Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Faculty of Natural Resources and Agricultural Sciences

Environmental Policy After Brexit

– How Does the Introduction of a Fossil-Energy Tax Affect the British Economy?

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Abstract

As the United Kingdom (UK) is set to leave the European Union (EU) in 2019, it faces large uncertainties especially with respect to international policy such as climate policies. The UK still has to meet previously agreed upon climate targets but it now has the possibility to abolish EU climate policies and implement different strategies on a national level. These chosen national strategies could be more beneficial to the UK as they are set according to its country-specific characteristics. A proposed strategy is the introduction of a carbon tax on energy sectors. Thus, this study analyses the effect of an ad valorem uniform fossil-energy tax on British energy sectors using a computable general equilibrium model. The envisioned tax is applied at two different levels: production and consumption. The differentiation of a tax according to channels allows to determine where an implementation of the tax would be least distortive to the economy and induce smaller welfare losses. The results found in the analysis confirm the hypothesis by the literature that a tax on producers leads to larger sectoral contractions in total and a larger decrease in welfare. Based on the outcomes, rough policy recommendations can be made. If the British government wants to support the production of green energy it should tax consumers rather than producers as producers might switch to cheaper inputs (i.e fossil fuels) if production costs increase through the introduction of a tax. Moreover, if the British government is interested in preventing welfare losses in form of negative % changes in value of GDP it should implement the tax on a consumer level as well.

Key words: environmental policy, CGE analysis, fossil-energy tax, GTAP, Brexit

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List of Abbreviations

AUD . . . . . . Australian dollars

BMCM . . . . . Basic materials & chemical products

CES . . . . Constant elasticity of substitution

CGE . . . . Computable general equilibrium

ETS . . . . Emission trading system

EU . . . . European Union

EV . . . . Equivalent variation

FOP . . . . Factors of production

GHG . . . . . . Greenhouse gas

GTAP . . . . . . Global Trade Analysis Project

P & c . . . . . . Petroleum & coal

ROW . . . . . . Rest of the world

SAM . . . . . . Social accounting matrix

TFD . . . . Tax on domestic commodity i purchased by firm

TPD . . . . Tax on domestic commodity i purchased by private household

UK . . . . United Kingdom

VDFA . . . . . . Value of firm's purchases at agent price

VDFM . . . . . Value of firm's purchases at market price

VDPA . . . . . . Value of private household's purchases at agent price

VDPM . . . . . Value of private household's purchases at market price

1 Introduction

1.1 Objectives and background

In June 2016, 51.89% of voters in the United Kingdom (UK) voted in favour of leaving the European Union (EU). Following this result, the question emerged how the envisioned exit of the UK out of the EU will take place. As of right now, the UK shares several international agreements with the EU with respect to climate policies. Thus, climate policy in the UK is largely based upon and supports these guidelines and policies set by the EU.

The EU climate policy envisages a at least 40% cut in greenhouse gas (GHG) emissions by 2030 compared with 1990 (European Commission, 2018). Furthermore, key targets with respect to renewable energy and energy efficiency are also defined. To achieve these targets, the EU has various relevant policies and strategies in place. One of the strategies is the set-up of an emission trading system (EU ETS) in order to reduce GHG emissions from an industry at the lowest cost. The EU ETS operates in 31 countries and covers around 45% of the EU's GHG emissions. It is the world's first and largest carbon market and works according to the "cap and trade" system. This means that a cap is set on total GHG emissions emitted by installations covered by the system. To reduce GHG emissions over time, the cap is gradually reduced so that total emissions fall. Companies can buy or receive emission allowances which have to cover their emissions. Additionally, they are also allowed to trade emission permits on the market. At the end of the year, total emissions emitted by the company must be covered by its emission permits. If there is an imbalance between emissions emitted and emission permits owned by the company, a heavy fine must be paid. This EU trading scheme provides a great deal of flexibility and allows to cut emissions where it is most cost-effective (European Commission, 2018).

1.2 The problem

As the UK decided to leave the EU, the opportunity arises to choose different actions on a national level to hinder climate change. This possibility poses an enormous challenge for the UK at the same time. Currently, the UK implements a carbon price floor to support the EU ETS but the UK might opt to exit the EU ETS and other EU climate policies altogether to follow a more suitable and country-specific climate policy. Following that, there have been some discussions in the UK concerning the appropriate climate policies to meet the internationally agreed upon climate targets after Brexit. Among the strategies discussed is the implementation of a carbon tax (Buisson Satre & Miu, 2017; Martin, 2017). Arguments in favour of leaving the EU climate policy package include the fact that a policy set on a national level might be more effective and more suitable for British needs and thus, less distortive to the British economy (Hirst, 2018). However, the broad consensus seems to be to still participate as an active member in the EU ETS and take additional measures such as a carbon tax to meet the targets (Hepburn & Teytelboym, 2017).
It has to be noted here that developing a carbon tax is not a trivial task and requires extensive research. An inefficient tax might distort the economy and thus, be detrimental for the UK. Along with the question which tax rate is appropriate, the level at which a tax is set is also subject to discussion. In this study, the carbon tax is approximated by an energy tax on British fossil fuels and their products. Therefore, the work aims at providing answers to the following two research questions:

1. How does a fossil-energy tax set at the production stage differ in terms of economic and welfare aspects from a tax implemented at the consumption stage?

2. Which tax is less distortive to the British economy and performs better overall?

According to Diamond & Mirrlees (1971) optimal taxation should ensure production efficiency. This might imply that levying a tax on intermediate inputs could interfere with a firm's choice of its input mix and prevent said production efficiency. A tax on final goods might therefore be less distorting to the economy. The results of my study will show whether this hypothesis can be supported.

1.3 The purpose

The development of a British specific fossil-energy tax has been the starting point of this study. The study aims at modeling an ad valorem uniform fossil-energy tax set at the producer and at the consumer level in the UK and quantifying its impact on the British economy. An ad valorem tax means that the amount of the tax is based on the value of a transaction or property. Thus, the tax is typically imposed at the time of the transaction. In line with previous studies in the field (Allan et al., 2014; Benavente, 2016; Guo et al., 2014; Orlov & Grethe, 2012; Wissema & Dellink, 2007), the tax is applied to energy-related sectors (primary energy sources such as fossil fuels and their products) as the introduction of a tax in these sectors is thought to bring the most relief to carbon dioxide emissions. The term "uniform" refers to the fact that the same tax rate is applied to all energy-related sectors and thus, there is no discrimination according to the specific carbon emissions of each fuel.

Applying the uniform tax on the five identified energy-related sectors in the model used allows for the taxation of sectors which heavily emit carbon dioxide. By introducing the tax at two different stages, it becomes evident which tax has a less distorting effect on the economy and welfare overall and the results may be compared to those in the literature. My study is different from others as it incorporates the very recent topic of Brexit in a computable general equilibrium (CGE) analysis and sets a fossil-energy tax at two different stages. To my knowledge, this has never been done before. Hence, my work provides results which could be used as a reference point for the UK's future climate policy.

The remainder of the thesis is structured as followed. Section 2 provides a quick glance at existing literature and in the third section, the theoretical framework of the model used is given in detail. After that, the data compilation and the method of my analysis is explained. Section 5 depicts the results of the study which are then discussed in the next section. Finally, some concluding remarks and further research options are given.

2 Literature Review

As there is a vast body of literature on the topic of carbon emissions, climate change and their economic impacts, the relevant literature has been screened and narrowed down to studies which use a CGE model to quantify economic impacts of energy taxes. Thus, five selected studies closely related to my own will be presented in the following. They were used as guidelines when carrying out my analysis.

A rather detailed study has been carried out by Siriwardana et al. (2011) who analyse the short-run impact of a carbon tax on the Australian economy. As the Australian government announced to price carbon at 23 Australian dollars (AUD) the authors make use of this event and further simulate carbon taxes below and above the envisioned tax level for comparison. To be able to quantify the economic effects, a static CGE model based on ORANI-G (Horridge et al., 2000) has been developed. They conclude that a 23 AUD carbon tax decreases GDP, increases consumer prices, raises electricity prices in the short-run and has negative effects on employment throughout all considered employment groups. However, it allows Australia to make severe cuts in its carbon dioxide emissions. Furthermore, the study finds that the tax burden will be unequally distributed among household groups with low-income households carrying the highest burden.

Wissema & Dellink (2007) developed a CGE model with specific detail in taxation and energy use to assess the impact of energy taxation to reduce carbon dioxide emissions in Ireland. Contrarily to other papers, this work does not just use pre-set tax levels but rather unveils tax levels which would satisfy the envisioned reduction target. A further core issue of their work is the application of two types of taxes: a uniform energy tax, where all fuels are taxed at the same rate and a carbon content tax which is related specifically to the carbon emissions of each fuel. The authors conclude that a uniform energy tax would have to be set higher than a carbon content specific tax to satisfy the same emission reduction target as it lacks the incentive to switch from carbon-intensive fuels to “cleaner” fuels. Overall, a uniform energy tax leads to greater welfare decreases. Moreover, consumption patterns would change due to changes in relative prices. It means that relatively “dirty” sectors would experience a substantial loss because of cost increases and decreasing demand. The renewable energy sector however, would benefit substantially and increase quite strongly. Lastly, Wissema & Dellink (2007) detect that low-income household groups are at risk and need special attention when implementing a carbon tax confirming a result already found by Siriwardana et al. (2011).

The study by Allan et al. (2014) investigates the economic and environmental impacts of a carbon tax implemented in Scotland. In contrast to other studies, they focus on the revenue raised by the tax and introduce three alternative assumptions. To carry out their research, the authors use AMOSENVI which is a large scale, multi-sectoral energy-economy-environment CGE model for Scotland. The simulation set-up imposes an ad valorem tax on the use of the three imported and domestic fossil fuel energy sources, i.e. coal, oil and gas, in their use as intermediate inputs of production. It means that the tax is levied on the production side of the economy. Similarly to Wissema & Dellink (2007), a carbon content specific tax is used rather than a uniform tax. Findings of the study include that the introduction of a carbon tax directly increases the price of taxed goods when they are used as inputs in production. Therefore, demand for these inputs falls which reduces domestic production and quantity of imports. The core result, however, shows that a carbon tax might stimulate economic activities under specific circumstances and at the same time reduce emissions. This is only the case in which the revenue is recycled through income tax.

There have been several studies on the impact of a carbon tax on the Chinese economy (Guo et al., 2014; Liang et al., 2007; Liu & Lu, 2015; Lu et al., 2010). One of them is the analysis carried out by Guo et al. (2014) which applies a static CGE model to assess the effects of a carbon tax. The developed four scenarios entail different carbon emission reduction targets and based on that, the specific duty is calculated. In scenarios with low emission reduction targets, the duty imposed by the carbon tax will be relatively lower than in scenarios with high emission reduction targets. The results show that a moderate carbon tax would significantly reduce carbon dioxide emissions and fossil fuel energy consumption and at the same time slightly reduce the pace of economic growth. A large carbon tax, however, would have a significant negative impact on the economy and social welfare and further induce marked price changes. Furthermore, the authors conclude that reducing coal consumption would have the biggest effect on reducing carbon emissions. Thus, their policy recommendations include the promotion of clean coal technology.

More recently, Benavente (2016) quantified the value of a carbon tax which will achieve the emission reduction target of 20% below business-as-usual by 2020 and assessed its impact on the Chilean economy. To compare the economy before and after the introduction of the carbon tax, a static CGE model of the national economy has been developed. Two different scenarios were assumed in the study. The first scenario levied the tax only on emissions from fossil fuels burned by producers, whereas the second scenario taxed emissions from fossil fuels burned by producers and households. According to the study findings, it is more cost-effective to tax only producers rather than taxing producers and consumers. Further results such as a loss in GDP, decrease of electricity production from fossil fuels, increasing prices of electricity and sectoral contractions of energy-intensive industries corroborate other findings in the literature.
In summary, according to the literature, the introduction of a carbon tax leads to increases in prices of taxed goods and decreases in their respective demand (Allan et al., 2014; Guo et al., 2014), decreases in import demand of taxed goods (Allan et al., 2014), contractions of energy-intensive sectors (Benavente, 2016; Wissema & Dellink, 2007),

decreases in employment (Siriwardana et al., 2011) and negative effects on welfare measured as losses in GDP (Benavente, 2016; Guo et al., 2014; Siriwardana et al., 2011; Wissema & Dellink, 2007). After having reviewed the existing literature it becomes evident that there are no CGE studies regarding the economic impacts of a carbon tax policy in the UK after Brexit. Furthermore, only one study (Benavente, 2016) implements a tax at different stages. Thus, my study aims at filling the gaps in the literature by (1) incorporating the recent issue of Brexit, (2) using a CGE model to detect the economic and welfare impacts after Brexit and finally, by (3) implementing a carbon tax through two different channels: production and consumption. In contrast to Benavente (2016) who applied the tax to producers in one scenario and to producers and consumers in another scenario, this analysis introduces the tax solely on producers in the first scenario and only on consumers in the second scenario.

3 Theoretical Framework

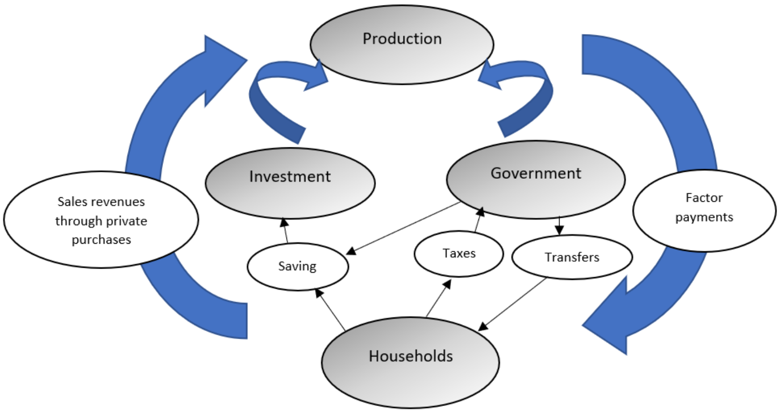
This section describes the detailed set-up of the model used for the research. Firstly, a brief overview of the general CGE model will be given. This approach has been chosen as it allows to depict the economy of a country and focuses not solely on one sector as a partial equilibrium model does. Furthermore, a CGE analysis unveils interlinkage effects in the economy which are of importance especially when assessing the impact of policy measures such as the introduction of a fossil-energy tax. To make the effects of a tax more understandable, Subsection 3.2 explains the implementation of a tax within a CGE framework. Finally, Subsection 3.3 deals with the assumptions behind the standard Global Trade Analysis Project (GTAP) model which is used as a base for my analysis.

3.1 The general CGE model

At first, it shall be explained what "CGE" stands for. The term "computable" means that the model is able to quantify shocks on an economy. Further, "general" is related

to the fact that a CGE model takes care of all economic activities in an economy and its interlinkage effects simultaneously. Lastly, the word "equilibrium" refers to supply and demand being balanced in an economy (Burfisher, Mary E, 2012).
CGE models can be thought of as simulations that combine the general equilibrium structure according to Arrow & Debreu (1954) with realistic economic data. By doing so, it allows to solve numerically for the levels of supply, demand and price which maintain equilibrium in a specific set of markets (Wing, 2004). Thus, a CGE model is a system of mathematical equations which are employed to describe an economy. Modeleres may decide which variables are exogenous and endogenous and depict them accurately in the equations. The model is solved for endogenous variables, whereas exogenous parameters are treated as given. Elasticity parameters are another crucial factor of CGE models as their size can be directly linked to the magnitude of the model. Elasticities of supply and demand measure the responsiveness of supply and demand to changes in relative prices and income (Burfisher, Mary E, 2012).
The general framework of a CGE model is based on a set of producers, consumers and institutions such as governments. This is shown in Figure 1. The activities of these actors are connected by markets for commodities and factors as well as taxes and subsidies. Normally, CGE models depict economic activities in a circular flow between three institutions: Households, firms and government (Burfisher, Mary E, 2012; Sue Wing, 2011).

Figure 1: Circular flow between institutions in a CGE model



Sources: Own figure, Burfisher, Mary E (2012).

Households are assumed to own the factors of production (FOP) such as capital and labour and maximise their utility subject to the budgetary constraint. The representative household's problem is shown in Equation (1) where the agent maximises the profit from the production of a utility good U. Consumption generates the output of U and p_u denotes the marginal utility of aggregate consumption. c_i stands for the commodity and p_i for its price

$$\max_{c_i} p_u U - \sum_{i=1}^{N} p_i c_i. \tag{1}$$

and solving this equation for the consumption of c_i yields Equation (2) which shows the demand function for the consumption of the i^{th} commodity (Wing, 2004).

$$c_i = \alpha \frac{m - \sum_{i=1}^{N} p_i s_i}{p_i}. \tag{2}$$

Firms rent the FOP from households in order to produce goods which are then bought by households and other firms in return. The representative firm maximises profit π by choosing levels of N intermediate inputs x and F primary FOPs v to produce output y. The production technology ϕ acts hereby as a constraint. Equation (3) portrays the maximisation problem of the representative firm.

$$\max_{x_{ij},v_{fj}} \pi = p_j y_j - \sum_{i=1}^{N} p_i x_{ij} - \sum_{f=1}^{F} w_f v_{fj} \quad \text{subject to} \quad y_j = \phi(x_{1j}, ..., x_{Nj}; v_{1j}, ...v_{Fj}). \tag{3}$$

Solving Equation (3) for the firm's demand for intermediate inputs of commodities and primary FOPs yields Equations (4) and (5).

$$x_{ij} = \beta \frac{p_j yj}{p_i}. \tag{4}$$

$$v_{fj} = \gamma \frac{p_j y_j}{w_f}. \tag{5}$$

Equations (2-5) are the main basis of the CGE model (Wing, 2004). The government occupies mostly a passive role in the model by collecting taxes and distributing subsidies. Nevertheless, it also contributes actively by providing government goods which are demanded by households and firms. All equations of the behaviour of firms, households and the government are called behavioural equations. As there are multiple goods and services traded in the economy, different markets for different goods exist. The open version of the CGE model includes a foreign sector with which services and goods may be traded.

Equilibrium in the economic flow results in conservation of product and value (Wing, 2004). Conservation of product implies that the quantity of a factor with which a household is endowed or a good produced by a firm V_f has to be completely consumed by the other firms or households in the economy respectively. This is shown in Equation (6) and holds even if the economy is not in equilibrium.

$$V_f = \sum_{j=1}^{N} v_{fj}. \tag{6}$$

Conservation of value can be associated with the so-called budgetary balance. It means that household expenses must be covered by their income, firm's expenditures on factors of production by the revenue made from selling their goods and every unit of expenditure has to purchase an amount of any commodity or factor (Wing, 2004). This concept of no free disposability of goods and services is closely related to the Walrasian general equilibrium. Goods and services produced by the firms are fully consumed by households and households' endowment of FOP is fully demanded by firms. Therefore, unemployment does not exist as no FOP is left idle. In summary, total quantity demanded by households c_i, other firms $\sum_{j=1}^{N} x_{ij}$ and saving activities s_i must be equal to the total quantity supplied y_i by a firm which reflects the concept of market clearance (Sue Wing, 2011; Wing, 2004) as portrayed by Equation (7).

$$y_i = \sum_{j=1}^{N} x_{ij} + c_i + s_i. \tag{7}$$

The market clearing constraints are depicted by identity equations in the system of equations of a CGE model (Burfisher, Mary E, 2012). Furthermore, conservation of value implies that firms produce with constant returns to scale and markets are perfectly competitive. Hence, firms make zero profits in equilibrium. It implies that the value of production output $p_j y_j$ must be equal to the sum of the value of intermediate inputs $\sum_{i=1}^{N} p_i x_{ij}$ and primary FOPs $\sum_{i=1}^{N} w_f v_{fj}$ used in the production process. The zero profit condition is shown in Equation (8).

$$p_j y_j = \sum_{i=1}^{N} p_i x_{ij} - \sum_{i=1}^{N} w_f v_{fj}. \tag{8}$$

$$m = \sum_{f=1}^{F} w_f V_f. \tag{9}$$

Equation (9) depicts the principle of income balance which means that income of the representative household m equals the value of producers' payments to the household for using the primary FOPs. In short, it makes sure that no FOP is left unused and households spend all their income on goods. These two conditions in Equation (8) and Equation (9) are adopted by the CGE model to solve simultaneously for prices and the quantities of goods and services which sustain a general equilibrium (Sue Wing, 2011). The flows of goods traded are expressed in the value of one good, the so-called "numeraire good" whose price is fixed. Hence, the CGE model only solves for relative prices (Sue Wing, 2011).

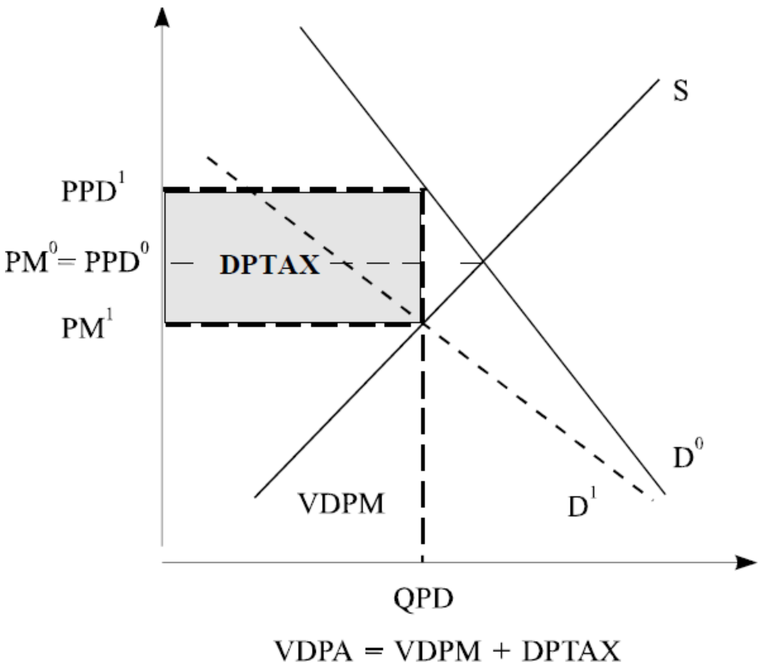
In terms of practical applications, CGE models are widely used especially in policy analysis (Burfisher, Mary E, 2012). As policies often influence prices across multiple sectors, CGE models are chosen because they are able to cover economic activities of an entire economy. Despite their usefulness in policy analysis, they are also criticised for being too complicated and seen by some as a "black box" meaning that the results cannot be meaningfully traced to a specific input parameter or a particular characteristic of the data base, algebraic structure or method of solution (Böhringer et al., 2003; Wing, 2004). This criticism often stems from the fact that CGE models are made up of many variables and parameters and are structurally complex. Due to this large number, there may be controversial assumptions hidden which end up influencing the results (Böhringer et al., 2003).

3.2 Introducing a tax in a CGE framework

CGE models have been extensively applied in tax policy scenarios as they are able to quantify both the direct and excess burdens of taxes (Burfisher, Mary E, 2012). According to Conrad & Löschel (2002), CGE models provide important insights about the relationship between environmental tax policy and the pre-existing tax system. There are different kinds of taxes which may be simulated in a CGE framework (e.g. trade tariffs, production taxes, factor use taxes). As this analysis deals with the introduction of a tax on private domestic households and domestic firms, these two kinds of taxes shall be further explained in detail.

Figure 2 shows the introduction of a tax on purchases by private domestic households. Initially, the market price PM^0 and the price domestic households have to pay PPD^0 are equal and thus, the power of the ad valorem tax on domestic commodity i purchased by private household (TPD) is one. A tax on households reduces the market price to PM1 and increases PPD to PPD^1. Hence, the figure shows that the tax places a wedge between the market price and the price households have to pay. The ratio between the value of domestic private household's purchases evaluated at agent's price (VDPA) and the value of domestic private household's purchases evaluated at market's price (VDPM) describes the power of the tax TPD. As TPD is greater than one, the price households have to pay to purchase commodities has to be bigger than the market price. Further, the rectangle DPTAX portrays the tax revenue accrued to the tax. The revenue may be collected by the government and is calculated by taking the difference between VDPA and VDPM (Brockmeier, 2001).

Figure 2: A tax on private household’s purchases



PM	Market price of commodity i
PPD	Private household's price of commodity i
QPD	Private household demand for commodity i
VDPA/VDPM	Value of private household's purchases of commodity i valued at agents'/market price
DPTAX	Tax/subsidy on commodity i purchased by private households
$D^{0,1}$	Pretax/taxed demand of commodity i
S	Supply of commodity i,

Source: Brockmeier (2001), p. 12.

The second option chosen in this thesis envisions an intervention on the supply side. Thus, a tax is levied on producers. However, the principle of imposing the tax does not differ from levying a tax on households and Figure 2 can be applied to this scenario with some minor alterations in terms of notation. If the power of the tax on domestic commodity i purchased by firm (TFD) is equal to one the price firms have to pay to purchase intermediate domestic goods PFD and PM are the same. A tax on firms increases TFD and therefore, places a wedge between the market price and PFD. The power of the tax can be calculated as the ratio between the value of domestic firm's purchases evaluated at agent's price (VDFA) and the value of domestic firm's purchases evaluated at market's price (VDFM). As it is the case in the first scenario, levying a tax on firm's purchases implies that TFD will be greater than one and therefore, PFD is bigger than PM. Following the implementation of a tax, a tax revenue arises and is calculated by taking the difference between VDFA and VDFM.

3.3 The GTAP model

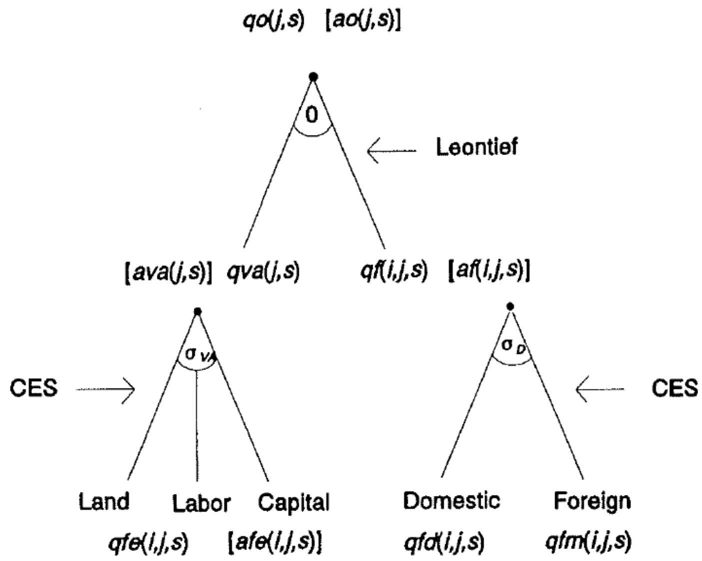
The following subsection explains the assumptions behind the standard GTAP model in detail. According to the GTAP website, the standard GTAP model is a multiregion, multisector CGE model with perfect competition and constant returns to scale. The book by Hertel, Thomas Warren (1997) was used as the main source for this subsection because it is the leading work when trying to understand GTAP modelling and therefore is referred to by most articles.

In short, GTAP is an online database which is publicly available on the GTAP website. Further, the website provides a free software, RunGTAP, which can be used to implement various policy scenarios and detect their impact on the economy of interest. The database is updated annually which involves for example adding new regions to the database or improving quality of existing data. Currently, the ninth version of GTAP is available. The standard GTAP model is a CGE model and thus, applies all the assumptions explained in section 3.1.

3.3.1 Production structure

One of the behavioural equations in the system of equations of the GTAP model explains the behaviour of firms. Figure 3 shows the production structure of a firm within the GTAP framework. The top level denotes total industry output in the economy $qo(j,s)$ by industry j. It is made of quantities demanded for intermediate inputs $qf(i,j,s)$ and value added $qva(j,s)$. The model assumes a Leontief technology which means that there is no substitutability between value added and intermediate inputs. The terms in brackets [] refer to rates in technical change. Value added is further broken down into three FOPs: land, labour and capital, whose quantity demanded is given by $qfe(i,j,s)$. As it is assumed that there is the possibility of substitution among the FOPs, the relationship is portrayed by a constant elasticity of substitution (CES) function. Depending on the specific elasticity parameters the FOPs are more or less substitutable. On the same level, intermediate inputs can either be purchased domestically, denoted by $qfd(i,j,s)$, or abroad, denoted by $qfm(i,j,s)$. Again, a CES function is applied which exhibits the possibility of substitution between domestic and foreign commodities. The underlying notion is that domestic and foreign intermediate goods can be separated. Thus, firms first decide from which country they want to import and in a second step, based on the resulting import price, decide on the optimal mix between domestically and foreign produced commodities. In trade economics, this is called the "Armington approach" and assumes product differentiation according to the origin of the product (Armington, 1969).

Figure 3: Production structure of a representative firm



Notes:

CES = Constant elasticity of substitution

af(i,j,s) = intermediate input i augmenting technical change by j in s

afe(i,j,s) = primary factor i augmenting technical change sector j in s

ao(j,s) = output augmenting technical change in sector j of s

ava(j,s) = value added augmenting technical change in sector j of s

qf(i,j,s) = demand for commodity i for use by j in region s

qfd(i,j,s) = domestic good i demanded by industry j in region s

qfe(i,j,s) = demand for endowment i for use in industry j in s

qfm(i,j,s) = demand for i by industry j in region s

qo(j,s) = total industry output of industry j in region s

qva(j,s) = value added in industry j in s

Sources: Hertel, Thomas Warren (1997), p. 39, Center for global trade analysis (2018).

The total output nest of a firm is described by the following equations:

$$qva(j,r) + ava(j,r) = qo(j,r) - ao(j,r) \tag{10}$$

$$qf(i,j,r) + af(i,j,r) = qo(j,r) - ao(j,r) \tag{11}$$

These two equations determine the firm's demand for intermediate inputs and value added. As the assumed substitution is zero, the relative price component drops out and only the expansion effect remains. Equation (10) shows that quantity of value added $qva(j,r)$, and the input augmenting technical coefficient of value added $ava(j,r)$ must be equal to total quantity $qo(j,r)$ minus $ao(j,r)$. $ao(j,r)$ stands for Hicks-neutral change and lowers the inputs needed at a certain production. Thus, the sign for $ava(j,r)$ is positive, whereas the sign for $ao(j,r)$ is negative. Having applied the zero profit condition to solve for the price of output in the concerned sector, Equation (10) depicts the effect of technical change on the price of the produced commodity j (i.e. value added) in region r. Equation (11) shows essentially the same thing for intermediate inputs with quantity of inputs $qf(i,j,r)$ and the factor of input augmenting technical change of intermediates $af(i,j,r)$. Thus, Equation (11) portrays the effect of technical change on the produced intermediate input j in region r. For a complete description of all behavioural equations of the representative firm see page 42 in the book by Hertel, Thomas Warren (1997).

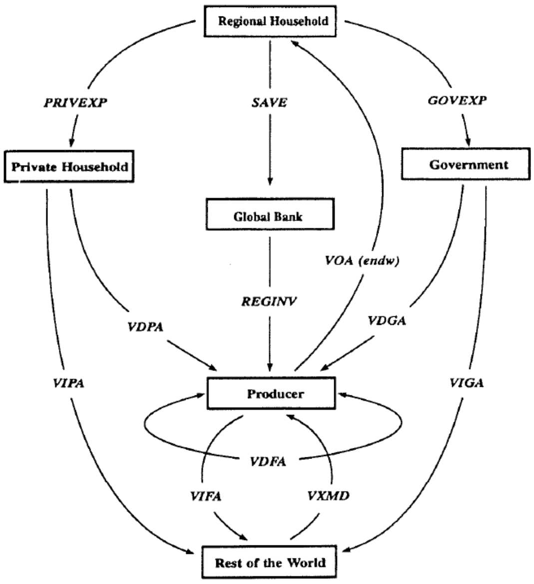
3.3.2 Household behaviour

The behaviour of households is shown in Figure 4 which portrays the entire structure of a multi-region and open economy without government intervention. The starting point of Figure 4 is a regional household which collects all income in the economy. The three forms of final demand, i.e. private household expenditures $PRIVEXP(r)$, government expenditure $GOVEXP(r)$ and savings $SAVE(r)$, use up all regional income $INCOME(r)$ according to a Cobb-Douglas per capita utility function. Aggregate utility is shown in Equation (12). As it can be seen from the equation, regional population $pop(r)$ enters negatively and thus, has diminishing effect on $GOVEXP(r)$ and

$SAVE(r)$.

$$\begin{aligned} INCOME(r) + u(r) = PRIVEXP(r) * up(r) + GOVEXP(r) * [ug(r) - pop(r)] \\ + SAVE(r) * [qsave(r) - pop(r)] \end{aligned} \tag{12}$$

Figure 4: Household behaviour in a multi-region and open economy without government intervention



Notes:

GOVEXP = government expenditures

PRIVEXP = private household expenditures

REGINV = regional investments

VDGA = value of government's domestic purchases at agent's price

VDFA = value of firm's domestic purchases at agent's price

VDPA = value of private household's domestic purchases at agent's price

VIGA = value of government's imports at agent's price

VIFA = value of firm's imports at agent's price

VIPA = value of private household's imports at agent's price

VOA = value of initial endowment of primary factors of production at agent's price

VXMD = value of export quantities sold at world's price

Source: Hertel, Thomas Warren (1997), p. 17.

4 Data and Method

This section describes the data compilation and the relevant method which was used in conducting my analysis. As I had the possibility of using an already existing and very detailed database, the data section is kept rather short.

4.1 Data compilation

The databases behind CGE models are the social accounting matrices (SAMs) (Kretschmer & Peterson, 2010). A SAM provides a summary of all economic transactions in a certain period, e.g. one year, and is always in balance. It means that the value of a sector's output must be equal to the value of its inputs. Thus, the economy represented by a SAM for a given time period is assumed to be in equilibrium. GTAP conducts new SAMs every couple of years for many countries worldwide. These are then used by almost all CGE models for data calibration. The most recent database GTAP 9, which is used in this study, summarises input-output and international trade activities for the year 2011. To carry out the analysis, the static, multi-region and multi-sector CGE model by GTAP has been used. The model applies standard neoclassical economic assumptions such as a perfectly competitive economy with constant returns to scale, cost minimisation for industries and utility maximisation for households and continuous market clearance. Details for all model assumptions and equations are given in Section 3. A static CGE model allows for a description of a new equilibrium after an exogenous shock such as the implementation of a tax. The existing database GTAP 9 has been modified to the needs of my study by using the GTAPagg program.

4.2 Data modification

Originally, there are 140 old regions in the database which have been aggregated to three new regions: UK, EU-27 and rest of the world (ROW). As my research question mainly aims at analysing the effects of a fossil-energy tax on the UK economy it suffices to sum up all the other countries in two categories, namely the EU-27 and ROW.

The next step was to aggregate and disaggregate the sectors. Moreover, all energy-related sectors in the GTAP 9 database needed to be filtered out and thus, kept separate from the other sectors. Out of the 57 sectors, 14 new sectors were created including five energy sectors: coal, oil, gas, petroleum & coal products (p & c) and electricity. The newly created agriculture sector contains all industries related to agriculture (animal or plant), livestock as well as forestry and fishing. All further processed food has been kept as its own sector. Contrarily to the old sector aggregation, the extraction sector has been removed so that oil, gas and coal each constitute their own sector. This modification has been made in order to be able to apply a fossil-energy tax at the primary production level. Furthermore, p & c products are separated from other manufacturing so that the implementation of a tax is possible. Manufacture industries that are expected to be influenced heavily by a fossil-energy tax are summarised under basic materials & chemical products (BMCM). All the other manufacture industries have been aggregated to either textiles & clothing or other manufacturing. Moving on to utilities and construction, electricity as well as construction were kept separately and constitute now each their own sector. Furthermore, a single transport sector has been created which is made out of different modes of transport (e.g. air, sea). The remaining sectors have been aggregated to other services and trade. A detailed description of the new sectors is given in Table H1 in the appendix .

The original aggregation consisted of five primary FOPs: land, unskilled labour, skilled labour, capital and natural resources. As this aggregation suits the needs of my study, nothing has been changed.

4.3 Method

As mentioned in the section above, a CGE model based on a modified GTAP 9 database was used in this work. To be able to assess the economic impacts of an ad valorem fossil-energy tax on the British economy the policy simulations were carried out with RunGTAP.

4.3.1 RunGTAP

RunGTAP is a free program available on the GTAP website and is used widely in policy analysis. The software allows to choose from different versions which differ in terms of sector and factor aggregation. As I had previously modified the database to my needs, I worked with this new version of the GTAP 9 database.

After having chosen the appropriate version it is crucial to specify exogenous and endogenous variables to be able to close the model. Table H2 in the appendix shows all exogenous variables of the model. The remaining variables are considered to be endogenous. Exogenous variables are independent and affect the model without being affected by it. They are treated as given and thus, are not solved by the model. Contrarily, endogenous variables are dependent variables and are generated within the model. Most exogenous variables within the RunGTAP frame are always considered to be exogenous regardless of which version is used. However, for my analysis it was crucial to have TFD and TPD as exogenous variables as they are the variables that needed to be shocked in the policy simulations. To achieve this, the main model had to be changed from GTAP to GTAPU. GTAPU stands for the uncondensed version of the main model. Once the model is changed to the uncondensed version, the variables TFD and TPD are ready to be shocked.

The next step is to clarify which type of shock should be used. RunGTAP allows for three different types of shocks. The first one is a % change rate in the tax, the second one a % change in power of the tax and the last one is a % change in the target rate. For this analysis, the first option was chosen as the objective of the study is to quantify the impacts of the introduction of a tax. The power of the tax is therefore not a variable of interest. Option three was not chosen as again it is not in line with the objectives of the study and further, there was no information available on the envisioned target tax rates by the UK. After having chosen the appropriate type of tax, the shock values need to be defined to carry out the simulations. As the literature and further research did not provide any fruitful results in terms of possible envisioned tax rates by the UK, a different approach was applied. The chosen approach is similar to what previous studies

(Benavente, 2016; Guo et al., 2014; Lu et al., 2010; Wissema & Dellink, 2007) have done. Thus, a series of arbitrary tax rates (5%, 10%, 15%, 20% and 40%) on existing tax rates was simulated in the RunGTAP software.

Having chosen the appropriate variables, type of shock and shock values the model is ready to be solved.

4.3.2 Simulations with RunGTAP

Production scenario

When applying a fossil-energy tax at the production level the exogenous variable TFD needs to be shocked. The ad valorem fossil-energy tax is introduced uniformly to the sectors coal, oil, gas, electricity as well as p & c products. However, the sector of electricity is excluded from taxation in the production scenario as 24.5% of electricity in the UK stemmed from renewable energy in 2016 (Energy UK, 2018). This number will increase during the next couple of years as the UK aims to meet the EU target which envisions a share of 30% from renewable sources in its electricity mix. Therefore, a tax on producers in the electricity sector would be counterproductive because it might discourage producers from using renewables in their production. Using renewables in the production is currently still more expensive than using fossil fuels in the UK (Gabbatiss, 2018). If producers in the electricity sector are taxed they might switch from relatively more expensive to cheaper inputs and thus, the share of renewables in the British electricity mix could decrease. After having excluded the sector of electricity from fossil-energy taxation, four sectors (coal, oil, gas and p & c products) remain to be shocked.

Levying a uniform tax means that the tax rate is the same for all sectors regardless of the specific carbon emissions. The first simulation envisioned a 5% increase of existing TFD rates in the sectors considered. The second, third, fourth and fifth simulations applied a 10%, 15%, 20% and 40% tax increase respectively.

Consumption scenario

For the second policy scenario, the version of the model and exogenous as well as endogenous variables remained unchanged. In contrast to a shock at the production stage, a different exogenous variable needs to be shocked when considering a tax set at the consumption stage. Hence, the variable TPD is shocked in the second policy scenario. The developed model has five energy sectors where a fossil-energy tax is most likely to be applied. However, coal was excluded from the tax simulations at the consumer stage as it is mostly used as a primary source of energy mainly in electricity or as a reductant in metal smelting (Natural Environment Research Council, 2010). Thus, British people consume coal rarely in its raw form and taxing the coal sector would not provide much relief to carbon dioxide emissions. This notion was confirmed by carrying out the simulations again, this time including the coal sector. The results from the second round of simulations did not differ greatly from the ones obtained in the first round and therefore, it is justified to exclude the coal sector at a consumption stage. After removing the coal sector four sectors remain to be shocked. As it is the case in the first policy scenario, the ad valorem fossil-energy tax is uniformly applied to the concerned sectors.

5 Results

The results of the different tax simulations are analysed according to their effect on the British economy as well as their impact on welfare overall. Welfare effects are portrayed by the equivalent variation (EV) in US$ million and the change in value of GDP. EV is defined according to Currie et al. (1971) who state that EV is "The amount of compensation paid or received, that will leave the consumer in his subsequent welfare position in the absence of the price change if he is free to buy any quantity of the commodity at the old price" (p. 746)." Thus, in short, a household's EV is equal to the difference between expenditure needed to achieve the new (post-simulation) level of utility at initial prices.

5.1 Production scenario

The economic effects induced by an introduction of a tax set at the production stage are analysed on a sectoral, household, primary FOPs and trade level. After that, the impacts on welfare are shown. A detailed summary of all simulation results obtained can be viewed in S1 in supplementary materials.

5.1.1 Economic effects

Sectoral effects

In general, market prices of all commodities in the UK are decreasing regardless of the tax rate considered. However, market prices of commodities in the BMCM and transport sector are increasing throughout the simulations. The same result can be observed when considering the supply price of commodities in the UK. Quantities of domestic sales are decreasing in eight sectors. This can be seen throughout all tax rate simulations with the effect being the highest at a 40% tax rate. Relatively to the other sectors, the gas sector experiences the largest fall in domestic sales. Further, total industry output is falling in secondary energy and energy-intensive sectors. This is depicted by Table 1. The largest fall in industry output can be seen in the p & c products and the transport sector. Primary energy sectors (i.e. coal, oil and gas) receive a moderate increase of industry output in every simulation.

The quantity demanded by the government is non-decreasing for six sectors, namely oil, gas, p & c products, other manufactures, utilities and other services. In every tax simulation, the transport sector experiences the largest drop in demand by the British government.

Table 1: Effect of a simulated (sim.) increase in TFD on total output by sector measured as a % change

Sectors	5% sim.	10% sim.	15% sim.	20% sim.	40% sim.
Agriculture	0.06	0.12	0.18	0.24	0.47
Basic materials & chemicals	-0.16	-0.33	-0.49	-0.66	-1.32
Coal	0.01	0.02	0.03	0.05	0.09
Construction	-0.17	-0.35	-0.52	-0.7	-1.39
Electricity	-0.03	-0.07	-0.1	-0.13	-0.26
Gas	0.06	0.11	0.17	0.23	0.46
Oil	0.01	0.02	0.03	0.04	0.07
Other manufacture	0.15	0.31	0.46	0.62	1.24
Other services & trade	0.04	0.07	0.11	0.14	0.28
Petroleum & coal products	-0.64	-1.28	-1.91	-2.55	-5.1
Processed food	0.01	0.01	0.02	0.02	0.04
Textiles & clothing	0.16	0.32	0.48	0.64	1.27
Transport	-0.56	-1.12	-1.68	-2.24	-4.48
Utilities	0.04	0.08	0.12	0.16	0.33

Source: Own calculations, 2018.

The prices firms must pay to purchase transport and BMCM commodities are increasing regardless of the tax simulation considered. Further, the prices for domestic coal and p & c products paid by firms are increasing in four and ten sectors respectively. Intermediate demand of primary energy sectors for other commodities is increasing in almost all economic sectors for every tax simulation. The sectors of BMCM and transport are the exception hereby. Intermediate demand of the p & c product sector is falling in every simulation and for all sectors.

In summary, the p & c product and transport sector experience the largest contraction in terms of domestic sales and total industry output. Further, other energy-intensive sectors such as BMCM and construction are suffering as well. Primary energy sectors also lose from the implementation of a fossil-energy tax at production stage. Altering the tax rate does not change the results greatly but intensifies them in magnitude.

Household effects

The prices private households must pay to purchase domestic goods are decreasing in all economic sectors apart from the transport sector. This result is true regardless of the tax rate considered. The biggest price decreases occur in the sectors of utilities and oil. The demand of private households for domestic goods is decreasing in six out of a total of 14 sectors. The transport sector experiences the largest decrease of private household demand in all simulations whereas the oil sector gains the most in terms of private household demand.

Effects on primary FOPs

The quantity of value added is decreasing in five sectors, namely p & c products, electricity, BMCM, construction and transport. P & c products experience the largest decrease of quantity of value added. Employment is falling in five sectors and experiences the largest drop in the p & c sector (- 5% in the 40% simulation). There is no notable difference between skilled and unskilled labour. Both FOPs decrease and increase by approximately equal amounts in the same sectors except for the sector of processed food where skilled labour drops slightly and unskilled labour increases by 0.13% in the 40% simulation.

Price effects on FOPs are negative throughout all five tax simulations. It means that the prices firms must pay for value added are decreasing when introducing a tax in the energy sectors. The intensity of the price decreases does not vary greatly among sectors. However, the gas sector receives the lowest decrease in price of value added.

Trade effects

The value of imports in the UK is decreasing in five sectors in the 5% tax rate simulation. As the tax rate increases, the value of imports becomes negative in more and more sectors. At a tax rate of 40% only three sectors (p & c products, BMCM and transport) have a positive value of imports. The p & c products sector receives the biggest increase in value of imports whereas the value of imports in the oil sector decreases the most. The effect on world prices of imports in the UK is moderate throughout the tax simulations. However, a trend of increasing world prices in all sectors is visible with the sector of gas experiencing the relatively largest increase. The quantities of imports, shown in Table H3 in the appendix, are falling in every sector apart from the p & c products, BMCM and the transport sector. Again, import quantities in the British p & c product sector rise the most.

The value of British exports is increasing in 12 out of 14 sectors in every simulation. The sectors of BMCM and transport pose the exception hereby. Both sectors experience a fall in value of exports with the transport suffering relatively more. The largest increase in value of exports can be found in the oil sector. Aggregate export prices are non-increasing in all sectors apart from the two sectors mentioned before. Further, aggregate export quantities from the UK are decreasing in the BMCM and transport sector but rise everywhere else. The British oil sector is exposed to the largest increase in export quantities compared to all other sectors.

5.1.2 Welfare effects

EV in the UK is decreasing in all five simulations as shown by Table 2. The loss in EV in the 40% simulation is approximately eight times the loss in the 5% simulation portraying an almost linear effect of the tax. The other regions maintain an increase in EV throughout all simulations.

Table 2: Effect of a simulated (sim.) increase in TFD on equivalent variation measured in US$ million

Region	5% sim.	10% sim.	15% sim.	20% sim.	40% sim.
European Union-27	137.31	274.63	411.94	549.25	1098.51
Rest of the world	6.06	12.12	18.18	24.24	48.47
United Kingdom	-521.4	-1042.81	-1564.21	-2085.61	-4171.23

Source: Own calculations, 2018.

The change in value of British GDP is negative regardless of the tax rate implemented which is shown in Table 3. The 5% simulation induces a negative change of 0.07%. The negative change is enhanced throughout the various simulations up to 0.57% in the 40% simulation.

Table 3: Effect of a simulated (sim.) increase in TFD on value of GDP measured as a % change

Region	5% sim.	10% sim.	15% sim.	20% sim.	40% sim.
European Union-27	0	0.01	0.01	0.02	0.04
Rest of the world	0	0.01	0.01	0.02	0.04
United Kingdom	-0.07	-0.14	-0.22	-0.29	-0.57

Source: Own calculations, 2018.

5.2 Consumption scenario

The economic effects induced by an introduction of a tax set at the consumption stage are analysed on a sectoral, household, primary FOPs and trade level. After that, the impacts on welfare are shown. A detailed summary of all simulation results obtained can be viewed in S2 in supplementary materials.

5.2.1 Economic effects

Sectoral effects

Overall, market prices of energy goods and transport are decreasing in every simulation. The sector of electricity poses an exception hereby and experiences a slight increase in its market price. The same result is observed when considering the supply price of the goods mentioned. Total industry output falls in every sector apart from food processing, construction, transport and other services as shown by Table 4. The sector of p & c products suffers from the largest decrease in output and the effect increases in magnitude with higher tax rates. Similarly, domestic sales are falling in all sectors apart from food processing, utilities, construction, transport and other services. Again, this is true regardless of the tax rate considered.

Concerning the quantity demanded by the government, all sectors are exposed to an increase in demand for domestic goods. As the tax rate increases, the rise in demand gets larger with the sector of oil experiencing the highest increase in demand.

For firms, prices they must pay for domestic purchases are falling in sectors which are heavily influenced by the tax, i.e. coal, oil, gas, p & c products and transport. This is true regardless of the purchasing sector and the tax simulation considered. Quantity demanded by firms is negative for most other sectors. However, intermediate demand by firms for domestic coal and oil is non-decreasing in most sectors.

In summary, the sectors which were targeted by the tax directly all experience a contraction. The tax also induces negative effects on industry outputs of the other sectors. In total, the sector of p & c products receives the biggest reduction in its industry output.

Table 4: Effect of a simulated (sim.) increase in TPD on total output by sector measured as a % change

Sectors	5% sim.	10% sim.	15% sim.	20% sim.	40% sim.
Agriculture	-0.01	-0.01	-0.02	-0.03	-0.05
Basic materials & chemicals	-0.01	-0.03	-0.04	-0.05	-0.11
Coal	-0.02	-0.04	-0.06	-0.08	-0.16
Construction	0.01	0.01	0.02	0.03	0.06
Electricity	-0.08	-0.17	-0.25	-0.34	-0.67
Gas	-0.01	-0.01	-0.02	-0.02	-0.05
Oil	-0.04	-0.08	-0.12	-0.16	-0.32
Other manufacture	-0.02	-0.03	-0.05	-0.07	-0.14
Other services & trade	0.01	0.01	0.02	0.02	0.05
Petroleum & coal products	-0.46	-0.92	-1.39	-1.85	-3.7
Processed food	0	0	0.01	0.01	0.02
Textiles & clothing	-0.01	-0.03	-0.04	-0.06	-0.11
Transport	0.01	0.02	0.02	0.03	0.06
Utilities	0	0	0	-0.01	-0.01

Source: Own calculations, 2018.

Household effects

Prices of domestic goods British households must pay are increasing for all sectors apart from coal, oil and transport. This result can be observed regardless of the tax rate considered. Prices of the sectors targeted by the fossil-energy tax directly, experience a higher increase relatively to the other sectors. Quantity demanded by private households falls for gas, p & c products and electricity. Additionally, for higher tax rates, private households demand less agriculture commodities as well as textiles & clothing.

Effects on primary FOPs

The overall effects on the primary FOPs are similar in every simulation but a difference in magnitude of the effects is visible. The quantity of value added used by firms is decreasing for all sectors except food processing, utilities, construction, transport and other services in the 5%, 10% and 15% simulation. The 20% and 40% simulations lead to higher decreases of quantity of value added in the same sectors and in addition, utilities also experience a decrease. As the tax rate increases, more and more sectors are exposed to a fall in quantity of value added. However, even with a tax rate of 40%, the sectors of food processing, construction, transport and other services are subject to a non-decreasing quantity of value added. Impacts on employment are negative in ten sectors and the highest decrease occurs in the p & c products sector. Further, there is no difference between skilled and unskilled labour. Both experience the exact same effects in the same sectors.

Moreover, the prices firms must pay for value added are increasing in all sectors apart from coal, oil and gas. Even as the tax rate increases up to 40%, the results do not change.

Trade effects

Regarding British imports, an increase in tax rates leads to a loss in value of imports in the sectors of coal, oil and gas. A very high tax rate (40%) eventually causes decreases in value of imports in other sectors as well (BMCM, transport). World prices are also influenced by the introduction of a fossil-energy tax on consumers. A relatively moderate tax rate (5-10%) induces a decrease of world prices of oil, gas, p & c products and

transport. As the tax rate rises to 40%, seven sectors experience a decrease in world prices of imports. Further, the quantities of imports are falling in all fossil fuel sectors for every tax simulation which can be seen in Table H4 in the appendix.
The value of exports of the UK is non-decreasing in every tax simulation considered for the sectors of coal, oil, gas, p & c products as well as transport. A higher tax rate intensifies the positive effect on the value of exports. For the same sectors, aggregate export prices fall in every scenario except for the sector of gas in the 5% scenario which experiences neither an increase nor a decrease in terms of export prices. Furthermore, aggregate exports from the UK to other regions increase for the sectors already mentioned.

5.2.2 Welfare effects

Table 5 shows that EV in the UK is decreasing in all five scenarios. The 5% scenario induces a loss of 580.5 million US$ and the value increases up to 4643.7 in the 40% simulation. Similarly, ROW experiences a decrease of EV in all simulations. In contrast, EV in the EU-27 increases regardless which tax rate is implemented. In general, the higher the tax rate, the greater the loss in EV.

Table 5: Effect of a simulated (sim.) increase in TPD on Equivalent Variation measured in US$ million

Region	5% sim.	10% sim.	15% sim.	20% sim.	40% sim.
European Union-27	92.62	185.25	277.88	370.5	741.01
Rest of the world	-75.45	-150.9	-226.35	-301.8	-603.6
United Kingdom	-580.45	-1160.92	-1741.37	-2321.82	-4643.66

Source: Own calculations, 2018.

Table 6 depicts the change in value of GDP throughout the tax simulations. As it can be seen from the table, change in value of GDP is positive for every simulation in the UK with the 40% simulation leading to the highest change in value of GDP (0.23%). Thus, the change in value of GDP increases with the tax rate. For low changes in tax rates, the other regions, EU-27 and ROW, do not experience any change in value of GDP. However, once the tax is set at higher levels (e.g. 40%) the change in value of GDP in the EU-27 is positive, whereas the change is negative in ROW.

Table 6: Effect of a simulated (sim.) increase in TPD on value of GDP measured as a % change

Region	5% sim.	10% sim.	15% sim.	20% sim.	40% sim.
European Union-27	0	0	0	0	0.01
Rest of the world	0	0	0	0	-0.01
United Kingdom	0.03	0.06	0.09	0.12	0.23

Source: Own calculations, 2018.

6 Discussion

In this section, the results obtained from the various simulations will be compared to and critically discussed with findings in the literature. Similarly to the previous section, this section deals separately with the economic and welfare effects. While discussing the results with the literature, it should be kept in mind that the simulated tax in this work is an ad valorem energy tax on fossil energy rather than a carbon content specific tax. However, the fossil-energy tax is levied on sectors which are thought to be largely responsible for carbon dioxide emissions and thus, the tax can be viewed as a proxy for a carbon tax.

6.1 Results

6.1.1 Economic effects

According to Allan et al. (2014) and Guo et al. (2014), the introduction of a carbon tax has a direct positive effect on prices of taxed energy goods (coal, oil, gas, p & c products and electricity in this case) when they are used as inputs in production and thus, quantity demanded in terms of domestic production and imports is expected to fall. My analysis partially supports these findings. Taxing fossil energy at a production level increases the price firms have to pay to purchase coal, gas and p & c products on average throughout all sectors. However, it does not imply that all sectors must pay higher prices to buy these inputs. In some sectors, prices to purchase coal, gas and p & c products are dropping but this effect is offset in total by high price increases in other sectors. The price to purchase oil, however, is decreasing for all sectors. A possible explanation for the non-increasing price of oil might be that the initial tax rate of TFD was zero for all sectors except the electricity sector which was excluded from taxation at the production stage (see Subsection 4.3.2). Hence, changing the TFD rate on oil does not have any effect and therefore, it is as if oil is not a taxed good at all and behaviour of firms is not distorted by introducing the tax. Further, total industry output of p & c products decreases, which is not surprising as domestic price of these products experienced a rather drastic increase due to the introduction of a fossil-energy tax. Total industry output in the sector of oil increases which is also no surprise as its tax is effectively zero. The demand for oil by firms, government and households is rising and thus, producers have no incentive to produce less. Coal mainly benefits from an increase in demand by private households. The gas sector experiences a rise in demand by the government and private households. The higher demands are probably due to the lower prices these institutions have to pay to purchase coal, oil and gas. Thus, taxing at the production stage in the energy sectors makes producers worse off as they carry the tax burden. Consumers of energy commodities partially benefit from taxation of producers as price drops occur, making these goods relatively cheaper. The discrepancy between the outcomes previously found by Allan et al. (2014) as well as Guo et al. (2014) and my results is therefore due to the fact that increases in private and public demand offset the negative effect of intermediate demand by firms.

Moving on to the discussion of my results regarding to the quantity of imports, it can be concluded that quantity of imports of coal, oil and gas decreases but imports of p & c products increase in the production scenario. The increase in imports of p & c products is rather surprising at first glance as import quantity demanded by the government and households of these goods decrease. However, as demand of quantity of imports by firms increases it is able to offset the negative demand effect by private households and the government. Firms which use p & c products as inputs in their production substitute domestic for foreign commodities when domestic prices increase. Especially sectors which are very energy-intensive, i.e. BMCM, other manufacturing, construction and transport, experience a drastic increase in quantity of imports. Thus, it seems as the high increase in domestic price of the p & c sector forces firms to purchase these intermediate inputs elsewhere. The expected drop in imports as found by Allan et al. (2014) is not happening as especially in the short-run the production structure of a firm is fixed and therefore, it is not easy to find substitutes right away. Considering the (very) long-run might provide a different picture where import quantity of p & c products demanded drops when a tax on fossil energy at the production stage is introduced.

Implementing a tax at the consumption level increases the price private households must pay to purchase domestic gas, p & c products and electricity. Therefore, private demand for these goods decreases. The price households must pay to purchase oil decreases and private demand increases which is counterintuitive at first but makes sense once the initial TPD rates on oil are checked. As it was the case for producers, initial TPD rates are zero and thus, there is effectively no tax on oil and no incentive for households to purchase less oil. The price firms have to pay to purchase domestic oil, gas and p & c products to use them as inputs of production decreases. The price to purchase electricity on a firm level is increasing. These findings might partly be due to the fact that in this scenario households carry the tax burden. Hence, the decision which intermediate input to purchase by firms is not highly influenced by a tax which is introduced at a consumer level. However, firms are affected by the introduction of a consumer tax on energy goods in the sense that the tax reduces private household demand for these goods and as a result, firms produce less. The results confirm this as total industry output drops in all four taxed sectors which is also consistent with findings by Allan et al. (2014) and Guo et al. (2014).

Concerning imports, quantity imported decreases in three sectors but increases in the p & c products sector in the consumption scenario. Even if the literature (Allan et al., 2014) suggests otherwise, this finding is not surprising. The price private households have to pay to purchase electricity and p & c products increases heavily and thus, households substitute domestic for foreign commodities. As a result, import demand by private households rises for these goods even if overall private household demand decreases.

Regarding the structure of the economy the literature suggests that a carbon tax leads to a contraction of energy-intensive sectors while less carbon-intensive industries grow (Benavente, 2016; Wissema & Dellink, 2007). My analysis shows that levying a tax on energy commodities at a production stage leads to a contraction of five out of 14 sectors. The concerned five sectors are all very energy-intensive industries such as BMCM, transport or construction. Industries which are less energy-intensive, i.e. food processing or other manufacturing benefit from the introduction of a tax. The findings are therefore in line with those by Benavente (2016) and Wissema & Dellink (2007). A fossil-energy tax implemented at the consumer level induces a contraction in ten sectors. However, the losses are smaller in absolute numbers. In terms of sectors, industries which use a lot of energy are exposed to higher sectoral contractions. It has to be mentioned, that some sectors which are considered to be energy-intensive such as transport or construction experience a slight increase in total industry output. A possible explanation for this might be the increase of government demand for these sectors which is shown in my results. Levying a tax leads to the emergence of a tax revenue which is usually collected by the government and thus, can be used by the government

to purchase commodities. Doing a general instead of a partial equilibrium analysis allows to unveil such effects and is the main reason why the approach has been chosen. Further, Siriwardana et al. (2011) claim that a carbon tax has negative impacts on employment especially in sectors which are heavily targeted by the energy tax. Employment effects are negative on average in both scenarios carried out with the TFD scenario leading to higher negative effects. Taxed industries and relatively more energy-intensive industries experience the biggest losses in employment. Thus, the results of the analysis seem to be consistent with the literature. However, it should be noted here that the scenarios differ in terms of where losses and gains in employment occur. Whereas a tax set at a production stage induces high decreases of employment in energy-intensive sectors such as BMCM, transport or construction, a tax set at a consumption stage mainly influences employment in the taxed sectors.
After having discussed my results with the literature it can be said that my findings are mostly consistent with the literature. Some discrepancies occur which have been addressed appropriately.

6.1.2 Welfare effects

Both tax policy scenarios lead to a loss in welfare measured by Hicksian EV. This finding corroborates results stated by the literature (Benavente, 2016; Guo et al., 2014; Siriwardana et al., 2011; Wissema & Dellink, 2007). In terms of EV it does not matter greatly whether producers or consumers are taxed. At a 5% change in tax rate the increase of EV is around 500 million US$ in both scenarios and rises to around 4500 million US$ at a 40% change in tax rate. A negative EV means that consumers are indifferent between receiving this specific amount of money and the project, i.e. the tax, being implemented.
The literature previously discussed claims that a carbon tax has negative impacts on GDP and slows down economic growth (Benavente, 2016; Guo et al., 2014; Siriwardana et al., 2011; Wissema & Dellink, 2007). Implementing a tax at the production stage agrees with these findings by the literature. However, as portrayed in the results sec-

tion, the change in value of GDP is positive for the consumption scenario. The positive change in value of GDP may be explained by positive changes in other sectors such as higher demand by the government for all sectors. As mentioned before, the general equilibrium analysis allows to detect these effects. An alternative explanation might be that these findings suggest that it is easier for consumers to substitute away from taxed commodities and as a result, welfare changes measured as a change in value of GDP can be positive. Furthermore, the results found in this analysis seem to support a stream of literature led by Goulder (1995), Diamond & Mirrlees (1971) and Stiglitz & Dasgupta (1971) who state that a tax on intermediate inputs induces larger costs in welfare than a tax on final consumption goods. Following this argumentation, implementing a tax at the production stage induces higher distortionary effects in the economy overall and leads to multiplier effects throughout all sectors. My analysis shows that increasing the TFD rate leads to relatively bigger losses in total industry output of all sectors (-8.3% overall in the 40% scenario) compared to increasing the rate of TPD (-5.1% overall in the 40% scenario). Similarly, total domestic sales decrease more when introducing a tax on producers than a tax on consumers. A possible explanation for this finding might be that producers cannot easily substitute their intermediate inputs for others as their production structure is usually fixed at least in the short-run. Thus, levying a tax on intermediate inputs drives up producer costs and leads to a contraction of the concerned economic sectors (i.e. p & c products, transport, construction). However, production structures are subject to change especially in the long-run and therefore, a tax on fossil fuels might set an incentive for producers to use substitutes (e.g. renewables) as their production inputs. It has to be noted here, that the study by Benavente (2016) concludes that taxing producers and consumers together is worse for welfare compared to only taxing producers. Even if the study is not directly comparable to the scenarios implemented in this analysis, it can be said that my results somewhat contradict the findings by Benavente (2016).

6.2 Limitations of my analysis

There are several limitations to my analysis. Firstly, the assumptions made by the underlying model in GTAP might not be appropriate. Especially the notion of perfectly competitive markets and constant returns to scale can be questioned. Moreover, the standard GTAP model is a static CGE model and hence, does not detect future impacts of the policy. Therefore, a dynamic CGE model might provide a better picture of the long-run effects of a particular policy.

A second limitation is the fact that the possibility of aggregating and disaggregating sectors was limited by the GTAPagg program. It would have been beneficial to my study to disaggregate the energy sectors even more and further, set up a renewable energy sector. As I was using the RunGTAP software and did not have access to GEMPack I was not able to take care of this issue appropriately.

Thirdly, the tax rate was uniformly applied throughout all energy sectors. Some studies chose to apply a tax rate specifically related to the carbon emissions of the sector. It was not done here as it would have been very time consuming and difficult to search for the specific carbon emissions emitted of every envisioned taxed good. However, using a different tax might be a possibility for further research.

Lastly, the results of my analysis should be interpreted with caution as the findings do not tell anything about the ability of carbon dioxide emission savings of the proposed taxes.

7 Conclusion

This thesis set out to answer two research questions. Firstly, in what way an ad valorem British fossil-energy tax set at the production level differs from one set at the consumption level in terms of economic as well as welfare impacts and secondly, which tax distorts the economy in the UK less and performs better overall. After having carried out the analyses it can be said that implementing a fossil-energy tax at a production level or at a consumption level both has distorting effects on the economy and leads to sectoral contraction especially in sectors which are targeted directly by the introduction of the tax. Further, employment effects are negative regardless of where the tax is applied. However, in terms of welfare measured as a % change in GDP it seems to matter where the tax is applied. Setting a tax at the consumption stage has small positive effects on changes in value of British GDP. Thus, the answer to the second research question is that rather consumers than producers should be taxed if the goal is to prevent a loss in welfare. The results of my analysis support my hypothesis at the beginning, namely that the introduction of a tax at a production stage might prevent producers from reaching production efficiency as their choice of intermediate inputs is distorted.

However, it must be noted that both taxes induce decreases in total industry output. Whereas a tax on producers leads to larger distortions in intermediate demand by firms, a tax on consumers has a relatively larger effects on private household demand. Hence, no matter where the UK decides to levy a fossil-energy tax the repercussions of such a policy have to be studied carefully.

Nevertheless, my study allows for some rough policy recommendations. If the British government aims at supporting the production of green energy it might be more beneficial to tax consumers as a tax on producers makes production in the energy sectors more expensive. Thus, producers might switch to relatively cheaper inputs in their production process and as of today, fossil fuels are still cheaper than renewables. Further, taxing consumers can be easier than taxing producers because of strong lobbying powers among energy producers. However, in terms of social fairness taxing producers could be the preferred possibility as studies show that a tax on private households leave low-income households relatively worse off (Siriwardana et al., 2011; Wissema & Dellink, 2007). Of course, this could happen anyway as firms pass on the tax burden to consumers in a production tax scenario. A way to make the tax burden more equal among households, could entail the introduction of a proportionary tax meaning that the level of the tax depends on a household's income.

Concludingly, more research is needed to make more accurate policy recommendations. Further work should address the issue of which tax is more efficient in terms of carbon dioxide emission savings as this is of importance when choosing where to apply a carbon tax. Moreover, models with a longer time horizon are needed to provide a picture of what may occur in the future. Such an analysis is especially crucial in the industry of renewable energy as it is expected to change a lot in the next couple of years. Lastly, studies show that a carbon content specific tax could provide more relief to carbon emissions and at the same time be less distortive to the economy. Hence, my analysis could be redone implementing this kind of tax which would allow for a more discriminatory approach towards the taxation of fossil fuels and their products.

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8 Appendix

8.1 Composition of the model used

Table H1: Sectoral aggregation by industries

Aggregated sector	**Industries**
Agriculture	Animal products; livestock; cereal and grains; forestry; fishing
Basic materials and chemical products	Minerals and mineral products; wood products; metals and metal products; chemical, rubber and plastic products
Coal	Coal
Construction	Construction
Electricity	Electricity
Gas	Gas
Other manufacture	Motor vehicles and parts; transport equipment; electronic equipment; machinery and equipment; manufactures
Other services & trade	Trade; public services; communication; insurance; financial and business services; dwellings
Petroleum & coal products	Petroleum & coal products
Processed food	All processed food; vegetables; beverages and tobacco
Textiles & clothing	Textiles; wearing apparel; leather products
Transport	All kinds of transport (sea, air etc.)
Utility	Gas manufacture and distribution; water

Source: Own calculations, 2018

Table H2: Exogenous variables in the model used

Exogenous variables	**Meaning**
AOALL	Output augmenting technical change in sector j of r
AOREG	Output technical change in region r
AOESEC	Output technical change of sector j, worldwide
AFALL	Intermediate input i augmenting technical change by j in r
AFCOM	Factor input technical change of input i, worldwide
AFEALL	Primary factor i augmenting technical change sector j in r
AFEREG	Factor input technical change in region r
AFESEC	Factor input technical change of sector j, worldwide
ATALL	Technical change in market supply shipping of i from region r to s
AU	Input-neutral shift in utility function
AVAALL	Value added augmenting technical change in sector j of r
AVAREG	Value added technical change in region r
AVASEC	Value added technical change of sector j, worldwide
CGDSLACK	Slack variable for qcdgs(r)
DPGOV	Government consumption distribution parameter
DPPRIV	Private consumption distribution parameter
DPSAVE	Saving distribution parameter
ENDWSLACK	Slack variable in endowment market clearing condition
INCOMESLACK	Slack variable in the expression for regional income
PFACTWLD	World price index of primary factors
POP	Regional population
PROFITSLACK	Slack variable in the zero profit equation
PSAVESLACK	Slack variable for the savings price equation
QO(ENDW_COMM, REG)	Initial endowment of commodities in region r
TF	Tax on primary factor i used by j in region r
TFD	Tax on domestic i purchased by j in r
TFM	Tax on imported i purchased by j in r
TGD	Tax on domestic i purchased by government household in r
TGM	Tax on imported i purchased by government household in r
TM	Source-generic change in tax on imports of i into s
TMS	Source-specific change in tax on imports of i into s
TO	Output (or income) tax in region r
TP	Commodity, source-generic shift in tax on private consumers

Table H2: Exogenous variables in the model used

Exogenous variables	Meaning
TPD	Commodity, source-specific shift in tax on private consumers of domestic i
TPM	Commodity, source-specific shift in tax on private consumers of imported i
TRADSLACK	Slack variable in tradeables market clearing condition
TX	Destination-generic change in subsidy on exports of i from r
TXS	Destination-specific change in subsidy on exports of i from r

Source: Center for global trade analysis (2018)

8.2 Additional simulation results

Table H3: Effect of a simulated (sim.) increase in TFD on quantity imported at market prices measured as a % change

Sectors	5% sim.	15% sim.	40% sim.
Agriculture	-0.09	-0.26	-0.7
Basic materials & chemical products	0.01	0.02	0.06
Coal	-0.2	-0.6	-1.59
Construction	-0.32	-0.95	-2.52
Electricity	-0.19	-0.57	-1.52
Gas	-0.02	-0.07	-0.18
Oil	-0.91	-2.73	-7.29
Other manufacture	-0.16	-0.47	-1.24
Other services & trade	-0.17	-0.5	-1.34
Petroleum & coal products	1.43	4.28	11.42
Processed food	-0.08	-0.24	-0.63
Textiles & clothing	-0.11	-0.34	-0.9
Transport	0.48	1.44	3.83
Utilities	-0.25	-0.76	-2.03

Source: Own calculations, 2018

Table H4: Effect of a simulated (sim.) increase in TPD on quantity imported at market prices measured as a % change

Sectors	5% sim.	15% sim.	40% sim.
Agriculture	0.01	0.03	0.08
Basic materials & chemical products	-0.00	0.00	0.00
Coal	-0.20	-0.59	-1.56
Construction	0.02	0.06	0.16
Electricity	0.18	0.55	1.46
Gas	-0.02	-0.08	-0.62
Oil	-0.63	-1.9	-5.08
Other manufacture	0.01	0.04	0.12
Other services & trade	0.02	0.06	0.15
Petroleum & coal products	0.46	1.39	3.7
Processed food	0.02	0.05	0.13
Textiles & clothing	0.02	0.06	0.15
Transport	0.00	0.00	0.01
Utilities	0.02	0.07	0.18

Source: Own calculations, 2018

8.3 Supplementary materials

Supplementary materials for this thesis including the detailed results for all tax simulations can be found online at www.ekoninternt.se/sup/reld0002.htm.

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