Green fiscal policy in an empirical UK E-SFC model

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Abstract

Green fiscal policy is at the core of the net zero commitments of countries around the world. However, the exact macroeconomic, financial and environmental implications of the use of green fiscal policy tools within country-specific contexts are not sufficiently understood. This paper develops an empirical ecological stock-flow consistent (E-SFC) model for the UK economy that can analyse how the UK macrofinancial system and emissions can be affected by the implementation of green fiscal policy tools, such as carbon taxes, green subsidies and green public investment.The model synthesises the empirical SFC approach with ecological macroeconomic approaches and is designed to accurately reflect the accounting structure of the UK economy. Our simulation analysis sheds light on the (direct and indirect) channels by which the use of different fiscal policy tools can affect the UK economy and emissions, and illustrates that the effects can be very different depending on how green fiscal policy tools are exactly designed and implemented.

Keywords

Ecological macroeconomics; Climate change; Green fiscal policy; Stock-flow consistent modelling

JEL classification

E12, E62, Q43, Q57, Q58

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1 Introduction

Governments' decarbonisation commitments around the world have increased over the last years. However, the gap between these commitments and the policies that are necessary to be put in place to limit global warming to 1.5^{o}C or 2^{o}C above pre-industrial levels is still very large (IPCC 2023). On top of this, there is a limited understanding of the country-specific macrofinancial implications of ambitious decarbonisation policies. This limited understanding act as a barrier to the design of effective climate policy mixes at the national level.

Green fiscal policy is at the core of these decarbonisation commitments (Pigato 2019; HM Government 2021). Although economists have traditionally considered carbon pricing as the main fiscal policy that should be used to address the climate crisis, recent years have seen a growing attention to other green fiscal tools as well. For example, proposals for a global 'Green new deal' have emphasised the crucial role of green public investment (Chomsky and Pollin 2020), while the recent Inflation Reduction Act (IRA) in the US has shifted a lot of attention to the role of green subsidies (Kleimann et al. 2023).

From a modelling perspective, the academic literature on green fiscal policy can be classified into three strands. First, there is a vast literature that has explored the implications of green fiscal policy within theoretical or global models. This literature includes the Integrated Assessment Models (IAMs) that have largely drawn on Nordhaus' Dynamic Integrated Climate Economy (DICE) model in which carbon pricing is analysed within a framework that combines a growth analysis a la Ramsey with a climate module that captures how carbon pricing interacts with emissions and climate damages (Nordhaus 2018; Barrage and Nordhaus 2023). It also includes environmental Dynamic Stochastic General Equilibrium (E-DSGE) models that have analysed the implications of carbon pricing from a business cycle perspective (Golosov et al. 2014; Diluiso et al. 2021), as well as ecological stock-flow consistent (E-SFC) models that have analysed a wide range of green fiscal policies, paying attention both to transition and long-run effects from a macrofinancial perspective (Monasterolo and Raberto 2018; Dafermos and Nikolaidi 2019).

Second, there are country-specific papers that rely on econometric models or input-output methods. For example, Batini et al. (2022) and Onaran and Oyvat (2023) have estimated country-specific output and employment effects of green public spending, while Pollin and Chakraborty (2015) and Pollin, Wicks-Lim, et al. (2022) have used input-output techniques to estimate environmental and employments effect of green spending.

Third, there are a few country-specific macro models that have been used to analyse the implications of green fiscal policies. These include environmental computable general equilibrium (CGE) models that have been used to analyse carbon taxes (Meng et al. 2013), green subsidies (Kalkuhl et al. 2013) and feed-in-tariffs (Wei et al. 2019), but also New Keynesian models, such as the National Institute of Economic and Social Research (NiESR) model that has been recently used for exploring climate policy scenarios (Hantzsche et al. 2018; NGFS 2022).

Despite this vast literature, significant gaps remain. IAMs, CGE models and DSGE models suffer from several key limitations when analysing climate policies. These models typically assume that agents make decisions under rational expectations, assume full employment in the economy leading to interventionist policy being viewed purely as a cost and have little to no role for finance or the financial system. Econometric models and input-output models provide valuable insights, but they cannot provide a holistic, forward-looking analysis of the direct and indirect effects of green fiscal policies. E-SFC models address the limitations of equilibrium frameworks, but have not so far been used for a country-specific evaluation of climate policies.

The purpose of this paper is to address this gap by developing the first country-specific E-SFC model that can be used to explore the environmental, macroeconomic and financial effects of green fiscal policies in the UK within a holistic framework that is not constrained by the straightjacket of equilibrium analysis and pays particular attention to macrofinancial feedback loops. The UK economy has been selected for two reasons: first, the national accounting data for the UK is very rich, permitting the development of detailed balance sheet and transactions matrices; second, the UK government has clear decarbonisation commitments, making it easier to develop a rich climate policy scenario analysis. However, the purpose of the paper moves beyond the UK since the methodology that we develop to build the E-SFC model can be applied to other countries as well.

The rest of the paper is structured as follows: Section 2 provides a brief overview of macroeconomic and environmental modelling approaches for the UK and justifies the use of the empirical E-SFC approach. Section 3 describes the overall structure and the key features of the model, while Section 4 zooms in on the channels through which fiscal policies affect macroeconomic, financial and environmental variables in the model. Section 5 shows the effects of several fiscal policy scenarios on key economic variables, with Section 6 summarising and concluding.

2 Macroeconomic and environmental modelling for the UK: the need for an E-SFC approach

2.1 Key UK macroeconomic models

While there are a many UK macroeconomic models, all with differing focuses and theoretical foundations, there are two that stand out as being used by key UK institutions for policy analysis and forecasting. These are the "Central Organising Model for Projection Analysis and Scenario Simulation" (COMPASS) model used by the Bank of England (BoE) and the "Office for Budget Responsibility (OBR) Macroeconomic Model" used by the OBR. Both models are data-driven and UK specific.

The COMPASS model (Burgess, Fernandez-Corugedo, et al. 2013) is a New Keynesian DSGE model and is similar to models used by other central banks. It is built on micro-foundations of representative utility maximising agents who make decisions under rational expectations. Exogenous stochastic stocks are included, which result in model fluctuations around a calibrated equilibrium position. The economic variables considered in the base model are limited to high level economic variables, with the model generally being used to inform the BoE's monetary policy.

The OBR macroeconomic model (OBR 2013) is a large scale macro-econometric model as opposed to a DSGE model like COMPASS. The model therefore drops some of the restrictive assumptions of DSGE models. For example, the representative utility optimising agent is replaced by econometric estimations of the behaviour of aggregated groups/sectors. The model employs a simplified representation of the economic activity recorded by the Office for National Statistics (ONS) with accounting identities forming the base of the model and econometrically estimated behavioural equations included where required. There is also no reliance on general equilibrium in the OBR model with the model evolving according the the econometric equations. The OBR model has been specifically designed with government budgets in mind, as such it has a highly disaggregated government sector and therefore includes a very large range of inputs to this sector.

While these models' differing focuses, there are some common limiting characteristics they share. In particular, both models have very limited treatment of the role of finance. Neither include an explicit financial sector with finance playing only an implicit role of inter-mediating funds between different sectors. This fundamentally ignores the role of banks as creating money endogenously (Lavoie 2014), with the issues this creates for modelling being highlighted by Jakab and Kumhof (2018). Additionally, the models do not consider financial balances extensively and focus primarily on monetary flows. This risks ignoring the structural and behavioural implications of phenomena, such as growing household indebtedness. Where financial balances are included, this is not done in a stock-flow consistent way, i.e. the stocks are not directly linked to flows, so their evolution in the model is not determined endogenously limiting the scope to analyse them. The fallout of the financial crisis made it clear that models should adopt a more integrated view of finance. This becomes even more important with the role of finance and financial instability becoming increasingly clear for analysing ecological effects and policies. Therefore, this limited approach to finance represents a key shortcoming of these modelling approaches.

2.2 Macreoconomic modelling of UK climate policies

Several models have been used to analyse the effects of climate mitigation policies in the UK. The first model to look at is the National Institute Global Econometric Model (NiGEM). This model was developed by the National Institute of Economic and Social Research (NiESR) and acts as a multi-country econometric model with different calibration for each country considered. The model is currently used in NiESR policy analysis, including specifically for the UK (e.g. King et al. (2022)). Additionally NIGEM is the model currently used by the Network for Greening the Financial System (NGFS) as the economic side of their climate scenario analysis (NGFS, 2022).

The NiGEM model is a New-Keynesian model which incorporates energy use on the supply side. It relies on agents with rational expectations and general equilibrium to function and does not include any role for the financial system. As such there is little role for financial assets and the interaction between stocks and flows. Furthermore, the UK specific module is simply a general model calibrated with UK data as opposed to a model derived specifically around the structure of the UK economy. As such, the model may ignore important phenomena to the UK, although this is already evident through its lack of finance which is known to play a key role in the functioning of the UK economy. Due to its theoretical limitations, the NiGEM model cannot incorporate key macro-financial effects which could be critical for analysing climate policy.

The next UK model is the Multisectoral Dynamic Model - Energy-Environment-Economy (MDM-E3) model developed by Cambridge Econometrics that has also developed the global Energy-Environment-Economy Macro-Econometric Model (E3ME) model. These models reject general equilibrium and incorporate some post-Keynesian principles such as allowing for long-term unemployment and imperfect markets. A key strength of these models is the high degree of dissagregation both in terms of sectors and geographic regions. The disaggregation of the model makes it suitable for analysing the sectoral effects of policies. However, there is still little to no role for finance and the models are not stock-flow consistent. This is understandable as this would greatly add to the complexity of already highly complex models. This does mean that these models cannot be used to properly analyse the financial effects of policies and the impacts of green financial policy. Therefore, while the theoretical foundations of MDM-E3 are stronger than NiGEM it is still limited by its treatment of finance.

Overall, although empirical Macro-climate models exist in the UK there are common gaps within these models, which suggest there would be a benefit to developing a UK focused empirical SFC model to assess climate policies. Since none of these models have a detailed view of finance they are unable to assess the effects of climate policies on the financial system along with the role of climate financial policy. Empirical SFC models include finance implicitly and therefore represent a promising methodology for the construction of our desired model. Additionally, the inclusion of post-Keynesian characteristics in MDM-E3 suggest that there is a recognition of the importance of these post-Keynesian fundamentals when assessing climate policy which lends support to adopting a post-Keynesian SFC modelling approach.

2.3 Towards an empirical E-SFC model for the UK

Stock-flow consistent modelling is an alternative macroeconomic modelling approach originating from post-Keynesian economics and first popularised by Godley and Lavoie (2006). The models take a holistic approach to modelling, not relying on micro-foundations, representative agents or rational expectations, leading to more realistic behavioural equations. In particular SFC models are well placed to analyse the role of finance in the economy, a key shortcoming of all models discussed thus far, as financial balances are explicitly included in the model to ensure stock-flow consistency. Furthermore the structure of SFC models closely resembles the system of national accounts which makes them particularly useful for empirical modelling. Recently, SFC models have been extended to include ecological factors and used to analyse climate policies (Dafermos, Nikolaidi, and Galanis 2018; Monasterolo and Raberto 2018). Most SFC models are not country-specific and rather take a theoretical approach to general macroeconomic analysis (see Godley and Lavoie (2006), Lavoie (2011), and Godley and Lavoie (2012)). This limits the models abilities to consider the varied effects that different policies will have within different countries and any unique characteristics of certain countries which should be modelled explicitly. There has however been work from the BoE to develop an SFC model for the UK economy.

Following the financial crisis Burgess, Burrows, et al. (2016) recognising the limitations of the DSGE approach to financial balances, developed an Empirical SFC model for the UK (Burgess, Burrows, et al. 2016). This model is a relatively complex SFC model which core structure is based heavily on Godley and Lavoie (2012). Elements of the model are tailored to the UK, in particular financial sectors are split between Banks and insurance companies and pension funds (ICPFs). While not stated explicitly, it can be assumed that this separation is due to the important role the ICPF sector plays in the UK economy and that this role is sufficiently different to that of the traditional banking sector such that it warrants separate modelling. However, while the UK context is taken into account, the model structure is still theory-based rather than data-driven. This is to say that, while the data is used to calibrate the model, it is not explicitly used when deciding on how the model should be structured.

Most empirical SFC models are, like that of Burgess, Burrows, et al. (2016), theoretical SFC models with behavioural parameters calibrated to available data. G. Zezza and F. Zezza (2019) propose an alternative approach where the real world data flows, provided within the system of national accounts, are used as the foundation of the structure of the model. As most sectors hold almost all types of assets this approach involves choices about what is considered significant enough to be modelled and what is not, usually based on the size of asset holdings or financial flows. The key advantage of this approach is that the model structure should, theoretically, be a good reflection of the economy it seeks to model and there is little risk of ignoring highly relevant economic processes. The development of such a model for the UK would contribute to a growing literature on empirical SFC models with models being developed for Italy (F. Zezza and G. Zezza 2020), Denmark (Byrialsen and Raza 2020) and the Netherlands (Meijers and Muysken 2022) to name a few.

However, developing an empirical SFC model for the UK would not be sufficient for analysing green fiscal policies. It is also necessary to extend the standard SFC approach to explicitly account for ecosystem variables. To do so we rely on the Dynamic Ecosystem-FINance-Economy (DEFINE) model developed by Dafermos, Nikolaidi, and Galanis (2017); (Dafermos and Nikolaidi 2019); (Dafermos and Nikolaidi 2021). Drawing on the flow-of-funds model of Georgescu-Roegen (1970), the DEFINE model incorporates physical stocks and flows into the standard SFC model structure. This allows the model to analyse how ecological variables, such as material use, energy, emissions and waste, interact with macroeconomic and financial variables.

Hence, the overall purpose of this paper is to synthesise the empirical SFC approach of G. Zezza and F. Zezza (2019) with the ecological macroeconomic modelling approach of DEFINE to develop a model of the UK economy, using ONS national accounting data. It will be shown that this approach leads to unique considerations for the UK economy and that the derived model, by taking this empirical approach, will differ in structure and scope when compared to current UK SFC models. Furthermore this approach explicitly integrates ecological variables into the empirical SFC approach to derive a DEFINE-UK model that can be used to assess the impacts of fiscal policies for a low-carbon transition.

3 Model Structure

3.1 Derivation of accounting structure

Drawing on the approach of G. Zezza and F. Zezza (2019), the models accounting structure is derived directly from UK national accounting data. The main source of this data will be the most recent publication of the ONS blue book (ONS 2022). Given that the aim is the derive the model from this data with as little theoretical assumptions, the first step is to decide which sectors to include in the model. The aim is to strike the balance between sufficiently disaggregated sectors to understand key relationships in the UK economy while not having so many sectors that the model becomes cumbersome and lacking in available data for calibration. While SFC models would typically decide which sectors to include based on theoretical assumptions, we instead shall be guided by the data at this early stage so that the chosen sectoral breakdown adequately reflects the structure and nuances of the UK economy. To begin with, we consider the highest level sectors in the data for which we still have a complete model[2]. These are Non-financial corporations (S.11), Financial corporations (S.12), General Government (S.13), Household and NPISH (S.14+S.15) and the Rest of the world (S.2). To assess the importance of these sectors we can look at their holdings of real assets, financial assets, financial liabilities and their contribution to output as a percentage of the total. As we have a complete model, the total value of assets minus liabilities will add up to zero across all sectors and all the sum of percentage values will equal 100, excluding the rest of the world sector. These values are displayed in Table 1.

Table 1: Stock and flow contributions by sector

Sector	Real Assets (%)	Financial Assets (%)	Financial Liabilities (%)	Output (%)
Non-financial corporations	36.2	7.2	17.3	64.1
Financial Corporations	1.4	70.7	70.7	8.9
General Government	7.6	2.0	5.7	11.0
Households and NPISH	54.8	20.0	6.3	16.0
Domestic Total	**100**	**100**	**100**	**100**
Rest of the world	-	34.6	33.6	-

It was found that for most of these sectors it did not make sense to subdivide further, usually due to a single sub-sector being very dominant meaning that the higher level sector is fairly representative. This was, however, not the case for the financial corporation sector. Table 2 shows the values when we subdivide financial corporations into Monetary financial institutions (S.121+S.122+S.123), Financial corporations except MFI and ICPF (S.124+S.125+S.126+S.127) and Insurance and pension funds (S.128+S.129).

Table 2: Stock and flow contributions with disaggregated financial sector

Sector	Real Assets (%)	Financial Assets (%)	Financial Liabilities (%)	Output (%)
Non-financial corporations	36.2	7.2	17.3	64.1
MFI	-	40.1	39.2	-
FC except MFI + ICPF	-	17.6	19.0	-
ICPF	-	13.1	12.6	-
General Government	7.6	2.0	5.7	11.0
Households and NPISH	54.8	20.0	6.3	16.0
Domestic Total	**100**	**100**	**100**	**100**
Rest of the world	-	34.6	33.6	-

Interestingly the non-MFI financial sub-sectors have large contributions in terms of financial assets and liability holding when compared to the MFI sector which includes the more “traditional” banking activities. In fact the two non-MFI sectors combined almost match the MFI sector for contribution to the economy in these terms. We know that MFIs and non-MFIs carry out different functions within an economy and the size of the UK non-MFI sector suggests it may be prudent to model it separately. Given

[2] By this we mean that all economic flows and stocks can be attributed to a sector. For example, one could ignore the rest of the world sector and create a closed economy model but this would not be complete as any flows and stocks associated with this sector would be ignored.

that the role of finance is a key area of analysis for this model, we decide to build a 6 sector model of Non-financial corporations, MFIs, non-MFIs, Government, Households (and NPISH) and the Rest of the world. It should be noted that there are clear parallels here to the Burgess, Burrows, et al. (2016) SFC model which is also a 6 sector model with finance split into two sectors. A key difference is that the Burgess, Burrows, et al. (2016) model has the Banking sector as opposed to MFIs and the ICPF sector as opposed to non-MFIs. In particular our non-MFI sector includes groups of other financial corporations which are not considered by only focusing on ICPFs such as certain consumer lending financial institutions and financial advisory firms. This means our model includes a fuller range of financial activities which, as seen in Table 2, can be highly significant in a UK context.

Next we derive the transaction flow matrix for the economy. We will not include all the flows listed in the system of national accounts, but will instead assess the significance of flows to the overall economy when choosing whether to model them. This again is a way in which the structure of the model is derived from country data. A significant flow will be defined by whether it is, on average, over 1%[3] of output for the data period. As flows are removed there will need to be a residual term added to the model to ensure consistency between the sectoral net lending position in the model and the net lending position in the data which is consistent with the approach taken by F. Zezza and G. Zezza (2020) for an empirical SFC model for Italy.

When assessing the significant flows we are confronted by a key issue faced by other empirical SFC models, that of the need for whom-to-whom sectoral data. SFC models use quadruple entry bookkeeping, which is to say each transaction is an outflow of one sector, an inflow to another sector and that the transaction results in balance changes for both sectors. While national accounting data does include sectoral outflows and inflows it does not provide the whom-to-whom link between them. Take, as an example, the interest outflow of the MFI sector. We have a value for the interest outflow of the sector and we have the interest inflows for all other sectors in our model, however we do not exactly know how much of the various interest inflows comes from the MFI sector. Similarly whom-to-whom relationships are required for stock relations to relate assets to their counterpart liabilities.

Fortunately, in most cases, once insignificant flows are removed there remains either one significant outflow or inflow sector which means a whom-to-whom relationship can be established. Issues remain for production flows, interest and distributed income of corporations. In any economy production occurs across all sectors so identifying the destination of expenditure flows is non-trivial. It is often assumed that all production occurs in the NFC sector. However, national accounts tell us that this could be misleading as a significant amount of production in the UK occurs in other sectors. Therefore, we choose to include a "Production" column in our transaction flow matrix which will be defined as the destination for all expenditure flows and the origin of all production flows. This is again consistent with the approach taken by F. Zezza and G. Zezza (2020). For interest and distributed income of corporations we note that these are flows which relate to specific assets therefore we can use the asset levels to determine how to split these flows between sectors, this will be shown when deriving the balance sheet matrix. The derived transaction flow matrix is given by Table 3.

[3]This value is arbitrary. A lower number would make more flows significant and increase the complexity of the model whereas a higher value would make the model simpler by removing more flows. 1% was found to be a good balance between representing sufficient flows without making the model overly difficult to manage.

Table 3: Transaction Flow Matrix

Transaction Flow Matrix								
Flows		Sector						
	Production	**NFC**	**MFI**	**Non-MFI**	**GVT**	**HH**	**RoW**	**Total**
GDP Expenditure								
Consumption	+CONS				-CONS_gvt	-CONS_hh		0
Gross Capital Formation	+GCF	-GCF_nfc			-GCF_gvt	-GCF_hh		0
Exports	+EXP						-EXP	0
Imports	-IMP						+IMP	0
GDP Income								
Wages	-WAGES					+WAGES		0
Taxes	-INDTAX				+INDTAX			0
Gross operating surplus	-GOS	+GOS_nfc	+GOS_mfi	+GOS_nmfi	+GOS_gvt			0
Transactions								
Interest		+/-	+/-	+/-	-	+/-	+/-	0
Dividends		+/-	+/-	+/-	+	+	+/-	0
Taxes on income		-INCTAX_nfc			+INCTAX	-INCTAX_hh		0
Social Contributions				+SOCC_nmfi	+SOCC_gvt	-SOCC		0
Social Benefits				-SOCB_nmfi	-SOCB_gvt	+SOCB		0
Residual Transaction	+/-	+/-	+/-	+/-	+/-	+/-	+/-	0
Net lending		LEND_nfc	LEND_mfi	LEND_nmfi	LEND_gvt	LEND_hh	LEND_row	0

For the balance sheet matrix we start by including real assets for NFCs, Households and the GVT sector as the level of real capital is not significant for other sectors. For financial assets we are conscious of the requirement for interest and dividend flows to be clearly related to balance sheet assets. Consider the high level stocks in the system of national accounts shown in Table 4.

Table 4: High level stocks in UK national accounts

Stock Code	Stock Name
F.1	Monetary gold and special drawing rights
F.2	Currency and Deposits
F.3	Debt Securities
F.4	Loans
F.5	Equity and investment fund shares/units
F.6	Insurance, pensions, and standardised guarantee schemes
F.7	Financial derivatives and employee stock options
F.8	Other accounts receivable

Of these stocks interest flows are derived from F.2,3 and 4 whereas F.5 is linked to dividend flows and F.6 to pension flows. Monetary gold and specialdrawing rights (F.1) and Other accounts receivable (F.8) are moved to the residual as both contribute less that 1% to overall asset levels. We also elect to move financial derivative and employee stock options (F.7) to the residual as, while this is a large item, it mainly includes inter-bank refinancing which should have limited effects on monetary flows in the economy. We therefore use an approach similar to Byrialsen and Raza (2020) in their Denmark SFC model, where balances are split between Interest bearing assets, Equities and Pensions. We overall derive the following balance sheet matrix in Table 5. The correspondence between this balance sheet and national accounting data is described in Table 4.

Table 5: Balance Sheet Matrix

Balance Sheet							
Assets/liabilities	Sector						
	NFC	**MFI**	**Non-MFI**	**GVT**	**HH**	**RoW**	**Total**
Real assets							
Capital (firms)	+KF						+KF
Capital (public)				+KG			+KG
Housing					+HOUSES		+HOUSES
Financial Assets							
Household Deposits		-DEP^{HH}			+DEP^{HH}		0
Household Loans		+$LOANS^{HH}$			-$LOANS^{HH}$		0
Household Pensions			-$PENS_{HH}$		+$PENS_{HH}$		0
Foreign Investment		+FI				-FI	0
NFC Deposits	+DEP^{NFC}	-DEP^{NFC}					0
NFC LOANS	-$LOANS^{NFC}$	+$LOANS^{NFC}$					0
GVT Borrowing		+BRW^{GVT}_{MFI}	+BRW^{GVT}_{NMFI}	-BRW^{GVT}		+BRW^{GVT}_{RoW}	0
NMFI Deposits		-DEP^{NMFI}	+DEP^{NMFI}				0
NMFI Borrowing		+BRW^{NMFI}	-BRW^{NMFI}				0
BRW IBL		-DEP^{RoW}				+DEP^{RoW}	0
Net Equity	+/-		+/-		+	+/-	0
Residual Transaction	+/-	+/-	+/-	+/-	+/-	+/-	0
Net Worth	NW_NFC	NW_MFI	NW_NMFI	NW_GVT	NW_HH	NW_ROW	K + HOUSES

Table 6: Balance Correspondance to National Accounting Data

Stock	Correspondence to national accounts
DEP^{HH}	Calculated as the sum of all Household IBAs (F2,F3,F4)
LOANS^{HH}	Calculated as the sum of all Household IBLs (F2,F3,F4)
PENS^{HH}	Taken as total household pensions (F6)
FI	Calculated as the sum of all RoW IBLs (F2,F3,F4)
DEP^{NFC}	Calculated as the sum of all NFC IBAs (F2,F3,F4) less the IBL^{RoW} holding
LOANS^{NFC}	Calculated as the sum of all NFC IBLs (F2,F3,F4)
BORROW^{GVT}	Calculated as the sum of all GVT IBLs (F2,F3,F4)
DEP^{NMFI}	Calculated as the sum of all NMFI IBAs (F2,F3,F4) less all the above IBL asets for other sectors
BORROW^{NMFI}	Calculated as the sum of all NMFI IBLs (F2,F3,F4)
BRW^{MFI}	Calculated as the sum of all MFI IBLs (F2,F3,F4) less other liabilities
Equity	Equity Holdings amongst and within sectors

3.2 Model calibration

The accounting structure provides the basis of the model in the form of identities corresponding to the rows and columns of the matrix. To complete the model we include behavioural equations to determine the evolution of most model variables. In general, the structure of these behavioural equations is based on post-Keynesian assumptions, as is common amongst SFC models. Parameters are then calibrated using the same national accounting data used to derive the model accounting matrices. We calibrate the model using quarterly data between 1997 and 2019.

For our econometric estimations, we use the ordinary least squares (OLS) approach, specifically auto-regressive distributed lag (ARDL) models. Key behavioural equations, such as household consumption and firm investment, are estimated using the ARDL models. However, it is not always possible to estimate parameter and variable values in this way. In these cases, we adopt a pragmatic approach: we either use other studies to estimate parameters for certain relationships, as is done by Burgess, Burrows, et al. (2016) or we assume that variable values are determined exogenously as is the case for some parameters within the OBR (2013) model.[4]

3.3 Model overview

With the accounting structure and behavioural equations established we can now describe the overall structure of the model, which is presented in Figure 1. Many of the transactions involve the production process; with GDP expenditure in the form of consumption (CONS), gross capital formation (GCF) and exports (EXP) less imports (IMP) flowing into the production module. Meanwhile GDP income in the form of wages, gross operating surplus (GOS) and indirect taxes on production (INDTAX) flow out from the production module. The separation of production in this way allows the model to reflect the fact that in the UK production occurs across many sectors to greater or lesser degrees. However, the productive module should not be confused with the other sectors: it does not hold any assets or liabilities and simply serves as receiving productive "expenditure" and then distributing productive"income". Along with the flows, Figure 1 displays the balance sheet of each sector with assets shown on the left column and liabilities on the right.

We now summarise the behaviour of each sector in the model. The household sector undertakes consumption and gross capital formation (in the form of house building) as its productive expenditure. Households receive wages from the production process which correspond, in national accounting, to the compensation of employees and mixed income, they also receive a portion of gross operating surplus which corresponds mostly to imputed rents from home ownership. They pay income tax directly to the government sector based on their wage level, make social contributions to both the government and Non-MFI sectors and receive social benefits in return. Households hold housing as a real asset. As for financial assets, they hold pensions, which are a liability of the Non-MFI sector, deposits, which are a liability of the MFI sector and equity. Loans are households' only financial liability (predominantly mortgages) and these are held as assets by the MFI sector.

Non-financial corporations undertake gross capital formation and receive gross operating surplus from the productive process, which is their main source of income. They hold capital as a real asset. Their financial assets are deposits with MFIs and net equity assets. Their primary liability is loans held by UK MFIs.

MFIs hold loans as assets which are liabilities of many other model sectors along with foreign investment (FI) in the RoW sector and borrowing from the government sector (bonds). Their liabilities are made up entirely by deposits from other model sectors.

[4]For example, we assume that the allocation of gross operating surplus between sectors follows a fixed ratio based on 2019 values. While sectors' relative surplus from production changes over time, major changes are unlikely in the short term and as such this assumption is justified, as the purpose of the model is not to provide a long term forecast but rather to explore the effects of green fiscal policy scenarios in the short to medium term.

Non-MFIs receive a potion of household social contributions and provide a portion of social benefits attributable to pension contributions and insurance. On the asset side of their balance sheet, they hold a portion of government bonds and net equity. Regarding liabilities, they hold household pensions and loans from the MFI sector.

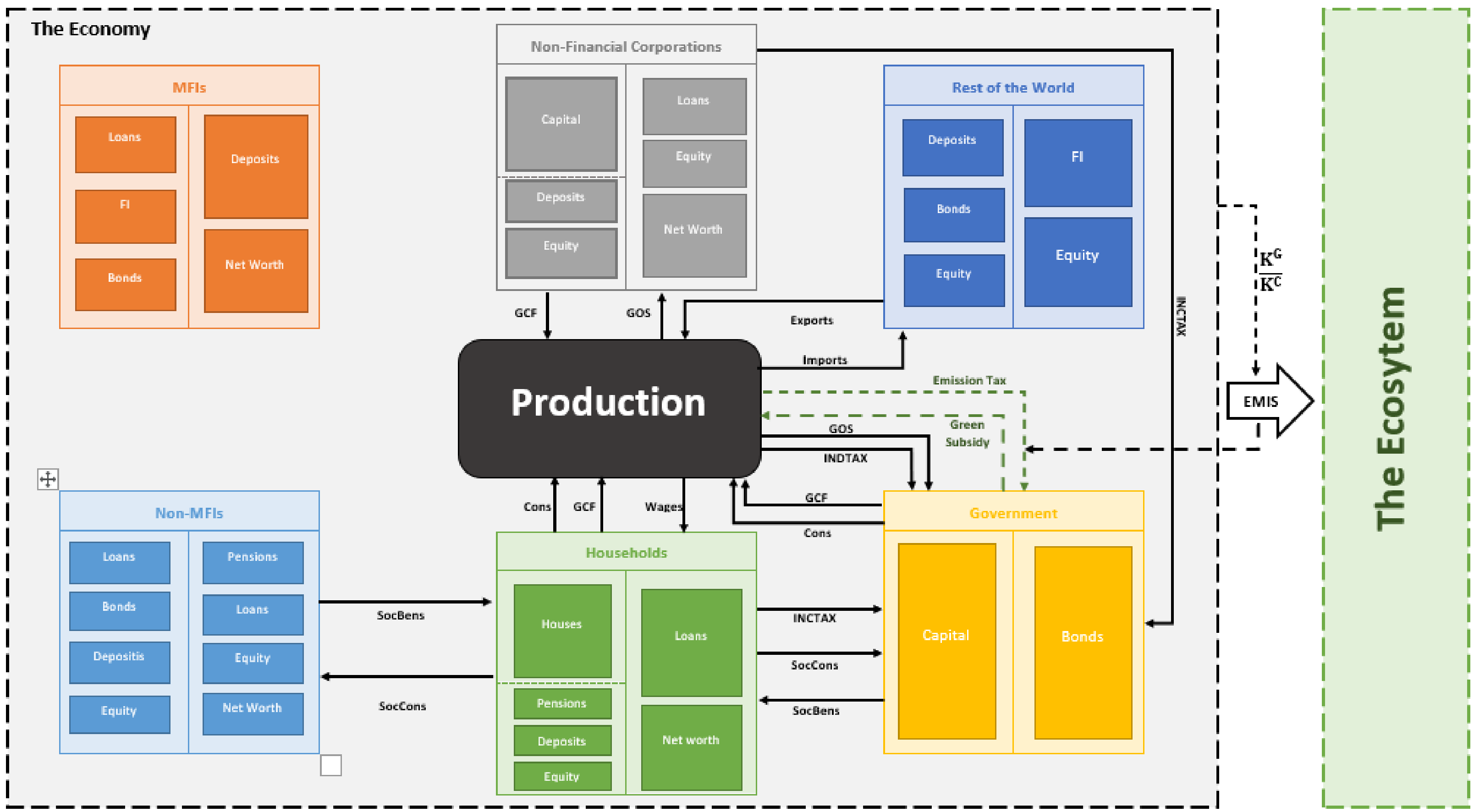
The government sector undertakes both government consumption and gross capital formation, which are assumed to equal a portion of GDP and can be adjusted in different fiscal policy scenarios. The government receives a portion of the gross operating surplus from production along with indirect taxes on production. Emission taxes are a part of indirect taxation and therefore flow between the production process and government as well with green subsidies on the other hand being paid into the productive module by the government. The government sector also receive a portion of household social contributions and provide social benefits, such as unemployment benefits and social protection transfers. Additionally, the government receives income tax based on wages from both Households and Non-financial Corporations. On the asset side, the government only holds real assets in the form of capital. Government borrowing (in the form of government bonds) is the only liability, with bonds being held by the MFIs, non-MFIs and the RoW, in effect all of the domestic and foreign financial corporations.

Finally the RoW sector pays for exports and receives income for imports in relation to the domestic production process. On the asset side, the RoW holds Deposits with UK MFIs, government bonds along with net equities. The main liability of the RoW sector that relates to the domestic economy is that of foreign investment (FI) held by MFIs.

Sitting alongside these interactions are, interest and dividend flows. These are related directly to the various assets and liabilities and flow between many sectors, with all financial assets having associated interest flows aside from net equities which lead to flows of dividends. These are not displayed as flows in Figure 1 for figure readability. They are, however, implied by the sectoral balances.

The ecosystem interacts with the model in terms of receiving carbon emissions, the level of which is driven by the ratio between green and conventional capital within the economy along with the overall level of domestic output.

While much of this structure is standard to macroeconomic models, and particularly SFC models, it can be seen how the empirical SFC approach has lead to different considerations to other models. Some examples that illustrate this: the separation of production is non-standard, but is necessary to reflect that production does not occur uniquely in one national accounting sector; pensions are not always included in SFC models but are found to be a highly significant household asset within the UK so are included in the model; social contributions and social benefits are rarely modelled but are found to be highly significant flows within the UK national accounts and therefore need to be included in the model.



Acronyms:

MFI: Monetary Financial Institutions

FI: Foreign Investment

GOS: Gross Operating Surplus

GCF: Gross Capital Formation

$\mathbf{K^G}$: Green Capital

$\mathbf{K^C}$: Conventional Capital

Cons: Consumption

INCTAX: Income Tax

INDTAX: Indirect Production Tax

SocBens: Social Benefits

SocCons: Social Contributions

Notes: This diagram presents a simplified version of the model. In particular, interest and dividend flows are not included as they flow between most sectors. In addition, stocks are presented as balance sheets with assets on the left and liabilities on the right but this daigram does not show the correspondence between different assets and liabilities.

Figure 1: Simplified Model Overview

4 Green Fiscal Policy: Key Model Channels

We now turn to describe some key channels through which green fiscal policies can affect macroeconomic, financial and environmental variables in the model.[5] The three key fiscal policy tools that we focus on are emission taxation/pricing, green subsidies and green public investment.

4.1 Macroeconomic Channels

The policies initially impact the income side of GDP. Emission taxation and green subsidies have an impact on indirect taxation ($INDTAX$). The carbon tax reduces sectors' overall operating surplus (GOS) in Eq.(1) and impacts, in particular, the NFC sector. This in turn has a negative impact on NFC investment demand, as this demand is driven positively by the ratio between NFC gross operating surplus (GOS_{NFC}) and NFC capital (K_{NFC}) (Eq. (6)). This in turn reduces total NFC investment (GCF_{NFC})(Eq. (7)). This reduction is also driven by the lower availability of loans to the NFC sector due to the higher credit rationing imposed by MFIs.

Gross domestic product (GDP), given by the sum of consumption ($CONS$), investment (GCF) and exports (EXP) minus imports (IMP), is therefore negatively impacted by an increase in carbon tax. This in turn leads to negative impacts on other components of GDP. For example, household consumption ($CONS_HH$) falls due to lower household income (YD_{HH}) driven by falling wages. In the case of a green subsidy, the opposite effects would be expected with this policy having an expansionary effect on GDP.

Green public investment, on the other hand, directly increases overall investment (4) by increasing government investment (GCF_{GVT}). This leads to higher overall GDP, which then has positive knock on effects on wages, consumption and private investment. Although green public investment has a negative immediate impact on the government deficit, this can be partly mitigated by higher overall GDP and additional tax revenue.

$$GOS = GDP - WAGES - INDTAX \tag{1}$$

$$GDP = CONS + GCF + EXP - IMP \tag{2}$$

$$CONS = CONS_{HH} + CONS_{GVT} \tag{3}$$

$$GCF = GCF_{HH} + GCF_{NFC} + GCF_{GVT} \tag{4}$$

$$CONS_{HH} = f(\overset{+}{YD}_{HH}, \overset{+}{NW}_{HH}) \tag{5}$$

$$GCF^D_{NFC} = f\left(\frac{\overset{+}{GOS}_{NFC}}{K_{NFC}}\right) \tag{6}$$

$$GCF_{NFC} = RP_{NFC} + \Delta LOANS_{NFC} \tag{7}$$

4.2 Financial Channels

On the financial side, the default rate on firm loans (DEF) depends positively on firms' illiquidity ratio ($ILLIQ$), the cash outflow of NFCs relative to their cash inflow, with higher default rates leading to negative impacts on the capital of banks. The level of credit rationing on bank loans (CR) is a positive function of firms' debt service ratio (DSR_{NFC}), which is the ratio of debt payment commitments (interest plus principal repayments) to profits before interest, and depends negatively on the capital adequacy ratio (CAR) of banks.

[5] A full description of model equations is provided in Appendix.A.

$$DEF = f(\overset{+}{ILLIQ}) \tag{8}$$

$$CR = f(\overset{+}{DSR}_{NFC}, \overset{-}{CAR}) \tag{9}$$

These equations outline how financial feedback effects are captured in the model. Credit rationing constrains actual firm investment and has a recessionary impact on the economy as a whole. Carbon taxes reduce the profits of firms and thus increase their debt-service ratio which in turn leads to higher credit rationing and a lower level of firm investment. Likewise, higher default rates lower the capital adequacy ratio on banks and further increase credit rationing. While mapping the precise financial impact of each policy scenario is non-trivial, in general incorporating these effects allows the model to show the potential impacts of green policies on the financial system and then the feedback effects from the financial system to the economy as a whole.

4.3 Environmental Channels

Emissions taxes serve to increase the total unit cost of fossil fuel energy ($tucn$). Eq.(14) shows that the proportion of firm green investment ($\beta_{GCF_{NFC}}$) as the unit cost of fossil fuel energy rises becomes higher. Conversely, green subsidies reduce the total unit cost of non-fossil fuel energy ($tucr$) which motivates the increase in the proportion of green investment in total investment. Green public investment directly increases the level of government green capital, thereby increasing the overall share of green capital in the economy. All policies, in different ways, serve to increase green investment and therefore increase the ratio between green and conventional capital in the economy (K^G/K^C).

The energy intensity (INT_{ENERGY}) and proportion of energy produced by non-fossil fuel sources ($PROP_{NFF}$) both depend on the ratio between green and conventional capital in the economy (K^G/K^C) (Eqs. 12 & 13). Therefore, by increasing this ratio, green policies increase the proportion of green energy and reduce the energy intensity of production. This leads to lower overall energy use ($ENERGY$) (Eq. 11) and a lower proportion of fossil fuel energy ($ENERGY_{FF}$) which both lead to lower overall emissions ($EMIS$) (Eq. 10).

Furthermore, it should be noted that total energy is a proportion of domestic GDP (GDP_{DOM}) therefore any policies with an expansionary effect on GDP will, ceteris paribus, to higher energy use, and higher emissions, leading to rebound effects occurring for expansionary green policies.

$$EMIS = INT_{EMIS} ENERGY_{FF} \tag{10}$$

$$ENERGY = INT_{ENERGY} GDP_{DOM} \tag{11}$$

$$INT_{ENERGY} = f(-\frac{K^G}{K^C}) \tag{12}$$

$$PROP_{NFF} = f(\overset{+}{\frac{K^G}{K^C}}) \tag{13}$$

$$\beta_{GCF_{NFC}} = \beta_0^{GCF_{NFC}} - \beta_1^{GCF_{NFC}}(tucr_{-1} - tucn_{-1}) \tag{14}$$

5 Scenario analysis

The model is run on a quarterly basis starting for the period 2022 Q1 - 2030 Q4. We first develop a baseline scenario and then run several green fiscal policy scenarios.

Baseline scenario

Our baseline scenario relies predominantly on the OBR projections between 2022 Q1 and 2028 Q1. For exogenous variables we take use the actual UK data to set the initial condition and then allow the variable to follow the same growth rate as that in the OBR forecast until Q1 2028[6]. Notable exogenous variables set this way are import prices, government spending, exports and imports. In our baseline scenario, a steep rise in import prices in 2022 leads to a rise in domestic prices and a sharp increase in the Bank of England base rate. Higher interest rates impact macroeconomic and financial variables in the baseline such that real GDP growth from 2024 is close to zero and begins to increase to around 1% towards 2030. This leads to a the growth rate of real GDP following a similar path to that of the OBR forecasts in the baseline scenario.

Emissions fall over the period in the baseline scenario, driven by technological change and current green policies, following a similar trajectory as the past decade. While this means total emissions fall over the period, in the baseline this reduction is far short of the 252 MTCO2e aim which would be consistent with the UK's current 2030 nationally defined contribution target of reducing carbon emissions to 68% below 1990 levels. Instead, emissions fall to just under 350 MTCO2e. This is consistent with a 'current policy' projections for the UK in the absence of additional carbon abatement policies. The baseline projection for several key model variables can be seen in Figure 3 alongside scenario results which we will discuss now.

Green fiscal policy scenarios

We run three green fiscal policy scenarios, all scenarios are implemented in 2024 Q1.

- **Carbon Tax Increase:** The tax on emissions is increased steadily from around £15/MTCO2e to over £150/MTCO2e by 2030.[7]
- **Green Public Investment:** The government invests an additional 1% of GDP in green projects by 2030.
- **Carbon Tax + Green Subsidy:** The carbon tax is the same as in the "Carbon Tax Increase" scenario. However, all revenue is recycled as green subsidies aimed to reduce the unit cost of renewable energy.

Results between 2022 and 2030 are shown in Figure 3 for key economic and ecological variables. Figure 3a shows the dynamics of the bank of England Base rate over the simulation period. In all scenarios there is a significant increase in the base rate and this drives much of the variable dynamics shown in other figures. In particular, baseline GDP growth falls over the period, after an initial peak due to a bounce back after the pandemic lockdown policies (Figure 3b). An increase in the carbon tax alone leads to lower GDP growth by decreasing the income of NFCs, leading to lower investment. Conversely, green public investment stimulates the economy leading to higher growth rates. When taxes and subsidies are combined, the impact of growth is overall close to neutral as the increase in taxation is matched by the corresponding subsidy.

Figure 3c shows how emission price changes for different scenarios, being considerably higher in the carbon tax scenarios when compared to the baseline. All policies have a positive impact on the proportion of green investment in the economy (Figure 3d). Initially, the combined carbon tax + subsidy scenario leads to the highest increase in green investment although by the end of the period it is overtaken by

[6]We then assume that the variable follows a steady growth between 2028 Q2 and 2030 Q4

[7]The baseline emission tax is calculated based on government revenue from the UK ETS scheme according to OBR forecasts, it is therefore considerably lower than the headline figure quoted by the UK ETS. This is because we calculate the carbon tax based on all emissions rather than a subset of emissions as the ETS does and our calculation will ignore free allocations in the UK ETS scheme.

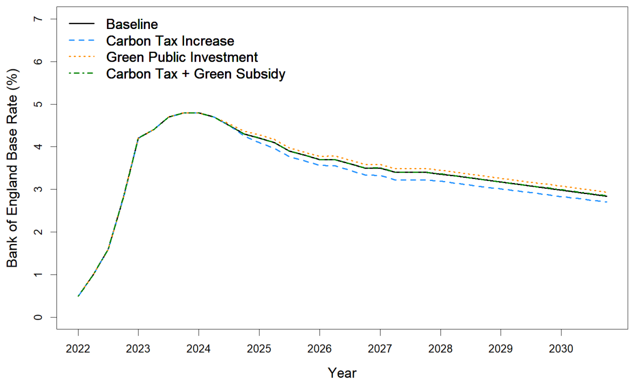
green public investment. A key reason for this is that increasing private green public investment relies on effecting the behavior of firms by making non-fossil fuel energy cheaper relative so fossil fuel energy, whereas the government can simply increase green public investment directly. The carbon tax scenario on its own is the least effective for increasing the proportion of green investment.

Figures 3e & 3f show a fall in energy intensity and emissions for all green scenarios driven by the higher level of green investment and capital. Both green public investment and carbon tax + green subsidy scenarios manage to reach the UK NDC emission level by 2030 with the latter having slightly lower emissions overall.

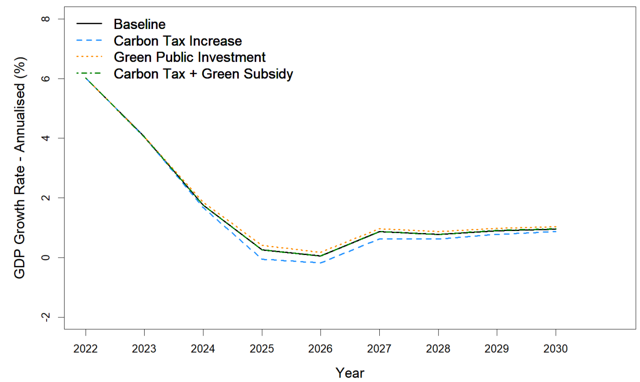
Real GDP and unemployment rate are shown in Figures 3g & 3h. It can be clearly seen that green public investment has expansionary effects while carbon taxation has recessionary impacts. Interestingly, labour does impose a supply side constraint on green public investment: a higher increase in green public investment could hit the 0% unemployment rate limit. This suggests that purely expansionary policies, in the absence of significant productivity/full time worker gains, will lead to unavailability of workers, constraining such policies.

Financial effects on firms' debt-service ratio, credit rationing and firms' default rate are shown in Figures 3i, 3j and 3h, respectively. All are negatively impacted by the recessionary impacts of a carbon tax increase, which reduces the income of firms. Furthermore, the financial impacts of policies show how these feedback effects can cause additional effects on the macroeconomy, highlighting the usefulness of models that include these channels.

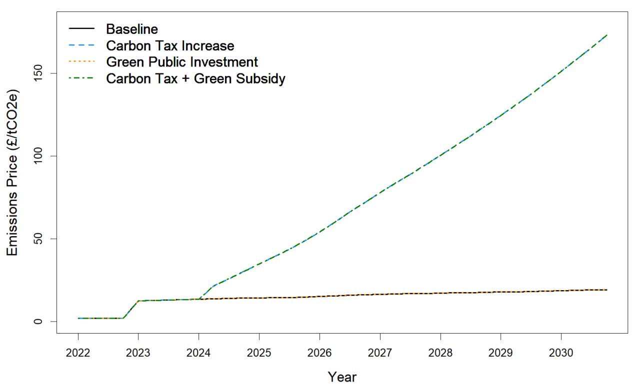
Finally, the government debt-to-GDP ratio (Figure 3l) is reduced from the baseline for the pure Carbon tax scenario which serves to increase the income of the government and is increased in the green public investment scenario.



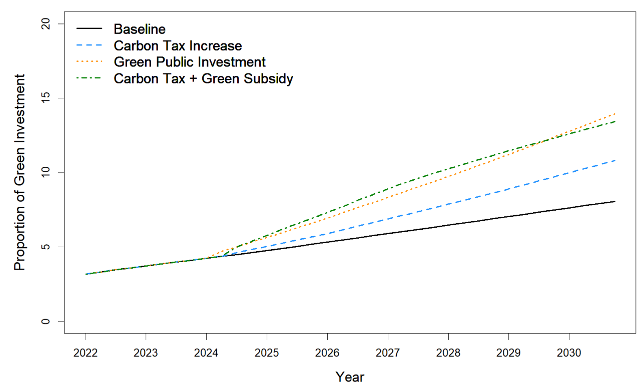
(a) Bank of England Base Rate



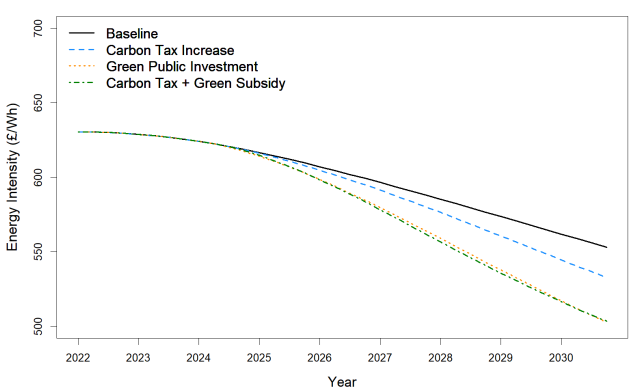
(b) Annualised GDP Growth



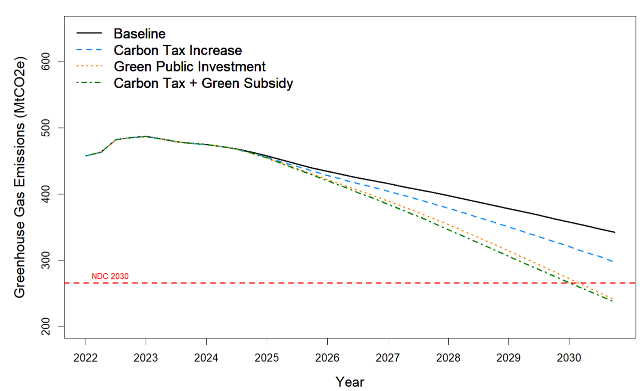
(c) Emission Price



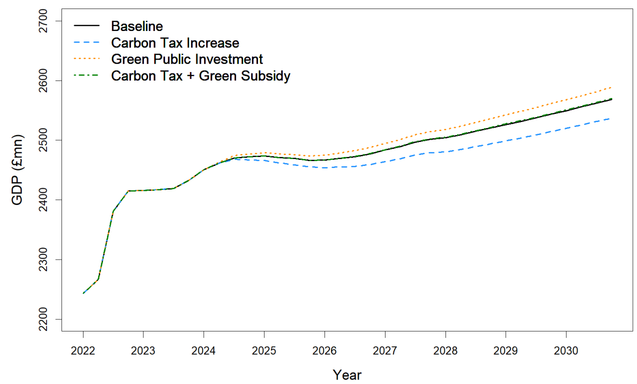
(d) Proportion of Green Investment



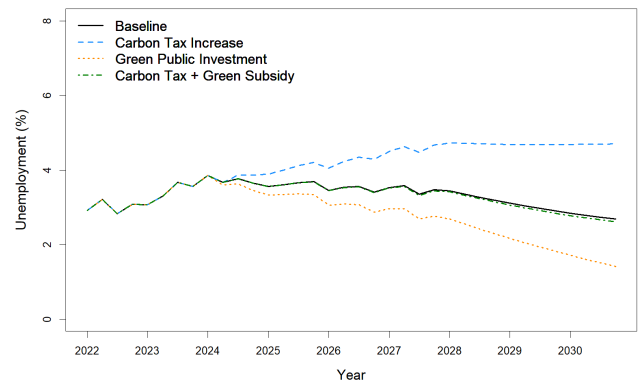
(e) Energy Intensity



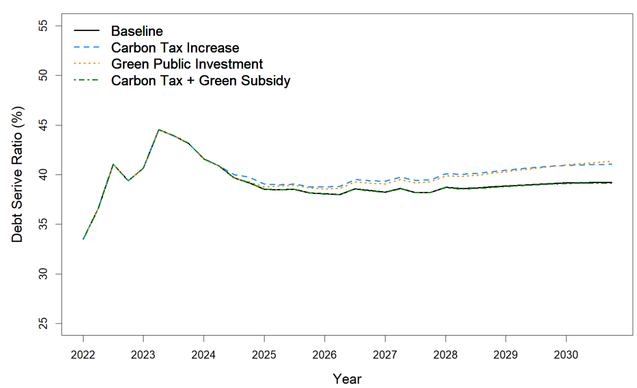
(f) Total Annualised Emissions



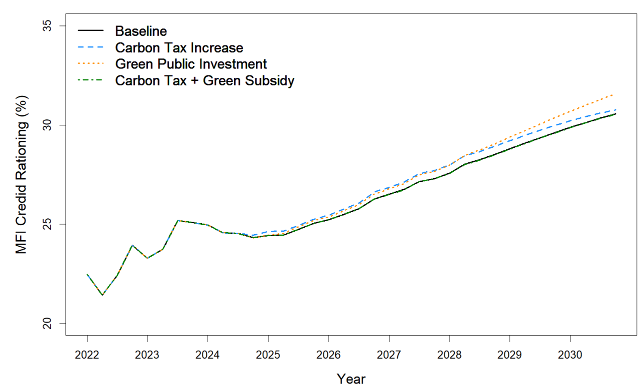
(g) GDP



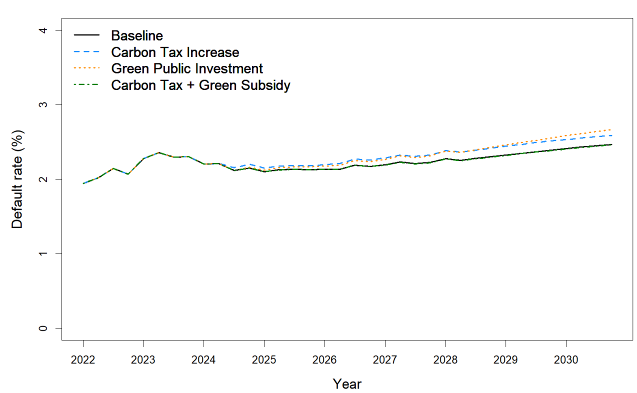
(h) Unemployment Rate



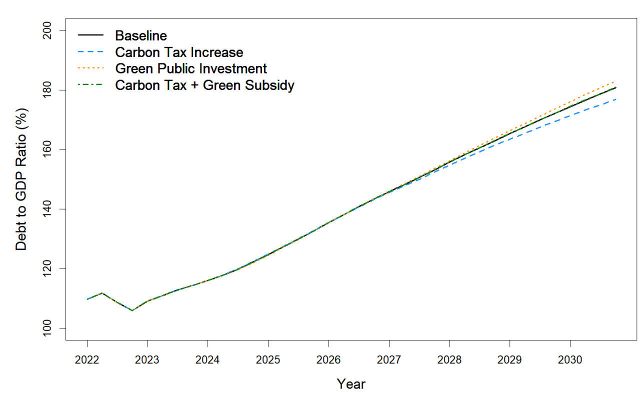
(i) Firms Debt-Service Ratio



(j) Credit Rationing on firms' loans



(k) Firms' Default rate



(l) Government debt-to-GDP ratio

Figure 3: Effects of green fiscal policies on UK macroeconomic, financial and environmental variables

6 Conclusion

This paper presents a novel empirical E-SFC model for the UK economy that is used to analyse the effectiveness of several green fiscal policies. Using the empirical SFC approach, the paper takes explicitly into account the individual country context in making modelling choices. The model structure is derived directly from UK national accounting data with that same data then forming the basis for calibrating behavioural equations and integrating ecological factors.

We use the model to conduct a policy scenario analysis until 2030. We analyse three green fiscal policies: a carbon tax policy, a carbon tax + green subsidy policy and a green public investment policy. The results illustrate that an isolated carbon tax policy has recessionary effects that are exacerbated by the decline in credit availability associated with the rise in debt defaults. These recessionary effects are prevented when the revenues from the carbon tax are used to provide green subsidies. Green public investment stimulates economic activity and reduces unemployment. Economic expansion generates some rebound effects that restrict the reduction of emissions. These rebound effects demonstrate the benefit of analysing the economy from a systems-based perspective so that these interconnected knock-on effects can be properly captured.

Several extensions of the model of this paper are in order. First, a more complete integration of ecological variables beyond carbon emissions would be crucial to allow the model to properly analyse the wider effects of policies on the ecosystem. Second, the role of non-banks, which constitute a significant part of the UK financial system, needs to be explored in more detail. Third, the housing market, which plays a key role in the UK economy, needs to be further developed. Fourth, since a key strength of SFC modelling is the full integration of finance, the model would be well placed to analyse the effects of green financial policies, such as green differentiated capital requirements, green asset purchases and green refinancing operations.

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A Full Model Equations - In progress

Ecosystem

Total greenhouse gas emissions ($EMIS$) depend on emissions intensity (INT_{EMIS}) and energy production from fossil fuel sources ($ENERGY_{FF}$) (Eq.(1)). Emissions intensity (INT_{EMIS}) reflects the emissions generated per unit of fossil energy and is assumed to follow a baseline path and does not change significantly over the modelling period (Eq.(2)). Total energy use in the economy is portrayed as a function og domestic GDP (GDP_{DOM}) and energy intensity (INT_{ENERGY}) (Eq.(3)). Energy intensity changes according to a logistic relationship driven by the ratio between green and conventional capital across relevant sectors (Eq.(3)). Energy can either be produced from non-fossil fuel ($ENERGY_{NFF}$) or fossil fuel ($ENERGY_{FF}$) sources (Eqs.(5) & (6)) with the proportion of non-fossil fuel energy again set according to a logistic relationship driven the ratio between green and conventional capital across sectors (Eq.(7).

$$EMIS = INT_{EMIS} ENERGY_{FF} \tag{1}$$

$$INT_{EMIS} = INT^{B}_{EMIS} \tag{2}$$

$$ENERGY = INT_{ENERGY} GDP_{DOM} \tag{3}$$

$$INT_{ENERGY} = \epsilon_{max} - \frac{\epsilon_{max} - \epsilon_{min}}{(1 + \pi_1 exp(\pi_2 (sh_{nfc} \frac{K^G_{NFC}}{K^C_{NFC}} + sh_{gvt} \frac{K^G_{GVT}}{K^C_{GVT}} + sh_{hh} \frac{K^G_{HH}}{K^C_{HH}}))} \tag{4}$$

$$ENERGY_{NFF} = PROP_{NFF} ENERGY \tag{5}$$

$$ENERGY_{FF} = (1 - PROP_{NFF}) ENERGY \tag{6}$$

$$PROP_{NFF} = \frac{1}{(1 + \pi_3 exp(\pi_4 (sh_{nfc} \frac{K^G_{NFC}}{K^C_{NFC}} + sh_{gvt} \frac{K^G_{GVT}}{K^C_{GVT}} + sh_{hh} \frac{DWELL^G}{DWELL^C}))} \tag{7}$$

The price of emissions ($EMIS_{PRICE}$) is driven by the sum of the baseline emission price ($EMIS^{B}_{PRICE}$) and any additional emission price in different policy scenarios ($EMIS^{SC}_{PRICE}$) (Eq.(8)). The unit cost of non-fossil fuel energy (ucn) is the sum of non-carbon costs (ucn^B) and the costs associated with carbon ($ucnc$) (Eq.(9)). The costs associated with carbon are driven by an increasing exogenous parameter (α^{ucnc}_0) reflecting increased scarcity of resources over time along with the effects of the costs associated with the emissions price ($INT_{EMIS} EMIS_{PRICE}$) (Eq.(10)). The unit cost of renewable energy (ucr) has a baseline path whereby it declines naturally over time. This reduction is accelerated by growth in the proportion of non-fossil fuel energy production, reflecting the learning processes and development of renewable infrastructure (Eq.(11)).

$$EMIS_{PRICE} = EMIS^{B}_{PRICE} + EMIS^{SC}_{PRICE} \tag{8}$$

$$ucn = ucn^B + ucnc \tag{9}$$

$$ucnc = \alpha^{ucnc}_0 + INT_{EMIS} EMIS_{PRICE} \tag{10}$$

$$ucr = g_{ucr} ucr \frac{1 - PROP_{NFF}}{1 - PROP_{NFF-1}} \tag{11}$$

Production

Total GDP is given by the sum of the components of GDP: Consumption ($CONS$), Gross Capital Formation (GCF), Exports (EXP) minus Imports (IMP) (Eq. (12)), with consumption being the sum of household and government consumption (Eq. (13)) and gross capital formation being the sum of the capital formation of households, non-financial corporations and the government (Eq.(14)). The level of indirect tax ($INDTAX$) is defined as a proportion of GDP plus any emission taxes (TAX_{EMIS}) minus any green subsidies (SUB_{GREEN}) (Eq.(15)). Therefore, green taxes are levied at the production level and impact all sectors involved in the production process.

$$GDP = CONS + GCF + EXP - IMP \tag{12}$$
$$CONS = CONS_{HH} + CONS_{GVT} \tag{13}$$
$$GCF = GCF_{HH} + GCF_{NFC} + GCF_{GVT} \tag{14}$$
$$INDTAX = \theta_{ind} GDP + TAX_{EMIS} - SUB_{GREEN} \tag{15}$$

The number of employees in the economy (EMP) is defined in Eq.(16) as GDP divided by productivity per worker ($PROD$). Full employment GDP is calculated in Eq.(17) as the product of the productivity and the total number of workers in the workforce (EMP_{FE}). The full employment level of employment grows at an exogenous rate $\alpha_{EMP_{FE}}$ set in the baseline scenario. Productivity likewise follows an exogenous baseline growth rate in Eq.(19). The total wage bill ($WAGES$), paid to households, is a function of the wage share ($WAGE_R$), and GDP (Eq. 20) with the wage share following an exogenous baseline path.

$$EMP = \frac{GDP}{PROD} \tag{16}$$
$$GDP_{FE} = PROD * EMP_{FE} \tag{17}$$
$$EMP_{FE} = \alpha_{EMP_{FE}} EMP_{FE-1} \tag{18}$$
$$PROD = PROD_g PROD_{-1} \tag{19}$$
$$WAGES = WAGE_R GDP \tag{20}$$

On the GDP income side, Gross operating surplus from production is defined as the residual of GDP after the deduction of wages and indirect taxes (Eq.(21)). This gross operating surplus is split between non-financial corporations, government and households in fixed proportions based on the initial values (Eqs.(22),(23),(24)). Finally, overall population (POP) grows at a decreasing rate, consistent with projections for the UK (Eqs.(25)&(26)).

$$GOS = GDP - WAGES - INDTAX \tag{21}$$
$$GOS_{NFC} = \beta_{gos1} GOS \tag{22}$$
$$GOS_{GVT} = \beta_{gos2} GOS \tag{23}$$
$$GOS_{HH} = \beta_{gos3} GOS \tag{24}$$
$$POP = (1 + POP_{g-1}) POP_{-1} \tag{25}$$
$$POP_g = POP_{g-1}(1 - \alpha_{POP}) \tag{26}$$

Households

Household primary income (YP_{HH}) is the sum of wages, gross operating surplus (GOS_{HH}), interest received ($INTR_{HH}$), net dividends received ($DIVN_{HH}$) minus interest payments ($INTP_{HH}$) (Eq.(27)). Equations for interest and dividend payments are based on respective rates of return on deposits (DEP_{HH}), net equity (NEQ_{HH}), and loans ($LOANS_{HH}$) (Eqs.(28),(29) &(30)). Final income (YD_{HH}) is given by the sum of primary income, social benefits ($SOCB$) and pension receipts ($PENSR$) minus income tax payments ($INCTAX_{HH}$) and social contributions ($SOCC$) (Eq.(31)). Income tax is a set proportion of wages (Eq.(32)), as there is income distribution in the model this is simply set as a rate by the government. Social benefits received by household are equal to the sum of social benefits from government ($SOCB_{GVT}$) and social benefits from non-MFIs ($SOCB_{NMFI}$) with the latter being related to pension contributions (Eq.(33)). Social contributions grow every period based on an exogenous trend (Eq.(34)). Income from pensions is based or a set rate of return on households holding of pension assets (Eq.(35)).

$$YP_{HH} = WAGES + GOS_{HH} + INTR_{HH} + DIVN_{HH} - (INTP_{HH}) \tag{27}$$
$$INTR_{HH} = r_{DEP_{HH}} DEP_{HH-1} \tag{28}$$
$$DIVR_{HH} = r_{EQ} NEQ_{HH-1} \tag{29}$$
$$INTP_{HH} = r_{LOANS_{HH}} LOANS_{HH-1} \tag{30}$$
$$YD_{HH} = YP_{HH} + (SOCB + PENSR) - (INCTAX_{HH} + SOCC) \tag{31}$$
$$INCTAX_{HH} = inc_{hh} WAGES \tag{32}$$
$$SOCB = SOCB_{NMFI} + SOCB_{GVT} \tag{33}$$
$$SOCC = \alpha_{SOCC} SOCC_{-1} \tag{34}$$
$$PENSR = r_{PENS} PENS_{-1} \tag{35}$$

Household real consumption ($CONS^R_{HH}$) is found to be dependent on real net-worth in the long run (NW^R_{HH}) along with changes in household income (YD^R_{HH}) in the short run (Eq.(36)). Parameters in the consumption equation are estimated econometrically. Nominal consumption ($CONS_{HH}$) is then derived by multiplying real consumption by the consumption deflator (P_{CONS}) (Eq.(13)). Household savings (SAV_{HH}) is equal to household disposable income minus consumption (Eq.(38)). Household investment in housing (GCF_{HH}) as a proportion of total stock of household dwellings ($DWELL$) is given by Eq.(39). Household investment depends on household income compared to the value of dwellings along with the ratio between the value of houses ($HOUSES$) and dwellings. The distinction between housing and dwellings is that dwellings are the physical assets which are created when houses are built whereas houses describes the total value of both the dwelling and the land. An increase in the ratio ($\frac{HOUSES}{DWELLINGS}$) implies the price of land is increasing quicker than the price of dwellings which encourages investment in housing as an asset. Household Investment is split between conventional and green investment (Eqs.(40) &(41)) in relation to the proportion β_{GCFHH} which, in the current model version, follows the same path as the proportion of firm green investment β_{GCFNFC} (Eq.(42)).

$$L\left(CONS^R_{HH}\right) = \alpha^C_0 + \alpha^C_1 L\left(CONS^R_{HH-1}\right) + \alpha^C_2 L\left(NW^R_{HH-1}\right) + \delta^C_1 \Delta L\left(YD^R_{HH-1}\right) \tag{36}$$
$$CONS_{HH} = P_{CONS} CONS^R_{HH} \tag{37}$$
$$SAV_{HH} = YD_{HH} - CONS_{HH} \tag{38}$$
$$\frac{GCF_{HH}}{DWELL} = \alpha^{gcfhh}_0 + \alpha^{gcfhh}_1 \frac{GCF_{HH-1}}{DWELL_{-1}} + \alpha^{gcfhh}_2 \frac{YD_{HH-1}}{DWELL_{-1}} + \alpha^{gcfhh}_3 \frac{HOUSES_{-1}}{DWELL_{-1}} \tag{39}$$
$$GCF^G_{HH} = \beta_{GCFHH} GCF_{HH} \tag{40}$$
$$GCF^C_{HH} = (1 - \beta_{GCFHH}) GCF_{HH} \tag{41}$$
$$\beta_{GCFHH} = \beta_{GCFNFC} \tag{42}$$

Household model lending ($LEND^M_{HH}$) is given by savings minus household investment (Eq.(43)). Actual household lending ($LEND_{HH}$) is then derived by adding the exogenous lending discrepancy ($LEND^{DISC}_{HH}$) which is used to ensure consistency between model lending and actual data (Eq.(44).

$$LEND^M_{HH} = SAV_{HH} - GCF_{HH} \tag{43}$$
$$LEND_{HH} = LEND^M_{HH} + LEND^{DISC}_{HH} \tag{44}$$

The total value of housing ($HOUSES$), is given by the sum of the value of dwellings ($DWELL$) and land ($LAND$) (Eq.(45)). Dwellings are split into conventional ($DWELL^C$) and green ($DWELL^G$) this split reflects the degree of greenness in the housing sector and feeds into ecological equations (Eq.(46)). Nominal dwelling value is driven by adjustments to the value of the previous periods dwellings stock due to price growth of capital (P^g_{GCF}) and depreciation (δ_{DWELL}) with the value of household investment (GCF_{HH}) then added (Eq.(47)&(48)). The value of land is defined residually such that the price growth of housing is given by the value P^g_{HOUSES} (Eq.(49)).

$$HOUSES = DWELL + LAND \tag{45}$$
$$DWELL = DWELL^C + DWELL^G \tag{46}$$
$$DWELL_C = (P^g_{GCF} - \delta_{DWELL})DWELL^C_{-1} + GCF_{{}^C_{HH-1}} \tag{47}$$
$$DWELL_G = (P^g_{GCF} - \delta_{DWELL})DWELL^G_{-1} + GCF_{{}^G_{HH-1}} \tag{48}$$
$$LAND = P^g_{HOUSES} HOUSES_{-1} - DWELL \tag{49}$$

Adjustments in the levels of household financial assets (Deposits (DEP_{HH}), Pensions ($PENS$) and Net Equity (NEQ_{HH})) and financial liabilities (Loans ($LOANS_{HH}$)) are driven by growth in the 'price' of these assets, which accounts for capital gains, along with the level of asset transfers (Eqs.(50)-(55)). Model financial net worth of households (FNW^M_{HH}) is given by total household financial assets (FA_{HH}) less liabilities (FL_{HH}) (Eq.(56)). Actual household financial net-worth (FNW_{HH}) is then derived by adding the exogenous net-worth discrepancy (FNW^{DISC}_{HH}) which is used to ensure consistency between model financial net worth and actual data (Eq.(57). Overall household net worth (NW_{HH}) is then given as the sum of financial net worth and physical assets in the form of housing (Eq.(58)).

$$DEP_{HH} = P^g_{DEPHH} LOANS_{HH-1} + DEPTR_{HH} \tag{50}$$
$$PENS = P^g_{PENS} PENS_{-1} + PENSTR_{HH} \tag{51}$$
$$NEQ_{HH} = P^g_{NEQ} NEQ_{HH-1} + NEQTR_{HH} \tag{52}$$
$$LOANS_{HH} = P^g_{LOANSHH} LOANS_{HH-1} + LOANSTR_{HH} \tag{53}$$
$$FA_{HH} = DEP_{HH} + PENS + NEQ_{HH} \tag{54}$$
$$FL_{HH} = LOANS_{HH} \tag{55}$$
$$FNW^M_{HH} = FA_{HH} - FL_{HH} \tag{56}$$
$$FNW_{HH} = FNW^M_{HH} + FNW^{DISC}_{HH} \tag{57}$$
$$NW_{HH} = FNW_{HH} + HOUSES \tag{58}$$
$$\tag{59}$$

Pension transfers ($PENSTR$) depend positively on the level of wages and the rate of return from pension schemes (Eq.(60)). Net-equity transfers ($NEQTR_{HH}$), relative to total household financial assets, depend negatively on the rate of return of deposits and positively to the ration between household income and financial assets (Eq.(61)). Household loan transfers ($LOANSTR_{HH}$), relative to household income, depend positively on both the rate between household consumption and house values realtive to household income (Eq.(62)). Household deposit transfers ($DEPTR_{HH}$), are then defined residually such that household lending is equal to the net asset transfers (Eq.(63)).

$$PENSTR = f(WAGES, r_{PENS}) \tag{60}$$
$$\frac{NEQTR_{HH}}{FA_{HH}} = f(r_{DEP}, \frac{YD_{HH}}{FA_{HH}}) \tag{61}$$
$$\frac{LOANSTR_{HH}}{YD_{HH}} = f(\frac{CONS_{HH}}{YD_{HH}}, \frac{HOUSES}{YD_{HH}}) \tag{62}$$
$$DEPTR_{HH} = LEND_{HH} + LOANSTR_{HH} - (NEQTR_{HH} + PENSTR) \tag{63}$$

Non-financial corporations

Non-financial corporations primary income (YP_{NFC}) is the sum of the gross operating surplus received by NFCs (GOS_{NFC}), interest received ($INTR_{NFC}$), net dividend income ($DIVN_{NFC}$) which will be negative for NFCs, minus interest paid ($INTP_{NFC}$) (Eq.(64)). Equations for interest and dividend payments are based on respective rates of return on deposits (DEP_{NFC}), net equity (NEQ_{NFC}), and loans ($LOANS_{NFC}$) (Eqs.(65),(66)&(67)). Income tax paid by NFCs ($INCTAX_{NFC}$) is set as a portion of the total wage bill ($WAGES$) (Eq.(68)).[8] NFC disposable income (YD_{NFC}) is then given as primary income minus income tax (Eq.(69)). NFCs retained profit (RP_NFC), to be used for investment, is a fixed proportion of their disposable income (Eq. (70)).

$$YP_{NFC} = GOS_{NFC} + (INTR_{NFC} + DIVN_{NFC}) - (INTP_{NFC}) \tag{64}$$
$$INTR_{NFC} = r_{DEPNFC} DEP_{NFC-1} \tag{65}$$
$$DIVR_{NFC} = r_{EQ} NEQ_{NFC-1} \tag{66}$$
$$INTP_{NFC} = r_{LOANSNFC} LOANS_{NFC-1} \tag{67}$$
$$INCTAX_{NFC} = inctax_{NFC} WAGES \tag{68}$$
$$YD_{NFC} = YP_{NFC} - INCTAX_{NFC} \tag{69}$$
$$RP_{NFC} = s_F * YD_{NFC} \tag{70}$$

NFC investment demand (GCF^D_{NFC}), relative to total NFC capital (K_{NFC}) is a function of capacity utilisation, here proxied by the ratio between GDP and NFC capital (Eq.(71). Investment demand is either conventional or green (Eqs.(72)&(73)) with the proportion of green investment demand ($\beta_{GCF_{NFC}}$) being driven by an increasing exogenous parameter ($\beta_0^{GCF_{NFC}}$)[9] and the difference in the unit costs of producing renewable ($tucr$) and non-renewable ($tucr$) energy (Eq.74). The demand for new NFC loans ($NLOANS^D_{NFC}$) can be either conventional or green and equal to investment demand minus profits retained for investment purposes plus the level of loans repaid during the current period ($repl * LOANS_{NFC}$) (Eq.(75)&(76)). The level of conventional and green NFC loans is then updated each period with loans being removed by either loan repayment ($repl$) or default (DEF) and new loans being added based on the demand for new loans then constrained by the level of credit rationing (CR) (Eqs.(77)&(78)). Total NFC loans is the sum of conventional and green loans (Eq.(79)). Actual nominal conventional/green investment is then determined by the level of retained NFC profits and the change in conventional and green loans respectively (Eqs.(80)&(81)), in this way credit rationing impacts overall investment by reducing the change in loans and thus overall investment. Total NFC investment (GCF_{NFC}) is given by the sum of conventional and green investment (Eq.(82)). Real investment is then given as nominal investment dividend by the investment price deflator (P_{GCF}) (Eq.(83)).

[8] In the UK case this captures employers national insurance contributions.

[9] This parameter captures the increasing drive for NFCs to make their operations greener independent of cost incentive.

$$\frac{GCF^D_{NFC}}{K_{NFC}} = \alpha_0^{gcfnfc} + \alpha_1^{gcfnfc}\frac{GCF^D_{NFC-1}}{K_{NFC-1}} + \alpha_2^{gcfnfc}\frac{GDP_{-1}}{K_{NFC-1}} + \delta_1^{gcfnfc}(\Delta\frac{GDP_{-1}}{K_{NFC-1}}) \tag{71}$$

$$GCF^{CD}_{NFC} = (1-\beta^{GCF_{NFC}})GCF^D_{NFC} \tag{72}$$

$$GCF^{GD}_{NFC} = \beta^{GCF_{NFC}}GCF^D_{NFC} \tag{73}$$

$$\beta_{GCF_{NFC}} = \beta_0^{GCF_{NFC}} - \beta_1^{GCF_{NFC}}(tucr_{-1} - tucn_{-1}) \tag{74}$$

$$NLOANS^{CD}_{NFC} = GCF^{CD}_{NFC} - (1-\beta^{GCF_{NFC}})RP_{NFC} + repl * LOANS^C_{NFC} \tag{75}$$

$$NLOANS^{GD}_{NFC} = GCF^{GD}_{NFC} - (\beta^{GCF_{NFC}})RP_{NFC} + repl * LOANS^G_{NFC} \tag{76}$$

$$LOANS^C_{NFC} = (1 - repl - DEF)LOANS^C_{NFC-1} + (1-CR)NLOANS^{CD}_{NFC} \tag{77}$$

$$LOANS^G_{NFC} = (1 - repl - DEF)LOANS^G_{NFC-1} + (1-CR)NLOANS^{GD}_{NFC} \tag{78}$$

$$LOANS_{NFC} = LOANS^C_{NFC} + LOANS^G_{NFC} \tag{79}$$

$$GCF^C_{NFC} = (1-\beta^{GCF_{NFC}})RP_{NFC} + \Delta LOANS^C_{NFC} \tag{80}$$

$$GCF^G_{NFC} = (\beta^{GCF_{NFC}})RP_{NFC} + \Delta LOANS^G_{NFC} \tag{81}$$

$$GCF_{NFC} = GCF^C_{NFC} + GCF^G_{NFC} \tag{82}$$

$$GCF^R_{NFC} = \frac{GCF_{NFC}}{P_{GCF}} \tag{83}$$

NFC model lending ($LEND^M_{NFC}$) is given by disposable income minus NFC investment (Eq.(84)). Actual NFC lending ($LEND_{NFC}$) is then derived by adding the exogenous lending discrepancy ($LEND^{DISC}_{NFC}$) which is used to ensure consistency between model lending and actual data (Eq.(85).

$$LEND^M_{NFC} = YD_{NFC} - GCF_{NFC} \tag{84}$$

$$LEND_{NFC} = LEND^M_{NFC} + LEND^{DISC}_{NFC} \tag{85}$$

The value of nominal conventional and green capital is driven by adjustments to the value of the previous periods capital stock due to price growth of capital (P^g_{GCF}) and depreciation ($\delta_{K_{NFC}}$) with the value of NFC investment (GCF_{NFC}) then added (Eqs.(86)&(87)). Total NFC capital is given by the sum of conventional and green NFC capital (Eq.(88)). Adjustments in the levels of NFC deposits (DEP_{HH}) are driven by growth in the 'price' of deposits, while net equity is defined residually based on the equity holding of other model sectors (Eqs.(89)&(90)). Total levels of financial assets and liabilities are then given in Eqs.(91)&(92). Model financial net worth of NFCs (FNW^M_{NFC}) is given by total NFC financial assets (FA_{NFC}) less liabilities (FL_{NFC}) (Eq.(93)). Actual NFC financial net-worth (FNW_{NFC}) is then derived by adding the exogenous net-worth discrepancy (FNW^{DISC}_{NFC}) which is used to ensure consistency between model financial net worth and actual data (Eq.(94). Overall NFC net worth (NW_{NFC}) is then given as the sum of financial net worth and physical assets in the form of NFC capital (Eq.(95)). Net equity transfers of NFCs ($NEQTR_{NFC}$) are defined as the residual of all other net equity transfers of other model sectors (Eq.(96)). Deposit transfers ($DEPTR_{NFC}$) are defined residually such that net asset transfers are equal to NFC lending (Eq.(97)).

$$K^C_{NFC} = (P^g_{GCF} - \delta_{K_{NFC}})K^C_{NFC-1} + GCF^C_{NFC-1} \quad (86)$$
$$K^G_{NFC} = (P^g_{GCF} - \delta_{K_{NFC}})K^G_{NFC-1} + GCF^G_{NFC-1} \quad (87)$$
$$K_{NFC} = K^C_{NFC} + K^G_{NFC} \quad (88)$$
$$DEP_{NFC} = P^g_{DEP}DEP_{NFC-1} + DEPTR_{NFC} \quad (89)$$
$$NEQ_{NFC} = NEQ_{NFC-1} + NEQTR_{NFC} + \Delta NEQ_{NFC} \quad (90)$$
$$FA_{NFC} = DEP_{NFC} + NEQ_{NFC} \quad (91)$$
$$FL_{NFC} = LOANS_{NFC} \quad (92)$$
$$FNW_{NFCM} = FA_{NFC} - FL_{NFC} \quad (93)$$
$$FNW_{NFC} = FNW_{NFCM} + DISC_{FNWNFC} \quad (94)$$
$$NW_{NFC} = FNW_{NFC} + K_{NFC} \quad (95)$$
$$NEQTR_{NFC} = -(NEQTR_{HH} + NEQTR_{NMFI} + NEQTR_{RoW}) \quad (96)$$
$$DEPTR_{NFC} = LEND_{NFC} + LOANSTR_{NFC} - NEQTR_{NFC} \quad (97)$$

The rate of loans default (DEF) is assumed to increase when firms become less liquid (Eq.(99)), def_{max} is the maximum default rate. The illiquidity ratio of firms ($ILLIQ$) is the cash outflow of NFCs relative to their cash inflow. Cash outflow includes interest, loans repayments along with NFCs share of wages and maintenance of capital expenditure. Inflows comprise revenue for production along with any funds obtained in the form of bank loans. Eq.(100) defines the debt service ratio (DSR_{NFC}), which is the ratio of debt payment commitments (interest plus principal repayments) to profits before interest.

$$DEF = \frac{def_{max}}{1 + def_0 exp(def_1 - def_2 ILLIQ)} \quad (98)$$
$$ILLIQ = \frac{(r_{LOANSNFC-1} + repl)LOANS_{NFC-1} + sh_{NFC}(WAGES_{-1} + INDTAX_{-1})}{GOS_{NFC-1} + (1 - CR_{-1})NLOANS^D_{NFC-1}} + \frac{INCTAX_{NFC-1} + \delta_{K_{NFC}}K_{NFC}}{GOS_{NFC-1} + (1 - CR_{-1})NLOANS^D_{NFC-1}} \quad (99)$$
$$DSR_{NFC} = \frac{(r_{LOANSNFC-1} + repl)LOANS_{NFC-1}}{YD_{NFC-1} + r_{LOANSNFC-1}LOANS_{NFC-1}} \quad (100)$$

Monetary financial institutions

For MFIs, model lending ($LEND^M_{MFI}$) is the net of interest received by MFIs ($INTR_{MFI}$) and interest paid by MFIs ($INTP_{MFI}$) (Eq.(101)). MFI Interest received and paid is the sum of respective rates of returns and stock levels (Eqs.(102)&(103)). Actual MFI lending ($LEND_{MFI}$) is derived by adding the exogenous lending discrepancy ($LEND^{DISC}_{MFI}$) which is used to ensure consistency between model lending and actual data (Eq.(104). In the case of MFIs, lending discrepancy is defined as the residual of all other lending discrepancies values such that flow consistency is maintained in the model.

$$LEND^M_{MFI} = INTR_{MFI} - INTP_{MFI} \quad (101)$$
$$INTR_{MFI} = r_{LOANSHH}LOANS_{HH-1} + r_{LOANSNFC}LOANS_{NFC-1} + r_{FI}FI_{-1} + r_{BRWGVT}BRW^{MFI}_{GVT-1} + r_{LOANSNMFI}LOANS_{NMFI-1} \quad (102)$$
$$INTP_{MFI} = r_{DEPHH}DEP_{HH-1} + r_{DEPNFC}DEP_{NFC-1} + r_{DEPNMFI}DEP_{NMFI-1} + r_{DEPRoW}DEP_{RoW-1} \quad (103)$$
$$LEND_{MFI} = LEND_{MFIM} + LEND^{DISC}_{MFI} \quad (104)$$

Government borrowing held by MFIs (BRW^{GVT}_{MFI}) is given by the price growth of government borrowing along with any acquisitions of government debt by MFIs (Eq.(105)). Total financial asset and liability levels for MFIs are given in Eqs. (106)&(107). Model financial net worth of MFIs (FNW^{M}_{MFI}) is given by total MFI financial assets (FA_{MFI}) less liabilities (FL_{MFI}) (Eq.(108)). Actual MFI financial net-worth (FNW_{MFI}) is then derived by adding the exogenous net-worth discrepancy (FNW^{DISC}_{MFI}) which is used to ensure consistency between model financial net worth and actual data (Eq.(109). As in the case of lending, the financial net-worth discrepancy of MFIs is defined as the residual of all other FNW discrepancies values such that stock consistency is maintained in the model. Acquisition of government debt by MFIs ($BRWTR^{GVT}_{MFI}$) is given as a fixed proportion of the total change in government borrowing (Eq.(110)).

$$BRW^{GVT}_{MFI} = P^{g}_{BRWGVT} BRW^{GVT}_{MFI} + BRWTR^{GVT}_{MFI} \tag{105}$$

$$FA_{MFI} = LOANS_{HH} + FI + LOANS_{NFC} + BRW^{GVT}_{MFI} + LOANS_{NMFI} \tag{106}$$

$$FL_{MFI} = DEP_{HH} + DEP_{NFC} + DEP_{NMFI} + DEP_{RoW} \tag{107}$$

$$FNW^{M}_{MFI} = FA_{MFI} - FL_{MFI} \tag{108}$$

$$FNW_{MFI} = FNW^{M}_{MFI} + FNW^{DISC}_{MFI} \tag{109}$$

$$BRWTR^{GVT}_{MFI} = \theta_1^{BRW_{GVT}} BRWTR_{GVT} \tag{110}$$

Credit rationing (CR) on NFC loans is given by Eq.(111), maximum credit rationing is set as cr_{max} and the degree of credit rationing increases as NFC debt service ratio increases and decreases the higher MFIs capital adequacy ratio (CAR) is, relative to the minimum capital adequacy ratio (car_{min}). The capital adequacy ratio of MFIs is then given as the ratio between MFI financial net worth and the sum of risk weighted financial assets (Eq.(112)).

$$CR = \frac{cr_{max}}{1 + r_0 exp(r_1 - r_2 DSR_{NFC} + r_3(CAR_{-1} - car_{min})} \tag{111}$$

$$CAR = \frac{FNW_{MFI}}{w_{lhh} LOANS_{HH} + w_{fi} FI + w_{lnfc} LOANS_{NFC} + w_{bgvt} BRW^{GVT}_{MFI} + w_{bnmfi} LOANS_{NMFI}} \tag{112}$$

Non-monetary financial institutions

For NMFIs, model lending ($LEND^{M}_{NMFI}$) is given as the sum of interest received, dividends received and social contributions to NMFIs minus interest paid, pensions payments and social benefit payments associated with NMFIs (Eq.(113)). Interest received, dividends received and interest paid equal the sum of the relevant rates multiplied by the associated stock values (Eqs.(114)-(116)). Social contributions to NMFIs are given as a fixed proportion of total social contributions (Eq.(117)) while social benefits paid by NMFIs are assumed to be proportional to the total value of pensions (Eq.(118)). Actual NMFI lending ($LEND_{NMFI}$) is derived by adding the exogenous lending discrepancy ($LEND^{DISC}_{NMFI}$) which is used to ensure consistency between model lending and actual data (Eq.(119).

$$LEND^{M}_{NMFI} = (INTR_{NMFI} + DIVR_{NMFI} + SOCC_{NMFI}) - (INTP_{NMFI} + PENSR_{HH} + SOCB_{NMFI}) \quad (113)$$

$$INTR_{NMFI} = r_{BRWGVT} BRW^{GVT}_{NMFI-1} + r_{DEPNMFI} DEP_{NMFI-1} \quad (114)$$

$$DIVR_{NMFI} = r_{EQ} NEQ_{NMFI-1} \quad (115)$$

$$INTP_{NMFI} = r_{LOANSNMFI} LOANS_{NMFI-1} \quad (116)$$

$$SOCC_{NMFI} = (1 - \beta_{socc}) SOCC \quad (117)$$

$$SOCB_{NMFI} = \theta^{socb}_{nmfi} PENS_{-1} \quad (118)$$

$$LEND_{NMFI} = LEND^{M}_{NMFI} + LEND^{DISC}_{NMFI} \quad (119)$$

Adjustments in the levels of NMFI government borrowing (BRW^{GVT}_{NMFI}), Deposits (DEP_{NMFI}), Net Equity (NEQ_{NMFI}) and loans ($LOANS_{NMFI}$) are driven by growth in the 'price' of these assets, which accounts for capital gains, along with the level of asset transfers (Eqs.(120)-(123)). Total financial asset and liability levels for NMFIs are given in Eqs. (106)&(107). Model financial net worth of MFIs (FNW^{M}_{MFI}) is given by total MFI financial assets (FA_{MFI}) less liabilities (FL_{MFI}) (Eq.(108)). Actual MFI financial net-worth (FNW_{MFI}) is then derived by adding the exogenous net-worth discrepancy (FNW^{DISC}_{MFI}) which is used to ensure consistency between model financial net worth and actual data (Eq.(109).

$$BRW^{GVT}_{NMFI} = P^{g}_{BRWGVT} BRW^{GVT}_{NMFI-1} + BRWTR^{GVT}_{NMFI} \quad (120)$$

$$DEP_{NMFI} = P^{g}_{DEP} DEP_{NMFI-1} + DEPTR_{NMFI} \quad (121)$$

$$NEQ_{NMFI} = P^{g}_{EQ} NEQ_{NMFI-1} + NEQTR_{NMFI} \quad (122)$$

$$LOANS_{NMFI} = P^{g}_{LOANSNMFI} LOANS_{NMFI-1} + LOANSTR_{NMFI} \quad (123)$$

$$FA_{NMFI} = BRW_{GVTNMFI} + DEP_{NMFI} + NEQ_{NMFI} \quad (124)$$

$$FL_{NMFI} = PENS_{HH} + LOANS_{NMFI} \quad (125)$$

$$FNW_{NMFIM} = FA_{NMFI} - FL_{NMFI} \quad (126)$$

$$FNW_{NMFI} = FNW_{NMFIM} + DISC_{FNWNMFI} \quad (127)$$

$$(128)$$

Acquisition of government debt by NMFIs ($BRWTR^{GVT}_{NMFI}$) is given as a fixed proportion of the total change in government borrowing (Eq.(129)). NMFI loan acquisition ($LOANSTR_{NMFI}$) is currently assumed to be proportional to the previous period NMFI deposit transfer (Eq.(130)). NMFI net equity transfer ($NEQTR_{NMFI}$) is assumed to be a fixed proportion of overall GDP (Eq.(131).Deposit transfers ($DEPTR_{NMFI}$) are defined residually such that net asset transfers are equal to NMFI lending (Eq.(132)).

$$BRWTR^{GVT}_{NMFI} = \theta^{BRW_{GVT}}_{2} BRWTR_{GVT} \quad (129)$$

$$LOANSTR_{NMFI} = \theta_{LOANSNMFI} DEPTR_{NMFI-1} \quad (130)$$

$$NEQTR_{NMFI} = \theta_{NEQNMFI} GDP_{-1} \quad (131)$$

$$DEPTR_{NMFI} = (LEND_{NMFI} + PENSTR_{HH} + LOANSTR_{NMFI}) - (BRWTR^{GVT}_{NMFI} + NEQTR_{NMFI}) \quad (132)$$

Government

Government income from production (YP_{GVT}) equals the sum of indirect taxation and government gross operating surplus (Eq.(133)). Disposable income of the government (YD_{GVT}) then adds income from income tax and social contributions to the government minus interest paid by the government and social benefits paid by the government (Eq.(134)). Interest paid by the government ($INTP_{GVT}$) equals the interest rate of government borrowing multiplied by the level of government debt (Eq.(135)). Total income tax ($INCTAX$) equals the sum of household and NFC income tax (Eq.(136)). Social contributions to the government are given as a fixed proportion of total social contributions (Eq.(137)) while social benefits paid by the government are set as a fixed proportion of GDP (Eq.(138)).

$$YP_{GVT} = INDTAX + GOS_{GVT} \tag{133}$$
$$YD_{GVT} = YP_{GVT} + (INCTAX + SOCC_{GVT}) - (INTP_{GVT} + SOCB_{GVT}) \tag{134}$$
$$INTP_{GVT} = r_{BRWGVT}BRW_{GVT-1} \tag{135}$$
$$INCTAX = INCTAX_{HH} + INCTAX_{NFC} \tag{136}$$
$$SOCC_{GVT} = \beta_{SOCC}SOCC \tag{137}$$
$$SOCB_{GVT} = \theta_{GVT}^{SOCB}GDP \tag{138}$$

Government investment (GCF_{GVT}) is assumed in the baseline to follow an exogenous path equal to the forecasts of the office of budgetary responsibility (OBR) with any additional green public investment (GPI_{GVT}) being added in policy scenarios (Eq.(139)). Real investment (GCF^R_{GVT}) is equal to nominal investment divided by the investment deflator (Eq.(140)). Baseline government Investment is split between conventional and green investment (Eqs.(141) &(142)) in relation to the proportion β_{GCFGVT} which, in the current model version, follows the same path as the proportion of firm green investment β_{GCFNFC} (Eq.(143)). Any green public investment in scenarios is added directly to government green investment. Government consumption is also set to follow a baseline rate according to OBR projections (Eq.(144)).

$$GCF_{GVT} = GCF^B_{GVT} + GPI_{GVT} \tag{139}$$
$$GCF^R_{GVT} = GCF_{GVT}/P_{GCF} \tag{140}$$
$$GCF^C_{GVT} = (1 - \beta^{GCF_{GVT}})GCF^B_{GVT} \tag{141}$$
$$GCF^G_{GVT} = (\beta^{GCF_{GVT}})GCF^B_{GVT} + GPI_{GVT} \tag{142}$$
$$\beta_{GCFGVT} = \beta_{GCFNFC} \tag{143}$$
$$CONS_{GVT} = CONS^B_{GVT} \tag{144}$$
$$CONS^R_{GVT} = CONS_{GVT}/P_{CONS} \tag{145}$$

Government model lending ($LEND^M_{GVT}$) is given by disposable income minus Government consumption and investment (Eq.(146)). Actual government lending ($LEND_{GVT}$) is then derived by adding the exogenous lending discrepancy ($LEND^{DISC}_{GVT}$) which is used to ensure consistency between model lending and actual data (Eq.(147).

$$LEND^M_{GVT} = YD_{GVT} - (CONS_{GVT} + GCF_{GVT}) \tag{146}$$
$$LEND_{GVT} = LEND^M_{GVT} + LEND^{DISC}_{GVT} \tag{147}$$

Nominal conventional and green capital value are driven by adjustments to the value of the previous periods capital stock due to price growth of capital (P^g_{GCF}) and depreciation ($\delta_{K_{GVT}}$) with the value of government investment (GCF_{GVT}) then added (Eqs.(148)&(149)). Total government capital is given by the sum of conventional and green government capital (Eq.(150)). Government borrowing (BRW_{GVT}) value changes based on asset price growth and transfers (Eq.(151)). Model financial net worth of the government (FNW^{M}_{GVT}) is given as $-BRW_{GVT}$ as government borrowing is the only liability (Eq.(152)). Actual government financial net-worth (FNW_{GVT}) is then derived by adding the exogenous net-worth discrepancy (FNW^{DISC}_{GVT}) which is used to ensure consistency between model financial net worth and actual data (Eq.(153)). Overall government net worth (NW_{GVT}) is then given as the sum of financial net worth and physical assets in the form of government capital (Eq.(154)). Transfer of government borrowing is determined entirely by the government net lending position (Eq.(155)).

$$K^{C}_{GVT} = (P^{g}_{GCF} - \delta_{K_{GVT}})K^{C}_{GVT-1} + GCF^{C}_{GVT-1} \tag{148}$$
$$K^{G}_{NFC} = (P^{g}_{GCF} - \delta_{K_{GVT}})K^{G}_{GVT-1} + GCF^{G}_{GT-1} \tag{149}$$
$$K_{NFC} = K^{C}_{GVT} + K^{G}_{GVT} \tag{150}$$
$$BRW_{GVT} = P^{g}_{BRWGVT}BRW_{GVT-1} + BRWTR_{GVT} \tag{151}$$
$$FNW^{M}_{GVT} = -BRW_{GVT} \tag{152}$$
$$FNW_{GVT} = FNW^{M}_{GVT} + FNW^{DISC}_{GVT} \tag{153}$$
$$NW_{GVT} = FNW_{GVT} + K_{GVT} \tag{154}$$
$$BRWTR_{GVT} = -LEND_{GVT} \tag{155}$$

Rest of the World

The income from production of the rest of the world sector is imports (IMP) minus exports (EXP) (Eq. (156)). Both imports and exports are assumed to be a fixed proprotion of the previous periods GDP with this proportion being driven by OBR forecasts in the baseline scenario (Eqs.(157)&(158)). Real values for imports and exports are then derived by dividing nominal value by price deflators (Eqs.(159)&(160)). Model lending for the RoW is derived by adding interest and dividend payments received minus interest payment to income from production (Eq. (161)). Interest received, dividends received and interest paid equal the sum of the relevant rates multiplied by the associated stock values (Eqs.(162)-(164)). Actual RoW lending ($LEND_{RoW}$) is derived by adding the exogenous lending discrepancy ($LEND^{DISC}_{RoW}$) which is used to ensure consistency between model lending and actual data (Eq.(165).

$$YP_{RoW} = IMP - EXP \tag{156}$$
$$IMP = (\alpha_{IMP})GDP_{-1} \tag{157}$$
$$EXP = (\alpha_{EXP})GDP_{-1} \tag{158}$$
$$IMP_{R} = IMP/P_{IMP} \tag{159}$$
$$EXP_{R} = EXP/P_{EXP} \tag{160}$$
$$LEND^{M}_{RoW} = YP_{RoW} + (INTR_{RoW} + DIVR_{RoW}) - (INTP_{RoW}) \tag{161}$$
$$INTR_{RoW} = r_{DEPRoW}DEP_{RoW-1} + r_{BRWGVT}BRW^{GVT}_{RoW-1} \tag{162}$$
$$DIVR_{RoW} = r_{EQ}NEQ_{RoW-1} \tag{163}$$
$$INTP_{RoW} = r_{F}I[t]FI_{-1} \tag{164}$$
$$LEND_{RoW} = LEND^{M}_{RoW} + LEND^{DISC}_{RoW} \tag{165}$$

Rest of the world deposits (DEP), net equity (NEQ_{RoW}), government borrowing (BRW^{GVT}_{RoW}) and foreign investment (FI) are driven by growth in the 'price' of these assets, which accounts for capital gains, along with the level of asset transfers (Eqs.(166)-(169)). Total financial asset and liability levels for the RoW are given in Eqs. (170)&(171). Model financial net worth of RoWs (FNW^{M}_{RoW}) is given by total RoW financial assets (FA_{RoW}) less liabilities (FL_{RoW}) (Eq.(172)). Actual MFI financial net-worth (FNW_{RoW}) is then derived by adding the exogenous net-worth discrepancy (FNW^{DISC}_{RoW}) which is used to ensure consistency between model financial net worth and actual data (Eq.(173). Change in foreign investment (FI) grows at an exogenous rate (Eq.(174)). Acquisition of government debt by RoW ($BRWTR_{RoW}^{GVT}$) is given as a fixed proportion of the total change in government borrowing (Eq.(175)). RoW net equity transfer ($NEQTR_{RoW}$) is assumed to be a fixed proportion of overall GDP (Eq.(176).Deposit transfers ($DEPTR_{RoW}$) are defined residually such that net asset transfers are equal to RoW lending (Eq.(132)).

$$DEP_{RoW} = P_{DEP}^{g} DEP_{RoW-1} + DEPTR_{RoW} \quad (166)$$
$$NEQ_{RoW} = P_{EQ}^{g} NEQ_{RoW-1} + NEQTR_{RoW} \quad (167)$$
$$BRW_{RoW}^{GVT} = P_{BRWGVT}^{g} BRW_{RoW-1}^{GVT} + BRWTR_{RoW}^{GVT} \quad (168)$$
$$FI = P_{FI}^{g} FI_{-1} + FITR_{RoW} \quad (169)$$
$$FA_{RoW} = DEP_{RoW} + NEQ_{RoW} + BRW_{RoW}^{GVT} \quad (170)$$
$$FL_{RoW} = FI \quad (171)$$
$$FNW_{RoW} = FA_{RoW} - FL_{RoW} \quad (172)$$
$$FNW_{RoW} = FNW_{RoW}^{M} + FNW_{DISC\,RoW} \quad (173)$$
$$FITR = \theta_{FITR} FITR_{-1} \quad (174)$$
$$BRWTR_{RoW}^{GVT} = \theta_{2}^{BRW_{GVT}} BRWTR_{GVT} \quad (175)$$
$$NEQTR_{RoW} = \theta_{NEQRoW} GDP_{-1} \quad (176)$$
$$DEPTR_{RoW} = LEND_{RoW} + FITR - (BRWTR_{RoW}^{GVT} + NEQTR_{RoW}) \quad (177)$$

Rates of return

The Bank of England base rate (r_{BOE}) is set based on a nominal GDP targeting rule using logs such that the rate does not fall below zero (Eq.(178)). All other rates are currently defined as a fixed spread over the base rate, so when the base rate increases all other rates increase as well (Eq.(186)).

$$L(r_{BOE}) = t_2 + t_1 L(r_{BOE}) + (1 - t_1) t_3 (L(GDP_{t-1}/GDP_{t-2})) \quad (178)$$
$$\mathbf{r}_i = r_{BOE} + spr_{r_i} \quad (179)$$

Prices

The consumption price (P_{CONS}) is driven by both domestic wages ($WAGES$) and import prices (P_{IMP}) (Eq.(180)). It is assumed currently that prices of capital formation and exports follow the same trajectory as consumption prices (Eqs.(181)&(182)). The price of imports and housing are assumed to follow exogenous growth paths according to OBR predictions (Eqs.(183)&(184)). The overall GDP deflator is calculated by dividing nominal GDP by real GDP (185). Finally, the price of various stocks, which captures capital gains, are assumed to grow at a fixed rate based on recent growth values (Eq.(186)).

$$L(P_{CONS}) = \alpha_0^{P_C} + \alpha_1^{P_C} L(P_{CONS-1}) + \alpha_2^{P_C} L(WAGES_{-1}) + \alpha_3^{P_C} L(P_{IMP-1}) + \delta_1^{P_C} (L(P_{IMP-1}) - L(P_{IMP-2})) \tag{180}$$

$$P_{GCF} = P_{CONS} \tag{181}$$

$$P_{EXP} = P_{CONS} \tag{182}$$

$$P_{IMP} = P_{IMP}^{B} \tag{183}$$

$$P_{HOUSES} = P_{HOUSES}^{B} \tag{184}$$

$$P = \frac{GDP}{GDP_R} \tag{185}$$

$$\mathbf{P}_i^S = g_{P_i^S} P_{i-1}^S \tag{186}$$