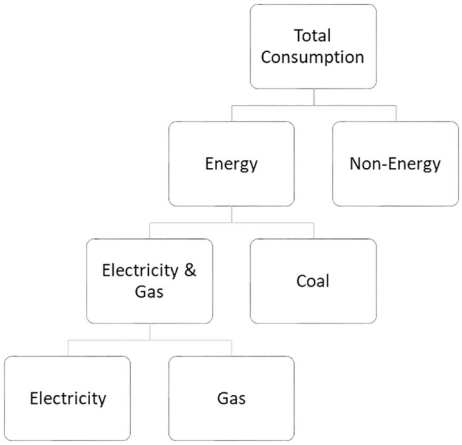

Fig. 3. Representative CES consumption function.

3.1.7. Government

Real government spending is fixed and determined exogenously, so that its nominal value only adjusts for changes in the government price index. The public budget is determined by a range of endogenous revenue sources and can be constrained to balance or not, with the latter allowing an accumulation of public surpluses or deficits, as explained in the next sub-section. To isolate the impacts associated with the introduction of the carbon tax, we constrain the government budget to balance to the initial (deficit) situation reflected in the SAM database and report net impacts relative to that base.

3.2. Simulation strategy

The carbon tax is introduced via the output price of the two fossil fuel supply/distribution sectors - 'Refined Petroleum Products' and 'Gas Distribution' - and corresponding imports (assumed to be of the same quality, generating the same level of emissions when used). The tax rate is determined by the average emissions generated when these fuels are used, imposing a low-to-mid range carbon price of £50 per tonne of CO_2. The average emissions intensity in use of each of these broad fuel types is estimated using data from the 2018 release of the BEIS Digest of United Kingdom Energy Statistics (DUKES).[6] The £50 per tonne tax rate is inputted to the model at the rates of 45p and 16p per £1 respectively for 'Refined Petroleum Products' and 'Gas Distribution'.

In our central, default case, we assume that the labour market is characterised by a wage curve and that the government accumulates the revenue from the carbon tax in the government budget, with no revenue recycling. The net impact on the budget in this case depends on changes in the level of other tax revenues as the economy adjusts to a new long-run equilibrium.

The main sensitivity analysis involves considering the effect of increasing the worker push-back by introducing real wage resistance in the labour market. Given the importance of competitiveness impacts where costs of all producers rise, we also examine the impact of reducing our (relatively elastic) default export elasticity values. We also consider cases where government balances the public budget in real (and absolute) terms over the long-run through endogenous changes in either the domestic income tax rate or elements of government spending. We do not formally hypothecate carbon tax revenues for recycling; rather considering adjustment to the net change in revenues and reactions that may be appropriate given the incidence of the carbon tax.

This allows us to build on the insight of the analytical model in Section 2. In the analytical model, there is only one form of domestic expenditure, which is private consumption. In the CGE we can produce a pure demand stimulus by either changing public expenditure or household income. First, we consider equal lump sum transfer to all household quintiles totalling any excess of revenues generated by the carbon tax over losses in revenues from other sources. This will allow some recovery of the disposable income of households and impacts household consumption. It goes partway to address the perceived problem that a carbon tax would be regressive, as lower income households spend a larger proportion of their income on energy. Second, the net revenues can be used simply to expand public expenditure.

Our second approach is to recycle any net gains in government revenues through adjustments of the income tax rate. In the CGE model any reduction in the income tax rate acts in a manner similar to introducing a subsidy to labour. That is, under the labour market options we consider, while the income tax is levied on the gross real wage, the crucial impact is what happens to the real take-home/post-tax wage. In scenarios where the introduction of the carbon tax does generate a net surplus, and we balance through an endogenous change in the income tax rate, this will allow some recovery of the real post-tax wage to be attained while reducing the gross wage paid by the firm. On the other hand, in scenarios where the introduction of the carbon tax leads to a net deficit, effective negative recycling occurs, with an increase in the income tax rate faced by workers.

4. CGE modelling results and discussion for the UK case

The CGE approach permits simulation of the macroeconomic impacts of a carbon tax using a more complex and detailed model than the one outlined in Section 2. The imposition of the carbon tax increases the price of fossil fuels to all users, where energy is supplied both domestically and imported. This directly and indirectly impacts output prices across the economy, including the domestic 'Electricity Generation and Supply' sector, where there is a strong indirect effect through the increased price of UK gas-powered generation.

4.1. The central (default) case: No domestic recycling of revenues (NDR) and a bargained real wage

As in the analysis in Section 2, our starting point is a simulation in which there is no domestic recycling (NDR) of the carbon tax revenues which simply accumulate in the public budget balance. The real wage is determined by a bargaining function (wage curve) where the real wage moves in line with labour demand. Further, all trade elasticities take the value of 2.0 in this central case. This is the central (default) case and the results are reported in the first data column of Table 2.

The mechanism is straightforward. In line with the analytical results in the Section 2, with no domestic recycling the labour demand curve shifts to the left. This leads to a new equilibrium, such as Z_{NDR} in Fig. 1, where in this simulation the real wage and employment fall by −1.27% and − 0.63% respectively. The fall in the real wage is decomposed into a nominal take-home wage reduction of −0.47% and a CPI increase of 0.81%. Results represented by the first bar in the columns in Fig. 4 indicate percentage price increases in all sectors. The price of output in the two domestic fossil fuel supply sectors directly affected by the imposition of the carbon tax are shown separately and are extremely high. The price of the relatively gas-intensive UK electricity sector also increases substantially more than the 0.81% rise in the CPI, which gives the average price level faced by UK consumers. In addition, note from Table 2 that the 0.87% and 0.85% increases in corresponding composite price indices for consumption bundles purchased by the two lowest household income quintiles (HG1 and HG2), where a greater share of spending goes to energy, exceeds the general CPI increase.

In all the simulations we assume that the UK acts alone in introducing the new carbon tax, so that domestic producers lose international competitiveness. In this default central case, rising UK prices trigger a −1.13% contraction in export demand and a slightly smaller income

[6] The DUKES dataset is available here: https://www.gov.uk/government/statistics/digest-of-uk-energy-statistics-dukes-2018-main-report

Table 2
Percentage long-run changes (relative to 2016 SAM data) in key macroeconomic variables due to the introduction of the carbon tax (different government budget and revenue recycling options).

		Bargained Real Wage				Fixed Real Wage		
			Balanced budget (BB)				Balanced budget (BB)	
		Central case (NDR)	Income tax adjusts	All govt. spend adjusts	Lump sum transfer to households	NDR	Income tax adjusts	All govt. spend adjusts
GDP		−0.84	−0.55	−0.69	−0.70	−2.13	−3.65	−2.60
Consumer price index		0.81	0.93	1.12	1.02	2.03	2.78	2.03
Gross nominal wage rate		−0.47	−0.22	0.15	−0.04	2.03	3.57	2.03
Post-tax nominal wage rate		−0.47	0.20	0.15	−0.04	2.03	2.78	2.03
Gross real wage rate		−1.27	−1.14	−0.95	−1.05	0.00	0.77	0.00
Post-tax real wage rate		−1.27	−0.73	−0.95	−1.05	0.00	0.00	0.00
Unemployment (% change on rate)		11.94	6.66	8.83	9.81	38.43	68.32	48.05
Employment		−0.63	−0.35	−0.46	−0.52	−2.02	−3.60	−2.53
Total investment		−1.07	−0.73	−0.94	−0.87	−2.20	−3.69	−2.61
Exports		−1.13	−1.36	−1.71	−1.52	−3.41	−4.74	−3.40
Imports		−1.06	−0.45	−0.55	−0.48	−0.50	−1.19	−0.87
Total energy consumption		−7.63	−7.17	−7.42	−7.25	−8.26	−9.57	−8.62
Total CO_2 emissions		−12.67	−12.26	−12.49	−12.37	−13.33	−14.58	−13.66
Total consumption of taxed fuels		−12.75	−12.33	−12.56	−12.42	−13.35	−14.59	−13.69
HOUSEHOLD IMPACTS								
Total real household spending		−1.22	−0.48	−0.93	−0.61	−1.49	−3.05	−1.84
Household disposable income	HG1	−1.00	−0.71	−0.79	0.06	−1.28	−2.02	−1.56
	HG2	−1.02	−0.60	−0.77	−0.24	−1.20	−2.10	−1.49
	HG3	−1.28	−0.67	−0.98	−0.65	−1.54	−2.85	−1.90
	HG4	−1.38	−0.60	−1.05	−0.80	−1.64	−3.25	−2.04
	HG5	−1.22	−0.18	−0.93	−0.77	−1.52	−3.65	−1.89
Composite price of consumption faced by each household income quintile	HG1	0.87	0.99	1.17	1.07	2.07	2.79	2.07
	HG2	0.85	0.96	1.15	1.05	2.04	2.77	2.04
	HG3	0.80	0.92	1.10	1.01	2.02	2.75	2.01
	HG4	0.78	0.90	1.08	0.99	2.00	2.75	2.00
	HG5	0.73	0.85	1.04	0.94	1.98	2.74	1.98
Household energy spending		−9.37	−8.71	−9.03	−8.72	−9.32	−10.48	−9.63
Household spending on taxed fuels		−19.06	−18.44	−18.75	−18.49	−18.96	−20.00	−19.24

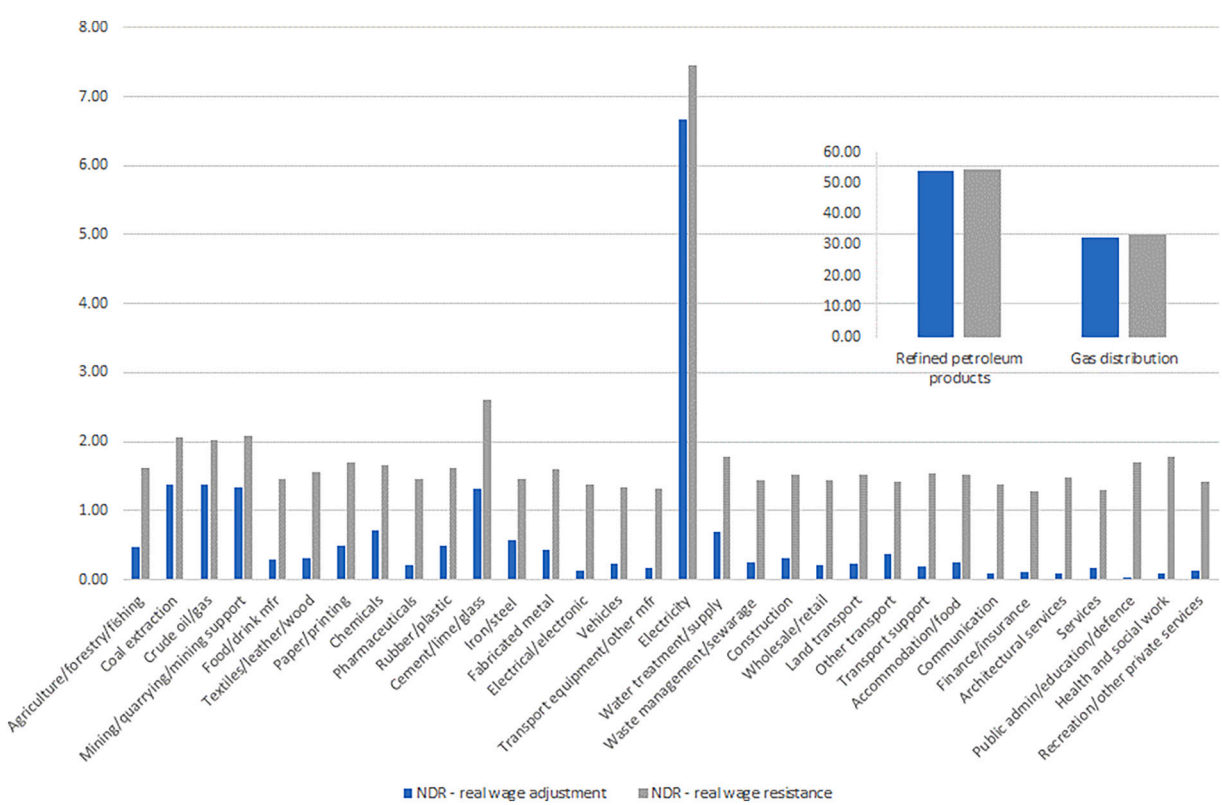

Fig. 4. Long-run percentage change (relative to 2016 SAM data) in the output price of all UK sectors following the introduction of the carbon tax - NDR case with labour market sensitivity.

driven −1.06% net decrease in imports. The consequent reduction in activity in all UK production sectors contributes to falls of −1.07% in total investment and − 0.84% in GDP. UK real household spending contracts by −1.22%, driven by the combination of the fall in employment and decrease in the real wage, along with reduced income from domestic capital. These macroeconomic effects dominate in determining the real income and spending impacts for the lowest two income quintiles, where the cushioning impacts provided by government transfers - which adjust for the increase in the CPI to sustain their initial real value – are particularly important, and the overall real disposable income impact becomes broadly progressive.

The impacts of the new carbon tax on government revenues for the central, wage bargaining case are given in the first data column of Table 3. The nominal direct revenues raised from the tax are £12.13 billion, which comprises £9.93 billion on domestic production and £2.20 billion on imported fuels. However, the net government budget surplus is only just over one third of this figure. This is the result of two main factors. The first is the £4.94 billion reduction in other government tax revenues as aggregate economic activity falls. The second is the required £3.12 billion nominal increase in the cost of government expenditure and transfers to maintain real spending as prices faced by government rise.

The −7.63% reduction in total spending on energy (not limited to fossil fuels) is around 9 times the contraction in GDP, even with limited (inelastic) substitution possibilities away from the taxed energy use. This reflects substitution away from taxed fossil fuel use, which falls by −12.75%. In terms of CO_2 emissions, there is a proportionate reduction of 12.67%, indicating that the emissions reduction is driven by the lower use of the taxed fossil fuels.

4.2. No domestic recycling (NDR) with real wage resistance

In our simulations, the change in competitiveness following the introduction of the carbon tax is a key determinant of the macroeconomic outcomes. An important driver of the price changes associated with the tax is the real wage adjustment in the labour market. The right-hand side of Table 2 shows the simulation results where we replace the bargained real wage with a fixed real wage – i.e., where we assume full pushback by workers to increased consumer prices. The results with default elasticities and no revenue recycling are given in the fifth data column. The −2.13% fall in GDP is over two and a half times the central case decline under wage bargaining.

The reason is straightforward. Under bargaining, as identified in Section 4.1, the nominal wage falls by −0.47%, along with the 0.81% increase in the CPI, in the −1.27% reduction in the real wage. However, with the fixed real wage, the nominal wage increases by 2.03% to match the rise in the CPI. The successful attempt to maintain the prevailing real wage rate sets in train a price multiplier process. The impact on the prices for individual sectors in this case is shown by the second bar in Fig. 4. Not surprisingly, the price increases in the non-energy sectors are now much higher with labour intensive sectors affected most. Service sectors with a low energy intensity therefore experience the biggest difference in their price change across the two labour market options.

Where there is real wage resistance, the greater impact on UK output prices triggers a substantially greater, −3.41%, contraction in export demand and increased import dependence. This drives a − 2.02% reduction in employment with the result that, despite the maintenance of the pre-shock real wage rate, all households are worse off under real wage resistance case; this reflects the relatively elastic long-run labour demand. With the bargained real wage, there is a fall of −1.22% in household consumption whilst under the fixed real wage, it falls by −1.49%. The increase in the nominal wage also slightly reduces the substitution effect of the carbon tax, so that the decrease in fossil fuel and wider energy intensity of GDP is also reduced. We emphasise again that in our simulations the UK acts alone in introducing the new carbon tax. Further, all types of energy are produced inputs. This implies that the price of domestically produced energy will rise more than otherwise-comparable energy imports as rising prices across the UK economy feed back into energy supply costs. As a result, the overall energy consumption, and consumption of taxed fuels, falls more than in the case of real wage bargaining, leading a slightly larger reduction in CO_2 emissions (13.33%).

4.3. Impacts of recycling the net revenues with a bargained real wage

It might be that the carbon tax is introduced with strict hypothecation. That is, to increase the public's acceptance of the carbon tax, the government might commit to spend all of the revenue the tax raises in a specific way. However, we have two reasons for not simulating such an approach. First, there is no evidence that the UK Government would adopt such a strategy; in general HM Treasury resists such schemes. Second, as should be apparent from the results shown in Table 3 and discussed in Section 4.1, to earmark all the carbon tax revenues would increase the overall budget deficit. If the government were committed to a prior budgetary target, this would typically imply a further fiscal adjustment, which overly complicates the analysis. However, it may be appropriate to consider that the government would use the net revenues raised by the tax in ways which could address some of the potential negative impacts associated with such a tax that have been identified in the ongoing public debate over net-zero policies.

We therefore analyse how outcomes are affected if recycling applies to the net revenues gained after introducing the carbon tax. We consider three forms of recycling. In the first we reduce the rate of income tax, the impact of which is identical to a labour subsidy under real wage bargaining. This form of recycling has both demand and supply-side implications. The other two options consist of alternative demand shocks. In the first, we simply increase the level of existing government expenditure. In the second, the government makes an equal lump sum income transfer to all households. For the bargained real wage, these results are shown in data columns 2 to 4 in Table 2.

We begin by analysing the impact of recycling the net revenue through a reduction in the income tax rate. The long-run outcomes are reported in the second data column of Table 2. With the introduction of the income tax cut, two broad issues are involved. The first is the initial incidence of the tax reduction. The second is the subsequent macroeconomic impact. The incidence of the tax reduction is typically shared between a reduction in the cost of labour to the firm, which is then passed on to the consumer, and an increase in the take-home income of the worker. The division will depend on the relative slopes of the labour demand and the wage curve, as discussed in the context of the simple analytical model in Section 2, where we take two extreme examples. In the first the wage curve is horizontal; there is a fixed real wage so that the reduction is reflected solely in the price of labour to the firm, which falls by the full amount of the tax. Essentially the tax benefits the consumer and exports. In the second case the labour force is fixed. This implies a vertical wage curve; employment is independent of the real wage. In this case the tax reduction is captured wholly by the worker, whose real wage will increase by the full amount of the tax.

In our CGE model, adopting the central case bargaining function brings us closer to the fixed employment case; the labour demand is relatively elastic and the wage curve inelastic. With our econometrically parameterised bargaining function the real wage must increase by just over 2% if employment is to rise by 1%. This means that much of the tax goes to increasing household income. This relative increase in consumption then has a macroeconomic impact as the expansion in domestic expenditure further increases employment, and real and nominal wages. It is useful to compare the results in data column 2 of Table 2 with those in data column 1. Ultimately, total household consumption falls by −1.22% in the no recycling scenario, but by only −0.48% with the income tax reduction. Any fall in the price of labour to the firm is now over-written so that the CPI increases and at 0.93% is above the level with no recycling. The reduction in income tax therefore reduces,

Table 3
Long-run changes (£million) relative to 2016 SAM values in government spending, revenues and net budget balance due to the introduction of the carbon tax - under different government budget balancing assumptions.

	Bargained Real Wage				Fixed Real Wage		
	No constraint	Balanced budget (BB)			No constraint	Balanced budget (BB)	
	Central case (NDR)	Income tax adjusts	All govt. spend adjusts	Lump sum transfer to households	NDR	Income tax adjusts	All govt. spend adjusts
Government budget balance	4067	0	0	0	−2428	0	0
Real government spending	0	0	5126	4796	0	0	−5039
Nominal government spending	3120	4163	10,927	9725	13,759	20,237	8624
Carbon tax revenues	12,127	12,180	12,149	12,165	12,040	11,877	11,997
Other UK tax revenues	−4940	−8016	−1221	−2441	−709	8360	−3373

rather than increases, competitiveness, with exports falling even more than with the no recycling option.

Basically, in reducing income tax we introduce a supply-side shock with demand side implications. An obvious alternative form of recycling is to increase general government expenditure. The existing pattern of UK government spending is less import-intensive that household consumption, so that high positive multiplier effects may be anticipated in a public spending-led recovery. Again, it is appropriate to compare the results in data column 3 of Table 2 to those in data column 1 to gauge the additional impact generated by the demand stimulus.

Although there is a strong demand stimulus, here we observe significant crowding out as government expenditure increases. The gross nominal wage rate faced by producers is now 0.15% above its initial value and the CPI increases by 1.12%, 0.31% greater than the level with no recycling. The further decline in competitiveness means that exports fall by −1.71% and though household spending is above the no recycling value, it is less than under the income tax reduction. GDP and employment are stimulated by the additional expenditure but again this is less than with the income tax cut.

A final simulation where budget surplus is recycled via a pure demand stimulus is activated through an equal lump sum transfer to all UK households. This directly (but only partially) compensates for the negative impacts of the carbon tax on real household spending. The results of this scenario are presented in the fourth data column of Table 2. In terms of the aggregate macroeconomic impact, it is the least effective of the three recycling mechanisms, with the change in GDP and employment at −0.70% and − 0.52% respectively. The transformation of household income to domestic expenditure requires savings and imports to be removed, reducing the positive impact of the domestic stimulus. Even for aggregate real household expenditure it performs less well than the reduction in income tax. However, it has positive distributional characteristics.

4.4. Distributional effects of recycling revenues with wage bargaining

A primary concern in carbon- and wider energy-pricing debates is the likely household distributional impacts given that expenditure on energy makes up a higher proportion of the budget of low-income families. Although we have mentioned distributional issues in the earlier discussions, we focus more closely on these now. Consider the results in the first data column of Table 2, which identifies the change in the composite price of consumption for the different household quintiles where there is no recycling. Whilst the aggregate CPI increases by 0.81%, for the lowest income quintile, HG1, the figure is bigger, at 0.87%, and the figure declines continuously as household income increases so that for the highest income households, HG5, it is only 0.73%. Because lower income households spend a larger proportion of their income on energy, the impact of a carbon tax has the biggest impact on their cost of living.

However, to concentrate solely on the price effect of the tax is to take a very partial approach. It is important also to see how the tax would affect the incomes of different household types. Table 2 also reports real household disposable income broken down to income quintiles. Note that without recycling, the simulated real income effects are broadly progressive. Although real income falls for all households, the lowest income quintiles HG1 and HG2 are affected the least and the negative impacts generally get larger as household income increases. The primary reason is that lower income households are more dependent on government transfers whose real value is held constant. However, the real value of other income sources is falling.

As was clear from Section 4.3, with the bargained real wage all the forms of revenue recycling offset some of the reduction in aggregate household consumption, but what happens to the distribution across household income quintiles? Consider first the reduction in income tax. This gives the largest stimulus to aggregate household income, but its impact is fiercely regressive. Comparing, the figures in the first and second data columns of Table 2, note that the lowest household income group, HG1, receive a 0.30% increase from the cut in income tax, while at the other extreme, this is 1.10% for the highest, HG5. This simply reflects variation in the relative importance of wage income across the household income distribution.

However, whether or not the outcome is regressive is not the only question. Compare the third and second data columns of Table 2. The distributional effects of increasing government expenditure, as compared to the income tax reduction, are less regressive; however, households in all quintiles are less well off, in terms of the recovery of their real incomes. Of course, policymakers will also consider how increasing government expenditure will improve the supply of public goods, which is likely to increase household welfare across the board. However, a more clearly progressive form of recycling is through the lump sum household payment option reported in the fourth data column in Table 2. Of the three recycling options, this gives the best outcome in terms of real income/spending for households HG1, HG2 and HG3 which are in the lowest 60% of the income distribution. Indeed, with the combined carbon tax and lump sum redistribution we observe the first gain in household real income, and this is in the lowest quintile, where it is 0.06% greater than before the carbon tax was introduced. Such outcomes suggest that a lump sum transfer approach may be favoured by the electorate, despite the income tax recycling delivering better overall outcomes.

4.5. Recycling with the fixed real wage

For the outcomes where there is real wage resistance in the labour market, shown in the final two columns of Table 2, the discussion around the macroeconomic and distributional impacts of recycling is completely different for two key reasons. First, as identified in Section 4.2, if there is labour market pushback, net revenues fall by £2.4billion with the introduction of the carbon tax. This loss in revenue is primarily

due to the accompanying price rises that increase the nominal cost of government expenditure and transfers. This means that if the government balances the budget it needs to increase income tax or reduce government expenditure, thereby exacerbating the negative impact on economic activity. The second issue is that the response of the economy to changes in tax and expenditure under a fixed real wage is quite different to that where there is a bargained real wage.

The sixth data column of Table 2 reports the results of imposing a balanced government budget through endogenous income tax adjustment where there is real wage resistance. In contrast to the positive recycling case with real wage adjustment, which delivered the best economic outcomes so far (apart from the impact on the UK's trade balance, and a slightly more limited reduction in CO_2 emissions), this delivers the worse economic (but best emissions) outcomes across all our scenarios. Crucially, in this case with a fixed real wage the wage curve is horizontal. The initial incidence of any change in income tax is therefore wholly borne by the firm, and then ultimately the customer. The increase in the income tax adds an additional 1.54% to the nominal cost of labour to the firm, and an increase of 0.75% to the CPI. Exports fall by a further −1.33% so that there are significant further falls in GDP and employment of −1.52% and − 1.58% respectively. With a rise in the income tax, the outcome across different household income groups becomes progressive, but with the greatest losses observed so far in all quintiles.

The final column of Table 2 shows that reducing government spending would be a preferable outcome where real wage resistance has led to a deficit outcome and government prioritises balancing the budget. In this case there is no change in prices, so that the level of exports is unaffected. The impact comes purely from the direct reduction in public sector activity and subsequent negative indirect and induced multiplier effects. The additional reductions in GDP and employment are −0.47% and − 0.51% respectively. Crucially, in this case with no additional wage or CPI pressure in the system so that the additional costs of balancing the public budget can be offset through reduced domestic consumption (by government and households) without further distortions impacting the competitiveness of UK producers. However, the picture is mixed as to whether outcomes could be considered progressive and the reduction in spending on public services will have negative welfare impacts for all households.

4.6. The sensitivity of NDR outcomes to variation in the export elasticity

A primary cause of the fall in economic activity accompanying the introduction of a carbon tax is the loss of competitiveness that it generates. Fig. 4 shows that for the central/default case, domestic prices increase (relative to foreign prices) in all sectors, with the associated results reported in Table 2 indicating a 0.81% increase in the CPI and a 1.13% reduction in exports. This, together with associated multiplier effects, generates falls in GDP, investment, employment and real household income ranging between −0.63% and − 1.22%.

In the central simulation export demand is elastic, taking the value of 2. Here, we test how sensitive the results are if we make export demand less responsive to price changes, by reducing the elasticity value first to 1.1 and then 0.5. We also investigate the role of the wage setting procedure in affecting this sensitivity by repeating these simulations under the fixed real wage closure.

The results are shown in Table 4, beginning with the results with the bargained real wage. As export demand becomes more inelastic, the volume of exports still falls, but the reductions are more limited; export volumes decline by −1.13%, −0.77% and then −0.41% as the export elasticity goes from 2.0, through 1.1 to 0.5. All measures of economic activity follow a similar, though generally more muted, pattern. For example, the corresponding changes in total real household income/spending are −1.22%, −1.12% and − 1.03%. Although the negative export shock is being reduced by the lower price sensitivity, the depressing impact of higher taxes without corresponding increased

Table 4
Changes in key macroeconomic variables and net changes to the government budget due to the introduction of carbon tax - NDR case varying wage determination and export elasticities.

		Bargained Real Wage			Fixed Real Wage		
			Export elasticity			Export elasticity	
		Central case (NDR) 2.0	1.1	0.5	NDR 2.0	1.1	0.5
GDP		−0.84	−0.77	−0.70	−2.13	−1.59	−1.21
Consumer price index		0.81	0.88	0.96	2.03	2.02	2.01
Gross nominal wage rate		−0.47	−0.31	−0.14	2.03	2.02	2.01
Post-tax nominal wage rate		−0.47	−0.31	−0.14	2.03	2.02	2.01
Gross real wage rate		−1.27	−1.18	−1.09	0.00	0.00	0.00
Post-tax real wage rate		−1.27	−1.18	−1.09	0.00	0.00	0.00
Unemployment (% change on rate)		11.94	11.08	10.19	38.43	28.78	22.20
Employment		−0.63	−0.58	−0.54	−2.02	−1.51	−1.17
Total investment		−1.07	−0.98	−0.89	−2.20	−1.63	−1.23
Exports		−1.13	−0.77	−0.41	−3.41	−1.94	−0.90
Imports		−1.06	−0.72	−0.38	−0.50	0.20	0.70
Total energy consumption		−7.63	−7.43	−7.26	−8.26	−7.69	−7.29
Total CO_2 emissions		−12.67	−12.36	−12.09	−13.33	−12.65	−12.14
Total consumption of taxed fuels		−12.75	−12.58	−12.42	−13.35	−12.82	−12.44
HOUSEHOLD IMPACTS							
Total real household spending		−1.22	−1.12	−1.03	−1.49	−1.09	−0.81
	HG1	−1.00	−0.92	−0.84	−1.28	−0.95	−0.72
	HG2	−1.02	−0.94	−0.85	−1.20	−0.87	−0.65
Household disposable income	HG3	−1.28	−1.18	−1.08	−1.54	−1.13	−0.85
	HG4	−1.38	−1.27	−1.16	−1.64	−1.20	−0.90
	HG5	−1.22	−1.12	−1.02	−1.52	−1.11	−0.83
	HG1	0.87	0.94	1.02	2.07	2.06	2.05
	HG2	0.85	0.92	1.00	2.04	2.03	2.02
Composite price of consumption faced by each household income quintile	HG3	0.80	0.87	0.95	2.02	2.00	1.99
	HG4	0.78	0.85	0.93	2.00	1.99	1.98
	HG5	0.73	0.81	0.89	1.98	1.97	1.96
Household energy spending		−9.37	−9.23	−9.10	−9.32	−8.92	−8.65
Household spending on taxed fuels		−19.06	−18.91	−18.76	−18.96	−18.57	−18.30

government expenditure is still present.

The qualitative distributional effects are unaffected, with the pattern of quintile price and income changes remaining unchanged. Also, the fall in energy consumption, CO_2 emissions and consumption of taxed fuels are slightly reduced with the lower demand elasticity but essentially these values are very stable.

The simulations outcomes with a fixed real wage are reported in the final three columns of Table 4. Where the real wage does not adjust to variations in labour demand, the impact of the tax on domestic prices is much greater, as already shown in Fig. 4 and reflected in the 2.13% increase in the CPI shown in column 4 for the default export elasticity of 2. Here the decline in exports is −3.41%, but this falls to −1.94% and −0.90% as the elasticity is reduced. Again, the energy consumption outcomes are relatively stable across different export elasticities and the qualitative characteristics of the price and income distribution across households is unchanged.

5. Conclusions

This paper has presented fundamental macroeconomic and more complex computable general equilibrium analyses that begin to consider how the introduction of broad carbon taxation might affect key macroeconomic indicators. Further research is clearly required, not only to further developing understanding of the key principles and mechanics governing the impacts of introducing broad carbon taxation, but also to explore the dynamic impacts of potential national policy scenarios. Nonetheless, five fundamental findings emerge from our initial analysis.

First, where a small open economy is an independent adopter of a carbon tax, all our scenarios point to negative effects on average household real income and the competitiveness of domestic producers.

Second, while our results demonstrate that the direct, indirect, and induced price impacts of introducing a carbon tax are regressive – reflecting a key source of political concerns - once the output effects are incorporated the real income impact, though negative, is mildly progressive. Here, our scenario results for the UK show that real income in all quintiles will fall, but the negative impact to those on the lowest incomes is cushioned by the maintenance of the real value of government transfers.

Third, the size and characteristics of the general equilibrium impact is highly dependent on the nature of the labour market, reflected in the extent of pushback by workers against attempts to squeeze their real wage. Flexibility in the real wage in the face of fluctuations in labour demand limits negative impacts on household incomes. The seemingly paradoxical result occurs because the labour demand curve is real-wage elastic. That is, there is a trade-off between real wage and employment rates, and the nature of this may be a key trade-off for policymakers to consider. There is evidence for bargained real wage (wage curve) relationships for a wide range of regional and national economies, which is why it is our default labour market setting (Blanchflower and Oswald, 2009). However, in the recent past the UK labour market has exhibited a high degree of real wage rigidity; despite low levels of unemployment there has been only limited real wage growth.[7] Thus, actual outcomes, if a carbon tax were to be imposed, may be expected to lie somewhere between the extremes of what our alternative labour market closures suggest.

Fourth, while recycling the revenues cushions the impact of the tax, the net revenue increase is always less than that raised from the carbon tax. This means that hypothecation, in the form of earmarking the carbon tax revenues to either offset costs to some or all economic actors, and/or to enable further emissions reductions, whilst perhaps politically (rhetorically) attractive, would lead to an increase in government borrowing. Therefore, committing the use of the carbon tax revenues to taking action to increase the substitutability away from taxed energy use by, for example, investing in lower carbon electrified heat solutions would be problematic for a government emphasising fiscal responsibility.

Fifth, in the simulations reported here, recycling net revenues never leads to an overall positive outcome in terms of conventionally measured GDP, employment or average household income. Reducing income tax is the option that has the biggest aggregate impact on economic activity. Whilst income tax reductions benefit households in each income quintile by more than recycling through increased government expenditure, they are fiercely regressive. Alternatively, recycling through a flat-rate household payment reinforces the relative income progressivity of the tax with the result that households in the lowest quintile actually experience a net increase in real income over their base year value.

Such findings reflect the challenges faced by policymakers in many practical political economy environments, such as the UK, where cost-of-living concerns currently dominate public and political debate, particularly in the context of wider energy price uncertainty.[8] They emphasise the importance of building understanding of the macroeconomic principles behind, and drivers of, the impacts of introducing the broad taxation of carbon. This is essential if policymakers are to effectively incorporate consideration of the complexity of the trade-offs between measures of household and macroeconomic welfare in the design and implementation of policies to support deep emissions reductions.

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Data statement

The model used in this study is calibrated using a 2016 UK Social Accounting Matrix (SAM), publicly available at: https://doi.org/10.15129/d70468cd-7fcc-4fb4-9a7d-9769a1292834.

Appendix: Industries/commodities identified in our CGE model (by Standard Industrial Classification, SIC)

Sector Number	Sector Name	SIC code
S1	Agriculture, Forestry and Fishing	01–03
S2	Coal and Lignite	05
S3	Crude Oil and Gas	06–07
S4	Other Mining and Mining Support	08–09
S5	Food, Drinks and Tobacco	10–12
S6	Textile, Leather and Wood	13–16
S7	Paper and Printing	17–18
S8	Coke and Refined Petroleum Products	19
S9	Chemicals	20
S10	Pharmaceuticals	21
S11	Rubber and Plastic	22
S12	Cement, Lime and Glass	23

(*continued on next page*)

[7] The evolution of real wages in the UK in the recent past is available at https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/employmentandemployeetypes/bulletins/averageweeklyearningsingreatbritain/october2022.

[8] See House of Commons Library (2022). We also note political actions such as the emergence of a 'Net Zero Scrutiny Group' formed by a group of Conservative Party Members of the UK Parliament. This group questions climate policy by emphasising its link to cost-of-living pressures (see https://www.bbc.co.uk/news/uk-politics-60572049).

(*continued*)

Sector Number	Sector Name	SIC code
S13	Iron, Steel and Metal	24&25.4
S14	Manufacture of Fabricated Metal Products, excluding weapons & ammunition	25.1–3&25.5–9
S15	Electrical Manufacturing	26–28
S16	Manufacture of Motor Vehicles, Trailers and Semi-Trailers	29
S17	Transport Equipment and Other Manufacturing (incl. Repair)	30–33
S18	Electricity	35.1
S19	Gas Distribution	35.2–3
S20	Natural Water Treatment and Supply Services	36
S21	Waste Management and Remediation	37–39
S22	Construction - Buildings	41–43
S23	Wholesale and Retail Trade	45–47
S24	Land Transport	49
S25	Other Transport	50–51
S26	Transport Support	52–53
S27	Accommodation and Food Service Activities	55–56
S28	Communication	58–63
S29	Financial and Insurance Services	64–66
S30	Architectural Services	71
S31	Services	68–70 & 72–82
S32	Public Administration, Education and Defence	84–85
S33	Health and Social work	86–88
S34	Recreational and Other Private Services	86–94

CRediT authorship contribution statement

Karen Turner: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing. **Oluwafisayo Alabi:** Data curation, Investigation, Writing – original draft. **Antonios Katris:** Data curation, Formal analysis, Investigation, Software, Validation, Visualization, Writing – original draft. **Kim Swales:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing.

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