Essays on household behaviour in macroeconomic models

by

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Declaration of Authenticity and Author's Rights

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed:

Date:

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Statement of Co-authorship

Chapter 4 is co-authored with my supervisor and colleague Dr. Gioele Figus.

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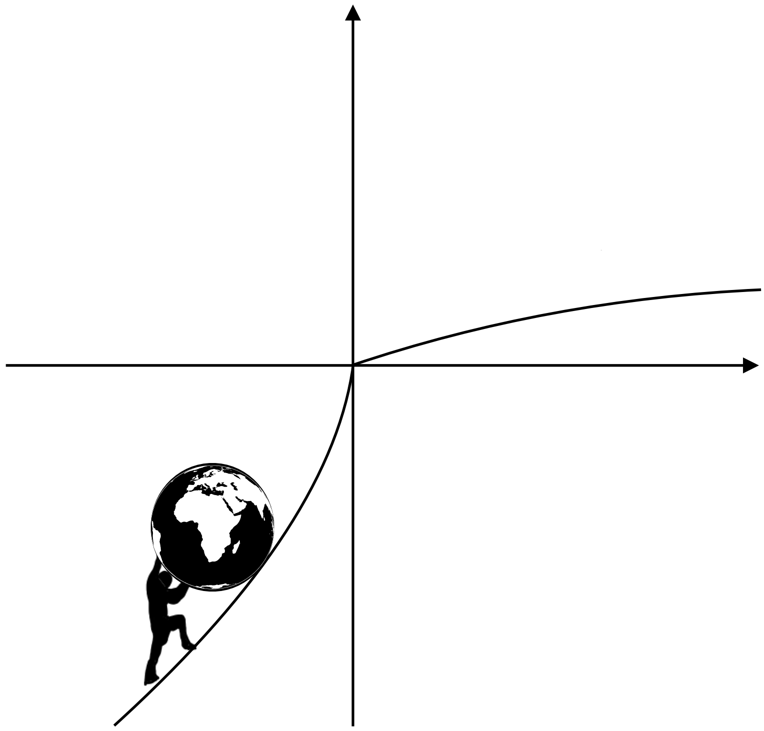
Chapter 1

An introduction to the thesis

Economists are deeply interested in the drivers of nations' welfare, at least in part so they can advise policymakers on maximising it. A key component of welfare is household wellbeing. Therefore, having a complete understanding of household behaviour and how it responds to the economic environment helps economists develop better policy advice to maximise welfare and shape the world around us.

Yet while Sisyphus' eternal punishment was to roll a boulder up a hill for eternity, economists' punishment is the knowledge that our recommendations will always be built on assumptions and models which are abstractions from reality. Whereas physicists estimate the coefficient of gravity with a high level of certainty, economists will always be constrained in their inferences by shortages of reliable counterfactuals, data limitations and statistical uncertainty.

Although this may dissuade some from conducting or trusting economic analysis, unlike Sisyphus' eternal journey, our eternal journey is not fruitless. Each development in economic thought improves and provokes our understanding of the world around us and, therefore, enables us to enhance the wellbeing of households through better policy recommendations.



With this philosophy in mind, this thesis seeks to improve our understanding of the world by developing and applying methods to capture household decisions and behaviours more accurately. Household decisions and behaviours are the central theme of this thesis as these are likely to have very large impacts on aggregate wellbeing. Indeed, households' consumption accounts for most of Gross Domestic Product (GDP). Moreover, households' labour market choices and savings decisions directly influence an economy's production capacity. Although economists have developed advanced theories and methods to estimate household consumption, saving, and labour market behaviour, we must keep pushing the boulder up the infinite hill to improve our knowledge, improving policy recommendations and increasing our ability to improve household wellbeing.

This thesis pushes the economic boulder up the infinite hill through four chapters in addition to this introduction and a conclusion. Each chapter is connected by the common theme of household decisions and behaviours and is designed as a distinct contribution. Beyond household decisions and behaviour, a set of common themes are investigated throughout the thesis.

The central connection between Chapters 2-4 is the role of household consumption in determining economic outcomes in macroeconomic models. Chapters 2 and 3 focus on intertemporal household consumption modelling explicitly, whereas Chapter 4 considers the importance of intratemporal consumption modelling. Chapters 2 and 3 are linked by the use of an extended Ramsey (1928), Cass (1965), Koopmans (1963) (RCK) model extended to capture consumption habits and reference dependence consumption behaviour. The chapters are separated as they contribute to distinct literatures. Chapter 2 introduces existing consumption theories to a representative household Computable General Equilibrium (CGE) model contributing to the CGE modelling literature whereas Chapter 3 contributes to the growth literature by investigating distributional impacts of growth focusing on the effects of behavioural heterogeneity. Other connections between the chapters include the focus on distributional impacts in Chapters 3 and 4 and the use of CGE model simulations.

Chapter 2 is titled *"Intertemporal consumption in general equilibrium models: What is the role of habits and reference dependence?"*. This chapter contributes to the CGE literature by introducing two intertemporal consumption modelling frameworks to the CGE modelling toolbox. This extends beyond current treatments of intertemporal consumption modelling in CGE, which have relied on Keynesian consumption functions (Hicks, 1937; Hansen, 1953) and neoclassical consumption assumptions built on the Permanent Income Hypothesis (Friedman,

1957) and Life Cycle Hypothesis (Modigliani, 1966). The frameworks introduced are the habit formation (Abel, 1990) and reference-dependent consumption (Kahneman and Tversky, 1979; Bowman et al., 1999) models.

These introductions are crucial as many research questions addressed using CGE models require a detailed understanding of short- to medium-run policy effects on household consumption and savings. For instance, environmental questions (e.g. Böhringer and Rutherford, 2002; Allan et al., 2014; Peter G. McGregor and Swales, 2021; Böhringer et al., 2021) and fiscal policy questions (e.g. Suárez-Cuesta and Latorre, 2023; Persyn et al., 2023) require a detailed understanding of dynamic effects. As household consumption is the dominant component of GDP and drives most CGE simulation results, it is imperative that CGE modellers consider which intertemporal consumption modelling framework is most appropriate to address their research questions. If intertemporal household consumption is better proxied by habit formation (as empirically found and summarised in Havranek et al., 2017) or reference-dependent behaviour (as suggested by Shea, 1995a,b; Bowman et al., 1999), employing neoclassical or myopic consumption models may lead to misleading results and policy recommendations.

To address these issues, Chapter 2 incorporates the Abel (1990) habit formation model and Bowman et al. (1999) empirical reference dependence model into a simple representative household CGE model. Novel and generalisable approaches are developed to incorporate these consumption models within an open economy RCK model, coded through the software package General Algebraic Modeling System (GAMS).

Comparing consumption responses to stylised productivity shocks, Chapter 2 draws three qualitative conclusions. First, for representative household models, the choice of the intertemporal consumption modelling framework does not affect long-run simulation results. This evidence supports the use of simple Keynesian consumption functions for long-run equilibrium analysis.

Second, when short- to medium-run responses are important research results, CGE modellers should choose their consumption modelling frameworks carefully. This is because the presence of consumption habits will speed up the transition to the new steady state if the elasticity of intertemporal substitution is less than 1 as is found in most empirical research (e.g. Hall, 1988; Yogo, 2004; Havranek et al., 2015). This will increase the magnitude of medium-run consumption responses relative to the neoclassical consumption model. If households are reference-dependent, ignoring short- to medium-run asymmetries in consumption responses to positive and negative shocks may also lead to inconsistencies between empirical evidence and model predictions made using neoclassical consumption models.

Third, CGE modellers should consider the importance of anticipation effects in modelling short to medium-run impacts when shocks are expected. Anticipation effects have qualitatively important implications for the results, especially in the case of the reference dependence model.

Chapter 3 is titled *"Growth, household behaviour and inequality: How do heterogeneity in habits and loss aversion affect the income distribution during growth?"*. Building on the pioneering works of Solow (1956), Ramsey (1928), Cass (1965), Koopmans (1963) and Alvarez-Cuadrado et al. (2004), this chapter extends neoclassical growth theory to consider how heterogeneity in household behaviours may affect the consumption and income distribution during growth. Applying a RCK model, this chapter develops simple empirically testable frameworks to help policymakers understand potential implications of growth on different household groups.

Chapter 3 yields four stylised conclusions. First, if the elasticity of intertemporal substitution (EIS) is not equal to one, heterogeneities in habit strength will unambiguously affect the consumption and income distribution during growth. Stronger habit strengths will be associated with higher (lower) consumption growth when the EIS is less (greater) than one. Importantly, this result can be empirically estimated to determine which groups are more likely to benefit from economic growth through their behaviours rather than their factor ownership.

Second, distributional effects on consumption in the short run will reverse in the long run. That is, reductions in consumption are associated with increases in savings following a positive productivity shock. Therefore, households which increase consumption by less in the short run accumulate more capital in the long run. This increases their future factor income which increases consumption in the long-run.

Third, if households are loss-averse, taking the average consumption in the economy as a reference point, relatively poorer households will increase their consumption disproportionately as compared to relatively rich households during economic growth. This is because relatively poor households wish to reduce the distance between their consumption and average consumption in the economy. This is achieved through short-run increases in savings, increasing future incomes and, therefore, medium to long-run consumption.

Fourth, the consumption and income convergence of loss-averse households only occurs if "loser" households are able to anticipate their future loss aversion. This highlights the importance of understanding household group-specific expectations.

Chapter 4 is titled *"How should governments respond to energy price crises? A horse-race between fiscal policies"*. This chapter has already been published in "Energy Economics", co-authored with Dr. Gioele Figus and compares the welfare and distributional implications of fiscal policies aimed at reducing sudden and significant energy price increases (Duparc-Portier and Figus, 2024).

A dynamic CGE model with households disaggregated by income groups is developed to compare the effectiveness of five energy price-reducing fiscal policies. The policies are assessed under two financing options, pure government debt and a mix of debt and windfall taxation on energy companies.

Simulation results demonstrate that targeted demand-side policies are more effective at reducing overall energy-driven inflation and improve long-run welfare the most as they redistribute income across the income distribution most effectively. Targeted income subsidies are the most effective demand-side policy if the marginal propensity to consume out of subsidies is close to 1. When this is not the case, targeted price subsidies on household energy consumption are the most effective policy tool to maximise long-run welfare. This observation highlights the importance of distinguishing between the marginal propensity to consume out of general income and unexpected income subsidies[1] in CGE models.

Supply-side policies and mixed demand- and supply-side policies achieve a smaller reduction in the consumer price index and increase output in the short run. These are the best policies to support domestic production; however, they are less effective at counteracting the distributional effects of the energy shock.

[1] An issue empirically investigated by Agarwal et al. (2007) and Parker et al. (2013).

Financing the policies partly through windfall taxation does not impact the ranking of policies but it delivers better distributional outcomes and higher welfare. The results motivate the use of windfall taxation if governments face high interest rates on debt financing and/ or if households care sufficiently about the provision of public goods.

The optimal policy is likely a mix of supply-side measures such as production tax reductions or general price subsidies and either targeted energy price subsidies or targeted income subsidies financed where possible through windfall taxation.

Chapter 5 is titled *"The UK Wage Curve Puzzle: Has the Wage Curve flattened since the Global Financial Crisis?"*. This chapter extends beyond household consumption behaviour by considering how labour market behaviours affect CGE simulation results. Specifically, having found that many CGE studies employ wage curves as a shortcut to introduce unemployment (See for instance Böhringer et al., 2003; Boeters and Savard, 2013; Lecca et al., 2013; Christensen, 2022; Duparc-Portier and Figus, 2022, 2024), this chapter investigates how the shape of the wage curve changed in the UK over time.

This chapter uses an extensive range of empirical methods common in the wage curve literature, including Bell et al. (2002) two-stage and region-mean wage curves (Blanchflower et al., 2024). Both the British Household Panel Survey/ Understanding Society survey (ISER, 2023) and the Annual Population Survey (ONS, 2023) are employed to estimate the unemployment elasticity of wages in the UK between 1992 and 2020.

The chapter discovers a flattening of the UK wage curve following the Global Financial Crisis. This result is robust to methodological choices and implies that the unemployment elasticity of wages is close to 0. Other measures of labour market slack, such as the non-employment rate and underemployment rate, do not explain the flattening of the wage curve, evidence contrasting US labour markets (Blanchflower et al., 2024). This result raises questions on the appropriateness of wage curves in CGE simulations of the UK as small changes in the unemployment elasticity of wages can lead to huge differences in aggregate results.

Indeed, CGE simulations of a Brexit-style trade shock suggest that the estimated unemployment elasticity of wages is associated with much larger aggregate output reductions than classical estimates employed in the CGE literature. This raises important questions for future CGE research capturing labour market behaviour in the UK.

Chapter 6 concludes the thesis by summarising the overarching aim and the key contributions of each chapter.

Chapter 2

Intertemporal consumption in general equilibrium models: What is the role of habits and reference dependence?

2.1 Introduction

Approximating household consumption behaviour is essential to the predictions and policy implications of General Equilibrium (GE) models. It is the dominant component of Gross Domestic Product (GDP) in most countries and is crucial in determining investment decisions and labour supply. Therefore, a broad body of literature exists that is incrementally evolving to capture more features of aggregate consumption behaviour.

Arguably the first breakthrough in this literature is the introduction of Keynesian consumption functions (Keynes, 1936) in the IS-LM model (Hicks, 1937; Hansen, 1953). This function explains the positive correlation between aggregate consumption and income in a simple empirically estimatable way. The constant Marginal Propensity to Consume (MPC) assumption employed by Hicks (1937) and Hansen (1953) draws criticism as Keynes had suggested that the MPC is decreasing in an economy's income. This criticism amplifies during the 1950s and 1960s, when Friedman (1957) in the Permanent Income Hypothesis (PIH) and Modigliani (1966) in the Life Cycle Hypothesis (LCH) famously highlight the importance of future expectations of income in households' contemporaneous consumption choices.

With a new emphasis on micro-foundations and expectations in macroeconomic models, consumption modelling continues evolving, most notably with the creation of the Ramsey-Cass-Koopmans (RCK) model (Ramsey, 1928; Cass, 1965; Koopmans, 1963). Incorporating time-separable, concave utility functions (Ramsey, 1928) and exponential discounting (Samuelson, 1937), Cass (1965) and Koopmans (1963) derive a household consumption problem in the form of an Euler equation. This captures the limitations Modigliani (1966) and Friedman (1957) highlighted as the consumption path depends on rational expectations of future consumption and income. This consumption modelling approach, named the neoclassical approach in this chapter, is still widely used today in Dynamic Stochastic General Equilibrium (DSGE) models and, to a lesser extent, in Computable General Equilibrium (CGE) models.

While the neoclassical approach has become a standard, it fails to capture some features of aggregate household consumption behaviour. Hump-shaped consumption responses following temporary shocks (Abel, 1990; Galí, 1994; Fuhrer, 2000) and asymmetric consumption responses to income shocks driven by loss aversion and diminishing sensitivities (Kahneman and Tversky, 1979; Tversky and Kahneman, 1992; Shea, 1995a,b; Bowman et al., 1999) are two such examples.

Hump-shaped consumption responses refer to situations in which medium-run consumption responses to unanticipated shocks are larger in magnitude than predicted by the LCH and PIH. These arise when households have a higher preference for consumption smoothing than predicted by the LCH or PIH. When households form habits, relative utility increases the incentive to smooth consumption over time. Thus, habit formation models have been introduced to capture this feature of aggregate consumption behaviour mainly in the DSGE literature (Abel, 1990; Galí, 1994; Fuhrer, 2000).

The theoretical reference dependence model of Kahneman and Tversky (1979) also introduces relative utility. It extends the habit formation framework by considering loss aversion, implying that the utility of gains is lower than the disutility of losses of the same magnitude.[1] It also suggests that households have diminishing sensitivities to both gains *and* losses.

[1]The reference dependence model is supported by experimental and empirical evidence summarised in Section 2.2.

Bowman et al. (1999) build on Kahneman and Tversky (1979) by developing a theoretical reference dependence model, which is empirically validated by Shea (1995a,b) and Bowman et al. (1999) and contradicts predictions of the PIH and LCH. The model suggests that consumption responds asymmetrically to positive and negative income changes. Following unanticipated negative shocks, Bowman et al. (1999) find that the magnitude of consumption decreases is lower than the magnitude of consumption increases after positive shocks. This is because households are both loss averse and have diminishing sensitivity to losses. As there is some likelihood that future income shocks will push the household back to the domain of gains, households prefer to maintain consumption close to the reference point contemporaneously following unanticipated adverse shocks. This reduces savings and, therefore, future capital stocks, increasing the likelihood that households will have to decrease consumption in the next period. When adverse shocks are anticipated, households have a precautionary saving motive, reducing consumption much more aggressively than when these are unanticipated. This behaviour occurs as households have an incentive to preemptively decrease future consumption reference points when adverse shocks are anticipated to reduce the likelihood of future relative utility losses.

Despite the evolution in intertemporal consumption modelling in the broader macroeconomic literature, CGE practitioners have mainly focused on developing intratemporal consumption modelling methods.[2] This is reasonable as the main feature of CGE models is the multisectoral structure. Following Occam's razor arguments, most CGE applications use the neoclassical approach or even Keynesian consumption functions to proxy aggregate household consumption behaviour in dynamic settings (e.g. Lecca et al., 2013; Cicowiez and Lofgren, 2017; Chris-

[2] Ho et al. (2020) undertake an in-depth discussion on the state of intratemporal consumption modelling in CGE focusing on CES, LES and AIDADS functions.

tensen and Persyn, 2022). Although parsimony increases the interpretability of macroeconomic models, many CGE research questions require intertemporal considerations. The dynamic effects of climate change, pension systems, and fiscal and trade policies may not be adequately captured through neoclassical or Keynesian consumption functions. Therefore, CGE modellers must introduce more advanced dynamic modelling frameworks to better capture the complexity of intertemporal consumption and savings choices.

For these reasons, this chapter introduces the Abel (1990) habit formation model and the empirical reference dependence (Kahneman and Tversky, 1979) model of Bowman et al. (1999) to a CGE context. By incorporating these models, relative utility and loss aversion can be captured in line with the broader macroeconomic literature. Habit formation helps to capture stronger preferences for consumption smoothing. Reference dependence captures the asymmetry in consumption responses when households face positive and negative shocks.

Crucially, the consumption models can be calibrated using empirically estimated parameters, increasing the external validity of the results, and are tractable and easy to implement in "General Algebraic Modeling System" (GAMS), the software package of choice of most CGE modellers. These models are nested into an open economy RCK (ORCK) model (Ramsey, 1928; Cass, 1965; Koopmans, 1963). The development of these models contributes to the evolution of consumption modelling in the broader macroeconomic literature and broadens the toolkit available to CGE modellers in evaluating policy outcomes.

Numerical simulations are employed to compare impulse response functions of the habit formation model and the reference dependence model compared to those of a neoclassical baseline. A set of positive and negative Total Factor Productivity

(TFP) shocks are introduced to ORCK under the three consumption modelling frameworks. Unanticipated permanent and temporary TFP shocks and anticipated permanent TFP shocks are evaluated to understand the qualitative implications of each of the consumption models.

From the simulations, three stylised conclusions are drawn. First, long-run consumption results *are not* affected by the choice of the intertemporal consumption model even in an open economy. This evidence is in line with Lecca et al. (2013), who find that forward-looking and myopic consumption models yield identical long-run results.

Second, short- to medium-run results *are* affected by the choice of the intertemporal consumption modelling framework. Following temporary TFP shocks, the habit formation model exhibits hump-shaped consumption responses as found by Fuhrer (2000). This is driven by the higher preference for consumption smoothing reducing the magnitude of consumption changes each period. In the case of positive shocks, the initial consumption response of the habit formation model is smaller than the neoclassical consumption model. Therefore, habit formation households save relatively more, increasing future capital stocks and income. This results in higher medium-run consumption and the notable hump-shape.

The empirical reference dependence model captures asymmetric consumption responses where households facing an unanticipated negative shock resist decreasing consumption more than they resist increasing consumption when faced with a positive shock. This is driven by loss aversion as households face a higher disutility when decreasing consumption. When a negative shock is anticipated, this resistance does not exist as households decrease consumption to lower future reference points. This is driven by a precautionary savings motive to avoid the domain of losses in future periods (in line with Bowman et al., 1999).

Third, introducing reference dependence behaviour to CGE models sheds light on the importance of distinguishing between anticipated and unanticipated shocks in CGE simulations.[3] Policies such as Brexit took years of preparation. If neoclassical households are assumed in such simulations, changes in household behaviour in preparation of the shock are very limited and symmetric[4] in contrast to the empirical evidence of Shea (1995a,b) and Bowman et al. (1999).

The remainder of this chapter is structured as follows: Section 2.2 summarises the state of play of consumption modelling in the CGE literature and selected literature on the neoclassical assumptions, habit formation and reference dependence; Section 2.3 defines the model used in this chapter and Chapter 3; Section 2.4 describes the methodology used to capture habit formation and reference dependence in consumption;[5] Section 2.5 describes and interprets numerical simulation results of the habit formation and reference dependence models relative to neoclassical assumptions; Section 2.6 discusses sensitivities and limitations of the models presented; Section 2.7 concludes the chapter.

[3] An idea investigated by Allan et al. (2017) in the context of tourism.
[4] Meaning that the magnitude of consumption responses is independent of its sign.
[5] Section 2.4 is also relevant for Chapter 3.

2.2 Literature Review

This section summarises the state of play of consumption modelling in CGE and alternative consumption models proposed in the broader literature. The alternatives which are focused on in this chapter are habit formation and reference dependence consumption models. These models are chosen as they have been widely adopted and empirically validated in the broader macroeconomic literature.

2.2.1 Consumption in CGE models

Depending on the research aim, CGE modellers choose specific assumptions to capture household consumption. These choices can be categorised into two parts, intratemporal and intertemporal consumption structure. The intratemporal consumption structure specifies the choice between consumption goods from different industries and regions within a time period whereas the intertemporal consumption structure specifies the choice of the aggregate consumption path over time.

In state-of-the-art CGE models such as the HMRC's CGE model (HMRC, 2013), AMOS (Lecca et al., 2011), GTAP (van der Mensbrugghe, 2019) and RHOMOLO (Christensen, 2022) amongst others, the focus is typically on intratemporal household consumption. Some standard methods of capturing intratemporal consumption are to use multi-level Constant Elasticity of Substitution (CES) functions (e.g. Lecca et al. 2011) and Linear Expenditure System (LES) functions[6] (e.g. HRMC 2013). Other more complex systems such as Constant Difference of Elasticities (CDE), indirect addilog systems (IAS) and an implicitly directly additive demand system (AIDADS) have also been proposed (Ho et al., 2020; de Boer et al., 2021; Chen, 2017). LES, CDE and AIDADS functions help capture income effects of consumption basket compositions.

[6]Stone-Geary utility functions, which are used in Chapter 4, belong to this particular family.

There have been great efforts to improve intratemporal consumption modelling in CGE models (Ho et al., 2020), however, relatively little focus has been placed on intertemporal consumption behaviour. As the focus of many CGE analyses is on long-run outcomes, modellers often omit intertemporal optimisation of the households and instead choose variations of Keynesian consumption functions (Christensen and Persyn, 2022). This omission is warranted for long-run analysis, as Lecca et al. (2013) find that representative agent neoclassical and Keynesian-style consumption models yield identical long-run results.

When short to medium-run results are of interest, this omission is problematic as the dynamic adjustment to the equilibrium may differ. For instance, emissions taxes may have delayed effects due to consumption habits that may slow the adjustment to the new equilibrium, leading to higher-than-predicted medium-run emissions. Unexpected tax increases may lead to short-run loss-aversion in consumption, depleting capital stocks, and leading to more adverse medium-run effects than predicted by neoclassical consumption models. Therefore, CGE modellers must introduce these features of consumption behaviour to capture the medium-run effects of policies better.

Beyond Keynesian consumption functions, two common consumption modelling approaches have been adopted in CGE settings. Perhaps the most popular family of CGE models in the World, the GTAP models often treat savings as a commodity in the household utility function to proxy for future consumption (Corong et al., 2017). The second approach is the neoclassical assumption popularised in CGE by Devarajan and Go (1998) and employed by Lecca et al. (2013) and HMRC (2013) amongst others. In this case, time-separable period utility functions are assumed and Samuelsons's (1937) exponential discounting model is employed.

Few CGE modellers have ventured beyond the exponential discounting model despite ample empirical evidence of habit formation and reference dependence in consumption behaviour (Duesenberry, 1952; Pollak, 1970; Kahneman and Tversky, 1979; Tversky and Kahneman, 1992) and modelling developments in the broader macroeconomic literature (see for instance Abel, 1990; Shea, 1995a,b; Bowman et al., 1999; Alvarez-Cuadrado et al., 2004). Only Koesler (2015), Niemi (2019) and Baikowski and Koesler (2020) introduce habit formation to CGE models. These early introductions of habit formation aim to capture sector-specific habits but fail to capture the intertemporal optimisation dimension of habit formation models. No CGE study has introduced reference-dependent household consumption behaviour.

2.2.2 Consumption in Macroeconomic models

The neoclassical agent

The baseline used to compare the habit formation and reference dependence models is the neoclassical consumption model. The neoclassical agent assumption[7] captures the key features of the PIH and LCH (Friedman, 1957; Modigliani, 1966). Although Friedman and Savage (1948) argue that the underlying assumptions are unlikely to hold, they suggest that the method proxies for aggregate consumption behaviour well.

In discrete time intertemporal problems, the neoclassical agent's utility function (U_h) can be represented as the sum of time-separable utility functions using

[7]The neoclassical agent is a forward-looking preference utilitarian with time-consistent preferences (Persky, 1995; Mill and Hausman, 2007, p.222).

Samuelson's (1937) exponential discounting model as shown in eq. (2.1).

$$U_h = \sum_{t=0}^{\infty} \beta^t \cdot u_N \left(C_{h,t} \right). \tag{2.1}$$

In eq. (2.1), $t \in \mathbb{N}$:= time subscript, h is an individual subscript,[8] $\beta \in (0,1)$:= discount factor, $u_N : \mathbb{R}_+ \to \mathbb{R}$:= twice continuously differentiable strictly increasing concave period utility function and $C_{h,t} \in \mathbb{R}_+$:= consumption by individual h at time t.

The Habit Formation agent

The neoclassical agent assumption encapsulates many features of aggregate consumption behaviour. However, one feature it fails to capture is consumption habits, which had been observed as far back as Duesenberry (1949) and Modigliani (1949). Although Brown (1952) presented an IS-LM model capturing consumption habits and Pollak (1970) proposed a utility function capturing habit formation, little progress was made in capturing habits in mainstream macroeconomic models until Abel (1990), Galí (1994) and Fuhrer (2000). Abel (1990) and Galí (1994) popularised external habit formation models; these are often called "Keeping up with the Joneses" (KUJ) models. In KUJ models, households incur a jealousy cost from consuming less than others in the economy. Fuhrer (2000) popularised internal habit formation models where the representative household optimises both consumption and its future habit stock. Numerous authors have since estimated statistically significant levels of habit persistence even after correcting for publication bias (Havranek et al., 2017).

[8] The individual subscript is redundant for models with a single representative household. The subscript is maintained as it becomes important for Chapter 3.

To capture habit formation, two utility functions can be used. These are the Pollak (1970) or the Abel (1990) forms. As most modern empirical estimates are based on the multiplicative form popularised by Abel (1990) (Havranek et al., 2017), this form is presented in eq. (2.2) and employed in the chapter's central simulations.[9]

$$U_h = \sum_{t=0}^{\infty} \beta^t \cdot u_H \left(\frac{C_{h,t}}{H_{h,t}^{\gamma}} \right). \tag{2.2}$$

The notation in eq. (2.2) is the same as that in (2.1) with the addition of two new terms: $H_{h,t} \in \mathbb{R}_+ :=$ contemporaneous habit level of individual h at time t and $\gamma \in \mathbb{R}_+ :=$ level of habit formation. $u_H : \mathbb{R}_+ \to \mathbb{R} :=$ twice continuously differentiable strictly increasing concave period utility function. When $\gamma = 0$ in eq. (2.2), the equations reduce to the classical time-separable utility function.

The Reference Dependent agent

One of the criticisms of the habit formation model is that it is an aggregate empirical relationship rather than a micro-founded behaviour. Moreover, it fails to capture asymmetric consumption responses following unanticipated shocks (Shea, 1995a,b; Bowman et al., 1999).

The reference dependence model first described by Kahneman and Tversky (1979) helps to capture these weaknesses. The reference dependence model captures three experimentally and empirically observed features of consumption behaviour: reference dependence, loss aversion and diminishing sensitivity to gains and losses.

[9] Appendix A.1 presents the Pollak (1970) habit form and Appendix A.3 compares Abel (1990) and Pollak (1970) habit formation model results.

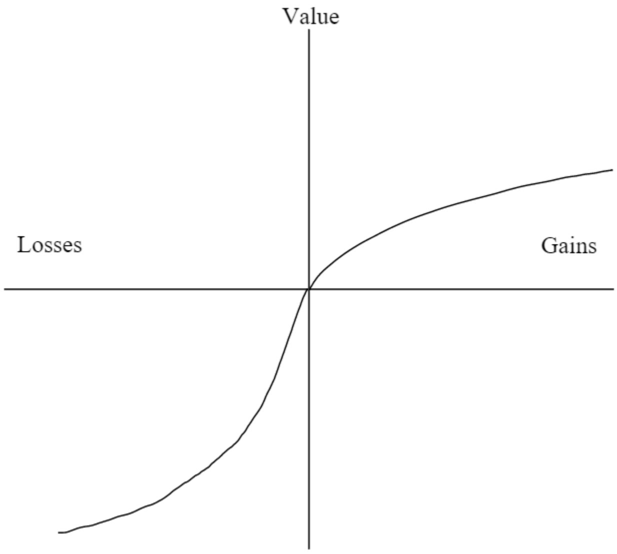


Figure 2.1: Author's drawing of Kahneman and Tversky's hypothetical value function

The reference dependence model is described graphically by Kahneman and Tversky's hypothetical function presented on Figure 2.1. Reference dependence refers to the fact that agents define value relative to a reference point (Tversky and Kahneman, 1974, p.274). Agents view points above the reference point as gains and those below it as losses. Loss aversion suggests that the disutility of losses relative to the reference point is larger than the utility of gains of the same magnitude. Diminishing sensitivity suggests that as the size of gains/ losses increases, the marginal value of these decreases.

Extensive and robust evidence of reference-dependent consumption behaviour has been found in microeconomic experiments (Kahneman et al., 1991), neurological experiments (Weber et al., 2007), specific market settings (e.g. Benartzi and Thaler (1995), Kaur (2019) in financial and labour markets) and aggregate consumption behaviour (Shea, 1995a,b; Bowman et al., 1999). A comprehensive overview of some of the wider literature is provided by O'Donoghue and Sprenger (2018).

In the consumption literature, Shea (1995a,b) finds empirical evidence that household consumption in the United States responds asymmetrically to income increases and decreases contradicting the LCH and PIH. Shea (1995a,b) finds that households resist decreasing consumption when facing bad news more than they resist increasing consumption in response to good news. This resistance is caused by loss aversion and risk seeking behaviour as households faced with an unanticipated loss prefer consuming closer to the reference point contemporaneously in the hope that future income will rebound in the subsequent periods (Bowman et al., 1999). Fundamentally, Shea (1995a,b) argue that liquidity constraints and myopia do not explain the asymmetry.

Importantly, when shocks are anticipated, the asymmetric response is reversed as households increase precautionary savings in preparation for the future shock to avoid being in the domain of losses. This empirical observation is in line with the theoretical reference dependence model of Bowman et al. (1999) which is built on Kahneman and Tversky (1979). Bowman et al. (1999) create a two-period consumption and saving model in which consumers are reference-dependent and loss-averse validating their theoretical results empirically using data from France, Canada, West Germany, Japan and the United Kingdom.

Following in the footsteps of Bowman et al. (1999), Kőszegi and Rabin (2007) and Foellmi et al. (2011) introduce infinite time reference dependence consumption models. Kőszegi and Rabin (2007) introduce a model of reference dependence in which the reference point is an expectation of future consumption rather than a past consumption level. The paper written by Kőszegi and Rabin (2007) is particularly influential as it proposes the first solution to a reference dependence problem in an infinite time model. Thus, with no uncertainty, the future reference points equal future consumption levels and the model collapses to a neoclassical consumption model. Foellmi et al. (2011) also introduce a reference dependence model within a Ramsey growth model context. This model uses past consumption as a reference point.

The models listed provide a strong foundation for introducing reference-dependent consumption behaviour in CGE models, yet this has not been done for an important reason. As CGE models are typically very large, the methods proposed have either not been generalisable to large-scale models or are not computationally feasible for larger sets of equations. For instance, to allow for the derivation of closed-form solutions, the models proposed by Bowman et al. (1999) and Foellmi et al. (2011) are simplified. The model proposed by Bowman et al. (1999) has two periods. This avoids issues of high dimensionality in deriving a solution to the reference dependence model at the cost of omitting some crucial discussion about dynamic adjustment in a reference dependence model. Although Foellmi et al. (2011) use a method capable of examining the dynamic adjustment process, their RCK model does not consider the labour market, removes many prices (wage, rental rate of capital) and more importantly, assumes a full depreciation rate each period. Thus, the adjustment process is very quick. This limits the model's applicability as full depreciation may only arise after over a decade. For such long time frames, one may expect reference points to have adjusted greatly between observations. These simplifications allow Foellmi et al. (2011) to use a grid search algorithm to estimate the solution of the model, but come at the cost of realism and inflexibility of adaptation to larger scale models such as CGE.

The typical utility function used to capture reference dependence is presented in eq. (2.3).

$$U_h = \sum_t \beta^t \cdot \Big(u(C_{h,t}) + v(C_{h,t}, X_{h,t})\Big). \tag{2.3}$$

In eq. (2.3), the notation follows from eq. (2.1) and (2.2). $v : \mathbb{R}_+ \times \mathbb{R}_+ \to \mathbb{R}$:= relative utility function capturing loss aversion and diminishing sensitivity as in Figure 2.1. The form of $v(\cdot, \cdot)$ proposed by Tversky and Kahneman (1992) is presented below:

$$v(C_{h,t}, X_{h,t}) = \begin{cases} (C_{h,t} - X_{h,t})^{\mu_1} & \text{if } C_{h,t} \geq X_{h,t} \\ -\lambda \cdot (X_{h,t} - C_{h,t})^{\mu_2} & \text{if } C_{h,t} < X_{h,t} \end{cases}. \tag{2.4}$$

Where: $X_{h,t} \in \mathbb{R}_+$:= reference point, $\mu_1, \mu_2 \in (0, 1]$:= diminishing sensitivity parameters in the domain of gains and losses respectively and $\lambda \in [1, \infty)$:= loss aversion parameter (O'Donoghue and Sprenger, 2018).

Due to the complexity of capturing the Tversky and Kahneman (1992) reference dependence model numerically, an empirical form of reference dependence has been introduced by Shea (1995a,b) and employed by Bowman et al. (1999). This form has also been estimated by Shea (1995a,b) and Bowman et al. (1999) yielding parameter estimates consistent with the theoretical reference dependence model of Bowman et al. (1999). The empirical reference dependence model is presented in eq. (2.5).

$$\Delta c_t = a + \lambda_G(POS_t)\Delta\hat{y}_t + \lambda_L(NEG_t)\Delta\hat{y}_t + b \cdot \hat{r}_t. \tag{2.5}$$

In eq. (2.5), $\Delta c_t \in \mathbb{R} :=$ changes in aggregate consumption, $\Delta\hat{y}_t \in \mathbb{R} :=$ expected income changes, $\hat{r}_t \in \mathbb{R} :=$ expected real interest rate, $a \in \mathbb{R} :=$ constant, $\lambda_G \in \mathbb{R} :=$ sensitivity of consumption to positive expected changes in income, $\lambda_L \in \mathbb{R} :=$ sensitivity of consumption to negative expected changes in income, $b \in \mathbb{R} :=$ sensitivity of consumption to changes in real interest rates. POS_t and NEG_t are dummy variables equal to 0 or 1. When $\Delta\hat{y}_t > 0$, $POS_t = 1$ and $NEG_t = 0$. When $\Delta\hat{y}_t < 0$, $POS_t = 0$ and $NEG_t = 1$.

When $\lambda_G = \lambda_L = 0$, the model collapses to a neoclassical consumption model (Campbell and Mankiw, 1990). Shea (1995a,b) and Bowman et al. (1999) estimate $\lambda_L \approx 1.1 > \lambda_G \approx 0.2$. These estimates imply that household consumption decreases by more to anticipated income decreases than it increases in response to anticipated income increases. It also implies that household consumption decreases less in response to unanticipated income decreases than it increases in response to unanticipated income increases.

Based on the literature summarised, this chapter aims to translate habit formation and reference dependence consumption behaviour to a simple CGE model. Thus, the next section defines a simple CGE model built on the RCK model. Habit formation and reference dependent consumption are then introduced to the model.

2.3 Model overview

For simplicity and ease of exposition, the consumption models are derived within a simple CGE model built on the RCK model with extensions to capture multiple household groups and trade (Ramsey, 1928; Cass, 1965; Koopmans, 1963).[10] This model will be named the open economy RCK model (ORCK).[11] Before deriving each of the putative consumption models, an overview of the structural equations of ORCK is provided.

In the RCK model, the economy has a representative firm producing a representative good operating in a perfectly competitive market (Acemoglu, 2007, p.40). This simplification is chosen as this chapter focuses on intertemporal choices rather than intrasectoral ones. Output ($Y_t \in \mathbb{R}_+$) is defined by a Cobb-Douglas function including a technology variable ($A_t \in \mathbb{R}_+$) and two factors of production, capital ($K_t \in \mathbb{R}_+$) and labour ($L_t \in \mathbb{R}_+$) (Solow, 1956, p.66). This form is extended to capture firms' intermediate imports of foreign goods and services ($M_{F,t} \in \mathbb{R}_+$), as demonstrated in eq. (2.6):

$$Y_t = A_t \cdot K_t^{\alpha} \cdot L_t^{\kappa} \cdot M_{F,t}^{1-\alpha-\kappa}. \tag{2.6}$$

In eq. (2.6), $\alpha \in (0,1)$ and $\kappa \in (0,1)$ are the capital and labour shares in production. In the open economy case, $\alpha + \kappa < 1$. This implies that firms require foreign goods to produce domestic output.[12] In the closed economy case, $\alpha + \kappa = 1$ and we return to Acemoglu (2007, p.40). Output is sold at price $p_t \in \mathbb{R}_+$.

[10]The RCK model is very simple, however, it is the cornerstone of many other GE models including business cycle models and dynamic CGE models.

[11]The acronym ORCK should not to be confused with the mythical "Ork" or "Orc" which are demons of alpine folklore and humanoid monsters in the work of Tolkien (1954).

[12]The Cobb-Douglas form is assumed for simplicity and without loss of generality. Multi-level CES production functions could be employed instead in more applied settings.

In the RCK model, labour supply and technology (TFP) grow at exponential rates $n \geq 0$ and $\overline{g} \geq 0$ respectively (Acemoglu, 2007, p.68, 84) whereas capital grows with investment which equals savings ($I_t \in \mathbb{R}_+, S_t \in \mathbb{R}_+$) and depreciates exponentially at a constant rate $\delta \in (0, 1)$ (Acemoglu, 2007, p.50). The ORCK model follows similar assumptions as demonstrated in eq. (2.7) - (2.9).

$$A_{t+1} = A_t \cdot (1 + g_t). \tag{2.7}$$

$$L_{h,t+1} = L_{h,t} \cdot (1 + n). \tag{2.8}$$

$$K_{j,t+1} = (1 - \delta) \cdot K_{j,t} + S_{j,t}. \tag{2.9}$$

j is a set containing both the household set h and the foreign agent (ROW). As Chapter 3 employs ORCK in a multiple household setting, the labour and capital laws of motion are household-specific (h). The capital law of motion is both household-specific and ROW-specific as, in an open economy, total investment (I_t) may not equal total domestic savings (S_t). This is because foreign direct investment from the Rest of the World (ROW) may increase domestic investment. Consequently, households and the ROW accumulate capital proportionally to their level of savings ($S_{j,t} \in \mathbb{R}_+$).

As some simulations will introduce temporary TFP shocks, TFP is modelled as an AR(1) process. This ensures that the transition back to equilibrium is gradual rather than sudden.

$$g_t = \overline{g} + \rho_A \cdot (g_{t-1} - \overline{g}) + e_t. \tag{2.10}$$

In eq. (2.10), $g_t \in \mathbb{R}$:= TFP growth rate in period t, $\overline{g} \in \mathbb{R}_+$:= Average TFP growth rate, $\rho_A \in [0, 1)$:= TFP shock autocorrelation and $e_t \in \mathbb{R}$:= TFP shock. In this paper, economic agents' behaviours are deterministic and $e_t \neq 0$ only when a temporary shock is introduced.

In contrast to the RCK model (Acemoglu, 2007, p.218), ORCK contains multiple representative households.[13] These make two key decisions. Intertemporally, the households choose how much to consume and save in each period (Ramsey, 1928). Following the RCK model, households maximise an intertemporal utility function of consumption ($C_{h,t} \in \mathbb{R}_+$) subject to their preferences.[14] These preferences are defined in Section 2.4.

The households can consume goods domestically and from ROW. To define the intratemporal optimisation decision, the Armington (1969) assumption is employed. Defining an Armington CES function:

$$C_{h,t} = \phi_h \cdot (\alpha_h^C \cdot D_{h,t}^{\rho} + (1 - \alpha_h^C) \cdot M_{h,t}^{\rho})^{\frac{1}{\rho}}. \tag{2.11}$$

In eq. (2.11), $\phi_h \in \mathbb{R}_+$ is a CES push parameter, $\alpha_h^C \in (0, 1]$ is a CES share parameter, $\rho = \frac{\sigma-1}{\sigma}$ is a substitution parameter linked to the Armington (1969) elasticity of substitution ($\sigma \in \mathbb{R}_+$) between domestic and foreign goods. $D_{h,t} \in \mathbb{R}_+$ and $M_{h,t} \in \mathbb{R}_+$ are household consumption from domestic and foreign firms respectively.

Households are constrained by a budget constraint as presented in eq. (2.12):

$$Q_{h,t} = cpi_{h,t} \cdot C_{h,t} + p_t \cdot S_{h,t} = r_t \cdot K_{h,t} + w_t \cdot L_{h,t}. \tag{2.12}$$

$Q_{h,t} \in \mathbb{R}_+$ is household income, $S_{h,t} \in \mathbb{R}_+$ is household saving, $cpi_{h,t} \in \mathbb{R}_+$ the consumer price index, $r_t \in \mathbb{R}_+$ is the rental rate of capital and $w_t \in \mathbb{R}_+$ is the wage. Eq. (2.12) implies that household h's income from labour ($w_t \cdot L_{h,t}$) and

[13]This feature of the model will become important in Chapter 3.

[14]It is important to note that labour does not enter the household utility function; a simplification.

capital ($r_t \cdot K_{h,t}$) must equal its expenditure consisting of consumption ($cpi_{h,t} \cdot C_{h,t}$) and savings ($p_t \cdot S_{h,t}$).

A set of market clearing conditions, zero profit conditions and definitions must hold to define the system:

$$Y_t = D_t + I_t + X_t. \tag{2.13}$$

$$I_t = \sum_h S_{h,t} + S_{F,t}. \tag{2.14}$$

$$p_t \cdot Y_t = r_t \cdot K_t + w_t \cdot L_t + p_{F,t} \cdot MF_t. \tag{2.15}$$

$$C_t = \sum_h C_{h,t}. \tag{2.16}$$

$$K_t = \sum_j K_{j,t}. \tag{2.17}$$

$$L_t = \sum_h L_{h,t}. \tag{2.18}$$

$$D_t = \sum_h D_{h,t}. \tag{2.19}$$

Eq. (2.13) is the goods market clearing condition in an open economy and implies that production equals total domestic consumption ($D_t \in \mathbb{R}_+$), investment (Acemoglu, 2007, p.49) *and* exports ($X_t \in \mathbb{R}_+$). As ORCK is an open economy model, domestic *and* foreign direct investment ($S_{F,t} \in \mathbb{R}_+$) equal investment as shown in eq. (2.14); in contrast to Acemoglu (2007, p.50). Eq. (2.15) is the zero profit condition of the representative firm. As ORCK is a multiple-household model, eq. (2.16) - (2.19) define the link between household-specific and aggregate consumption, capital, labour and domestic consumption. The solution of ORCK can be found by solving the firm and household problems. Taking the foreign price level as the numéraire we must define equations for r_t, w_t, $M_{F,t}$, $D_{h,t}$, $M_{h,t}$, $cpi_{h,t}$, $C_{h,t}$, X_t and $S_{F,t}$.

2.3.1 Firm optimisation

As the economy is perfectly competitive (Solow, 1956, p.79), the firm faces a zero-profit condition and factor prices equal marginal productivity levels. Taking first-order conditions (FOCs) of eq. (2.6) with respect to K_t, L_t and $M_{F,t}$, it can be shown that:

$$r_t = p_t \cdot \alpha \cdot \frac{Y_t}{K_t}. \tag{2.20}$$

$$w_t = p_t \cdot \kappa \cdot \frac{Y_t}{L_t}. \tag{2.21}$$

$$p_{F,t} \cdot (1+\tau_t) = p_t \cdot (1-\alpha-\kappa) \cdot \frac{Y_t}{M_{F,t}}. \tag{2.22}$$

$p_{F,t} = 1$ is the foreign price. As ORCK is a model of a small open economy, foreign prices are not influenced by domestic activity. Therefore, $p_{F,t}$ is the numéraire. τ_t is a bilateral price equivalent tariff equal to 0 in the baseline.

2.3.2 Household optimisation

In contrast to the classical RCK model, ORCK's households optimise *both* intratemporal and intertemporal consumption. The intratemporal optimisation problem is solved by taking first-order conditions of the intratemporal consumption function, eq. (2.11), with respect to $D_{h,t}$ and $M_{h,t}$:

$$D_{h,t} = C_{h,t} \cdot \left(\phi_h^\rho \cdot \alpha_h^C \cdot \frac{cpi_{h,t}}{p_t}\right)^{\frac{1}{1-\rho}}. \tag{2.23}$$

$$M_{h,t} = C_{h,t} \cdot \left(\phi_h^\rho \cdot (1-\alpha_h^C) \cdot \frac{cpi_{h,t}}{p_{F,t} \cdot (1-\tau_t)}\right)^{\frac{1}{1-\rho}}. \tag{2.24}$$

$$cpi_{h,t} = \left(\alpha_h^C \cdot p_t^{1-\sigma} + (1-\alpha_h^C) \cdot \left(p_{F,t} \cdot (1+\tau_t)\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}}. \tag{2.25}$$

In eq. (2.25), $cpi_{h,t}$ is defined as the CES composite of domestic and foreign prices adjusted for any trade costs.

The intertemporal problem of ORCK follows that of the classical RCK model closely. The households choose how much to consume and save to maximise eq. (2.1) subject to eq. (2.12) and eq. (2.9) :

$$\max_{C_{h,t}\in\mathbb{R}_+, S_{h,t}\in\mathbb{R}_+} \sum_{t=0}^{\infty} \mathbb{E}_t\left(\beta^t \cdot u_m(C_{h,t})\right) \text{ s.t. } cpi_{h,t} \cdot C_{h,t} + p_t \cdot S_{h,t} = r_t \cdot K_{h,t} + w_t \cdot L_{h,t}.$$
$$\text{s.t. } K_{h,t+1} = K_{h,t} \cdot (1-\delta) + S_{h,t}. \tag{2.26}$$

$u_m(\cdot)$:= placeholder utility function which refers to the neoclassical consumption utility model when the subscript $m = N$, habit formation model when $m = H$ or, in Chapter 3 the reference dependence model when $m = R$. As choosing savings contemporaneously is equivalent to choosing capital[15] next period and combining eq. (2.12) and eq. (2.9), a Lagrangian can be defined:

$$\mathcal{L}(C_{h,t}, K_{h,t+1}, \lambda_{h,t}) = \sum_{t=0}^{\infty} \beta^t \cdot \mathbb{E}_t\bigg(u_m(C_{h,t}) - \lambda_{h,t}\Big(cpi_{h,t} \cdot C_{h,t} + K_{h,t+1} \cdot p_t - K_{h,t} \cdot \Big(r_t + p_t \cdot (1-\delta)\Big) - w_t \cdot L_{h,t}\Big)\bigg).$$

Taking FOCs with respect to $C_{h,t}$ and $K_{h,t+1}$ we get:

$$\lambda_{h,t} = \frac{u'_m(C_{h,t})}{cpi_{h,t}}. \tag{2.27}$$

$$\lambda_{h,t} \cdot p_t = \beta \cdot \mathbb{E}_t(\lambda_{h,t+1} \cdot (r_{t+1} + p_{t+1}(1-\delta))). \tag{2.28}$$

In eq. (2.27), $u'_m(C_{h,t}) \in \mathbb{R}_+$ is the marginal utility of consumption. Combining eq. (2.27) and eq. (2.28) we define the Euler equation:

$$u'_m(C_{h,t}) \cdot p_t = \beta \cdot \mathbb{E}_t\left(\frac{cpi_{h,t}}{cpi_{h,t+1}} \cdot u'_m(C_{h,t+1}) \cdot (r_{t+1} + p_{t+1} \cdot (1-\delta))\right). \tag{2.29}$$

[15] As each household is assumed to be too small to affect aggregate variables, prices are treated as constants.

Finally, to close the system, we define an export and foreign direct investment function:

$$X_t = \phi_X \cdot \left(\frac{p_{F,t}}{p_t \cdot (1 - \tau_t)} \right)^{\frac{1}{1-\rho}} . \tag{2.30}$$

$$S_{F,t} = \phi_F \cdot \left(\frac{p_{F,t} \cdot r_{t+1}}{p_t \cdot (1 - \tau_t)} \right)^{\frac{1}{1-\rho}} . \tag{2.31}$$

Both exports and foreign direct investment are decreasing in relative prices and trade costs. Additionally, foreign direct investment is increasing in the future rental rate of capital to proxy for returns on investment.

For ease of exposition, Table 2.1 summarises the system of equations which fully defines ORCK's solution and Table 2.2 defines the general form of the Social Accounting Matrix.

Table 2.1: ORCK Equations

Equation	Type	Number
$A_{t+1} = A_t \cdot (1 + g_t)$	TFP law of motion	(2.7)
$L_{h,t+1} = L_{h,t} \cdot (1 + n)$	Labour law of motion	(2.8)
$K_{j,t+1} = (1 - \delta) \cdot K_{j,t} + S_{j,t}$	Capital law of motion	(2.9)
$g_t = \overline{g} + \rho_A \cdot (g_{t-1} - \overline{g}) + e_t$	TFP shock process	(2.10)
$Q_{h,t} = cpi_{h,t} \cdot C_{h,t} + p_t \cdot S_{h,t} = r_t \cdot K_{h,t} + w_t \cdot L_{h,t}$	Budget constraint	(2.12)
$Y_t = D_t + I_t + X_t$	MCC goods market	(2.13)
$I_t = \sum_h S_{h,t} + S_{F,t}$	MCC flow of savings	(2.14)
$p_t \cdot Y_t = r_t \cdot K_t + w_t \cdot L_t + p_{F,t} \cdot MF_t$	Zero profit condition	(2.15)
$C_t = \sum_h C_{h,t}$	Definition	(2.16)
$K_t = \sum_j K_{j,t}$	Definition	(2.17)
$L_t = \sum_h L_{h,t}$	Definition	(2.18)
$D_t = \sum_h D_{h,t}$	Definition	(2.19)
$r_t = p_t \cdot \alpha \cdot \frac{Y_t}{K_t}$	Rental rate of capital	(2.20)
$w_t = p_t \cdot \kappa \cdot \frac{Y_t}{L_t}$	Wage	(2.21)
$p_{F,t} = p_t \cdot (1 - \alpha - \kappa) \cdot \frac{Y_t}{M_{F,t} \cdot (1+\tau_t)}$	Firm imports	(2.22)
$D_{h,t} = C_{h,t} \cdot (\phi_h^\rho \cdot \alpha_h^C \cdot \frac{cpi_{h,t}}{p_t})^{\frac{1}{1-\rho}}$	Domestic consumption	(2.23)
$M_{h,t} = C_{h,t} \cdot (\phi_h^\rho \cdot (1 - \alpha_h^C) \cdot \frac{cpi_{h,t}}{p_{F,t} \cdot (1+\tau_t)})^{\frac{1}{1-\rho}}$	Foreign consumption	(2.24)
$cpi_{h,t} = (\alpha_h^C \cdot p_t^{1-\sigma} + (1 - \alpha_h^C) \cdot (p_{F,t} \cdot (1 + \tau_t))^{1-\sigma})^{\frac{1}{1-\sigma}}$	Consumer price index	(2.25)
$u'_m(C_{h,t}) \cdot p_t = \beta \cdot \mathbb{E}_t \left(\frac{cpi_{h,t}}{cpi_{h,t+1}} \cdot u'_m(C_{h,t+1}) \cdot (r_{t+1} + p_{t+1} \cdot (1 - \delta)) \right)$	Euler equation	(2.29)
$X_t = \phi_X \cdot \left(\frac{p_{F,t}}{p_t \cdot (1+\tau_t)} \right)^{\frac{1}{1-\rho}}$	Exports	(2.30)
$S_{F,t} = \phi_F \cdot \left(\frac{p_{F,t} \cdot r_{t+1}}{p_t \cdot (1-\tau_t)} \right)^{\frac{1}{1-\rho}}$	Foreign direct investment	(2.31)

Table 2.2: ORCK Social Accounting Matrix structure

	F	**K**	**L**	**H1**	...	**HN**	**S**	**ROW**
F	0	0	0	$D_{1,t}$	...	$D_{N,t}$	I_t	X_t
K	K_t	0	0	0	...	0	0	0
L	L_t	0	0	0	...	0	0	0
H1	0	$K_{1,t}$	$L_{1,t}$	0	...	0	0	0
⋮	⋮	⋮	⋮	⋮	...	⋮	⋮	⋮
HN	0	$K_{N,t}$	$L_{N,t}$	0	...	0	0	0
S	0	0	0	$S_{1,t}$	...	$S_{N,t}$	0	$S_{F,t}$
ROW	$M_{F,t}$	$K_{F,t}$	0	$M_{1,t}$	...	$M_{N,t}$	0	0

F= Firms, K= Capital, L= Labour, Hi= Household i,
S= Capital formation, ROW= Rest of the World

2.4 Method

The neoclassical (Ramsey, 1928), habit formation (Abel, 1990) and empirical reference dependence (Bowman et al., 1999) models are compared in the stylised simulations. For these simulations, the representative agent assumptions are employed. Hence, the set h contains a single household. In Chapter 3, this assumption will be relaxed and therefore, the h subscript is maintained for generality. In the neoclassical and habit formation models, the first order condition of $u_m(\cdot)$ is defined to solve ORCK. In the reference dependence model, eq. (2.29) is replaced by the empirical reference dependence model (Shea, 1995a,b; Bowman et al., 1999). The benchmark model is the neoclassical model presented in eq. 2.1.

2.4.1 Neoclassical consumption

In this chapter, the neoclassical utility function has an inverse constant relative risk aversion (CRRA) form. Hence, letting $\epsilon > 0$ be the constant elasticity of intertemporal substitution (EIS), utility is defined in eq. (2.32).

$$u_N(C_{h,t}) = \begin{cases} \frac{\epsilon}{\epsilon-1} \cdot C_{h,t}^{\frac{\epsilon-1}{\epsilon}} & \epsilon \neq 1 \\ \ln C_{h,t} & \epsilon = 1 \end{cases} . \tag{2.32}$$

The first order condition of eq. (2.32) is presented below:

$$u'_N(C_{h,t}) = C_{h,t}^{-\frac{1}{\epsilon}} \tag{2.33}$$

2.4.2 Habit Formation

As Alvarez-Cuadrado et al. (2004) demonstrates that representative agent internal and external habit formation models provide qualitatively identical results, the Abel (1990) habit formation model is chosen under external habits (KUJ habits).[16] The Abel (1990) habit formation model is defined in eq. (2.34).[17]

$$u_H(C_{h,t}|H_t) = \begin{cases} \frac{\epsilon}{\epsilon-1} \cdot \left(\frac{C_{h,t}}{H_t^{\gamma_h}}\right)^{\frac{\epsilon-1}{\epsilon}} & \epsilon \neq 1 \\ \ln\left(\frac{C_{h,t}}{H_t^{\gamma_h}}\right) & \epsilon = 1 \end{cases}. \tag{2.34}$$

Under external habits, $H_t = H_{h,t}$ $\forall h$. Therefore, the habit stock is the weighted average of past consumption levels following eq. (2.35).

$$H_t = (1 - \Theta) \cdot C_{t-1} + \Theta \cdot H_{t-1}. \tag{2.35}$$

In eq. (2.35), $\Theta \in [0, 1] :=$ memory parameter. When $\Theta = 0$, H_t is the weighted average consumption of the household groups in the last period. When $\Theta > 1$, H_t is a weighted average of infinitely many past average aggregate household consumption levels with weights decreasing over lags.

[16] Appendix A.2 demonstrates that this assumption has no bearing on the results.
[17] From henceforth, I assume that $\varepsilon \neq 1$.

When households form KUJ habits, as households are too small to affect future habit stocks, the marginal utility function is defined in eq. (2.36).

$$u'_H(C_{h,t}|H_t) = \left(\frac{C_{h,t}}{H_t^{\gamma_h}}\right)^{-\frac{1}{\epsilon}} \cdot H_t^{-\gamma_h}. \tag{2.36}$$

2.4.3 Reference Dependence

The final consumption model is the reference dependence model. As micro-founded, representative agent infinite time dynamic reference dependence models are not tractable within CGE models, this chapter adopts the empirical reference dependence model (Shea, 1995a; Bowman et al., 1999). This model is used to proxy for reference-dependent household consumption behaviour as presented in eq. (2.37).

$$\Delta C_t = a + \lambda_G(POS_t)\Delta\hat{Y}_t + \lambda_L(NEG_t)\Delta\hat{Y}_t + b \cdot \hat{r}_t. \tag{2.37}$$

The notation follows directly from eq. (2.5).[18]

2.5 Simulation results

This section compares consumption impulse response functions (IRFs) for three stylised shocks to determine the importance of behavioural assumptions to consumption results of CGE models. The simulation scenarios are designed to extract the qualitative differences of the consumption models.

A priori we anticipate observing a few notable qualitative features. First, habit formation IRFs should have a more pronounced hump shape, as compared with neoclassical consumption models (Fuhrer, 2000). This is since, when households

[18]Households may choose consumption relative to their incomes Q_t rather than output Y_t. In a closed economy, $Q_t = Y_t$. Therefore, $\Delta\hat{Q}_t = \Delta\hat{Y}_t$.

form habits, they will have a stronger motive to smooth consumption over time as their utility is a combination of absolute and relative utility.[19] Second, we anticipate that the reference dependence model should have asymmetric consumption responses depending on whether the shock is positive or negative (Tversky and Kahneman, 1992; Bowman et al., 1999; Shea, 1995a,b). Households should resist increasing consumption less in response to unanticipated positive shocks than they resist decreasing it in response to negative unanticipated shocks (Bowman et al., 1999). Third, if the negative shock is anticipated, we expect households to reduce consumption more aggressively than if the shock is unanticipated, as households have the incentive to reduce future reference points to decrease the likelihood of remaining in the domain of losses (Bowman et al., 1999).

2.5.1 Calibration

Shock scenarios

Table 2.3: Simulation Summary

Shock variable	Size	Type	Anticipated	Figure
A_t	$\pm$ 2%	Permanent	No	2.2
			Yes	2.3
		Temporary	No	2.4

Table 2.3 summarises the three simulation scenarios. Each of the simulations demonstrates the impacts of a shock to total factor productivity (A_t) in the economy. The shock size is always 2%, with both positive and negative shocks considered in each figure. Positive and negative shocks of the same sizes are presented within the same figures to determine whether the consumption responses are symmetric or asymmetric as predicted by Shea (1995a,b) and Bowman et al. (1999).

[19]This holds when the elasticity of intertemporal substitution is less than one, as shown in Appendix A.3. Typically, estimates are much lower than one (Havranek et al., 2015).

The shock is permanent in Figures 2.2 and 2.3, whereas it is temporary in Figure 2.4. A temporary shock is considered as we expect a more pronounced hump-shaped consumption response for habit formation models than for neoclassical consumption models for temporary shocks (Fuhrer, 2000). In Figures 2.2 and 2.4, the shock is unanticipated, whereas in Figure 2.3, the shock is anticipated and occurs at time $t = 5$. The distinction between anticipated and unanticipated shocks is made to determine whether negative anticipated shocks lead to more pronounced decreases in consumption than unanticipated ones (as predicted by Bowman et al., 1999).

Parameters

Table 2.4: Parameters

Parameter	Value	Model(s)	Source
δ	0.1	All	Jorgenson (1996)
ρ_A	0.4	All	Sims and Wu (2019)
ϵ	0.3	Classical/ Habit Formation	Havranek et al. (2015)
γ	0.6	Habit Formation	Havranek et al. (2017)
λ_G	0.2	Reference Dependence	Bowman et al. (1999); Shea (1995a)
λ_L	1.1	Reference Dependence	Bowman et al. (1999); Shea (1995a)
b	0.2	Reference Dependence	Assumption

Table 2.4 summarises the calibration of the simulations' key parameters. The depreciation rate is set exogenously to a value of 10% (Jorgenson, 1996). In the case of temporary shocks, the autocorrelation of TFP is set to $\rho_A = 0.4$ which is the yearly equivalent of the estimate of Sims and Wu (2019). The Elasticity of Intertemporal Substitution (ϵ) is set equal to 0.3 following Havranek et al. (2015) while the level of habit persistence (γ) is set equal to 0.6 following Havranek et al. (2017). For simplicity, the level of habit memory (Θ) is set equal to 0. For the Bowman et al. (1999) reference dependence model, $\lambda_G = 1.1$ and $\lambda_L = 0.2$ following Bowman et al. (1999) and Shea (1995a). Finally, $b = 0.2$ by assumption as no estimate is presented by Shea (1995a,b) or Bowman et al. (1999). This value will be a function of ϵ, β and the frequency of the observations in estimation.

For simplicity, the parameter value is chosen such that the reference dependence and neoclassical consumption IRFs overlap. This does not affect the qualitative differences between the consumption models.

Social Accounting Matrix

Table 2.5: ORCK Social Accounting Matrix

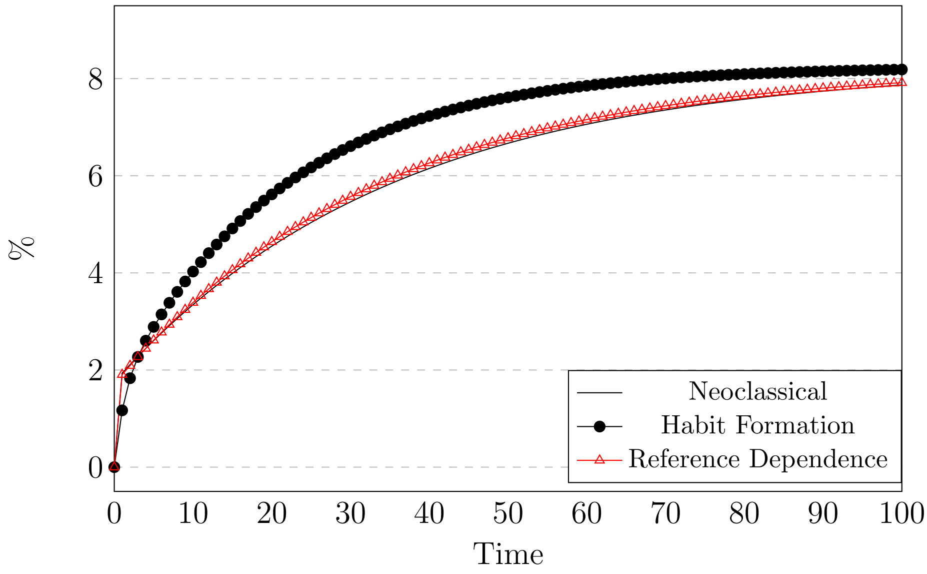
	F	**K**	**L**	**H**	**S**	**ROW**
F	0	0	0	1.6	0.4	0
K	1.5	0	0	0	0	0
L	0.5	0	0	0	0	0
H	0	1.5	0.5	0	0	0
S	0	0	0	0.4	0	0
ROW	0	0	0	0	0	0

F= Firms, K= Capital, L= Labour, H= Household, S= Capital formation, ROW= Rest of the World

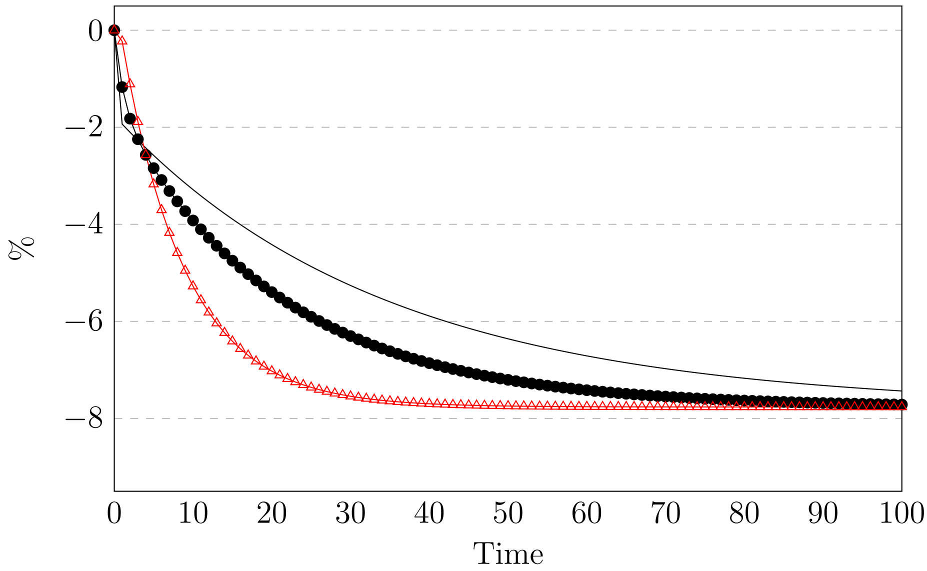
To illustrate the implications of the consumption models, these are embedded in a representative agent closed-economy version of ORCK, which is identical to a steady-state RCK model. This decision is made for illustrative purposes however, the open-economy version of ORCK has identical qualitative results as demonstrated in Appendix A.4. The fictitious Social Accounting Matrix (SAM) of the simulations is presented in Table 2.5.

2.5.2 Permanent unanticipated shock

Figure 2.2 presents the simulation results for the permanent unanticipated 2% TFP shocks. Subfigures 2.2a and 2.2b present the positive and negative versions of the shock. The solid black line is the neoclassical consumption model. The black line with circular marks is the Abel (1990) habit formation model. The red line with triangular marks is the Bowman et al. (1999) and Shea (1995a) empirical reference dependence model. This style is maintained for Figures 2.3 and 2.4.



(a) Positive TFP shock (+2%)



(b) Negative TFP shock (-2%)

Figure 2.2: Consumption IRF for unanticipated permanent TFP shock ±2%: Classical model $\epsilon = 0.3$; Abel (1990) habit formation model $\gamma = 0.6$; Reference dependence model $\lambda_G = 1.1$, $\lambda_L = 0.2$

In the short-run, capital stocks are fixed and labour is exogenously fixed in all periods. For simplicity, the simulations are conducted in a closed-economy setting.[20] Consequently, production unambiguously increases (decreases) with wages and the rental rate of capital increasing (decreasing) relative to the output price

[20] This choice has no bearing on the qualitative results as demonstrated in Appendix A.4.

for positive (negative) TFP shocks. This increases (decreases) households' real incomes. The increase (decrease) in TFP leads to an income effect increasing (decreasing) the intertemporal consumption possibilities. Meanwhile, there is a substitution effect as the next period's rental rate of capital increases (decreases) when TFP increases (decreases). Thus, households must choose how much to save and consume from the additional (lower) income. These decisions will determine the speed of adjustment to the new steady-state consumption level.

As demonstrated in Figure 2.2, the consumption IRFs of neoclassical households are symmetric. That is, households' consumption responses are identical over time and in magnitude regardless of the sign of the shock. Following the unanticipated positive (negative) TFP shock, neoclassical households increase (decrease) consumption by approximately 1.9% in the short run. This is followed by a monotonic convergence towards the new long-run steady-state consumption level. When consumption is increasing (decreasing), the new steady state consumption level is approximately 8% larger (smaller) than the initial steady state. The speed of the convergence to the new steady state is positively related to the EIS.[21]

In line with the neoclassical consumption model, the habit formation consumption IRFs are symmetric. This arises as the neoclassical and habit formation utility functions are homogeneous treating positive and negative changes equivalently. Short-run consumption increases (decreases) by approximately 1.2% following the unanticipated positive (negative) TFP shock. With lower short-run increases (decreases) in consumption, habit-forming households increase (decrease) savings proportionally more than neoclassical households. Consequently, capital stocks accumulate (depreciate) towards the new steady state at a quicker rate. This

[21]See Figure A.2 for an exhibition of the impacts of the EIS on the speed of convergence to the new steady state.

increases (decreases) medium-run production capacity in the economy, speeding up the adjustment towards the new steady-state consumption level. Based on the model's calibration, we deduce that if household behaviour is best characterised by a habit formation model, short-run consumption responses may be overestimated by neoclassical consumption models. We also deduce that the speed of adjustment towards the new steady state may be underestimated by the neoclassical consumption model.[22]

In contrast to the neoclassical consumption model and the habit formation model, the reference dependence model has asymmetric consumption IRFs. In the domain of losses, consumption only decreases by 0.2% whereas in the domain of gains, consumption increases by 1.9%. This asymmetric response is driven by loss-aversion and diminishing sensitivity. Contemporaneously, households incur large losses from reducing consumption (Kahneman and Tversky, 1979; Tversky and Kahneman, 1992; Bowman et al., 1999; Foellmi et al., 2011; Kőszegi and Rabin, 2007). Dynamically, as losses have diminishing sensitivities, households are willing to gamble on future incomes increasing (Kahneman and Tversky, 1979; Tversky and Kahneman, 1992; Bowman et al., 1999). This is consistent with risk seeking behaviour in the domain of losses (Tversky and Kahneman, 1992; Bowman et al., 1999). These combined effects pull contemporaneous consumption closer to the reference point in the domain of losses immediately after the shock.

With lower reductions in consumption, savings must decrease. As a result, capital stocks depreciate faster in the reference dependence model than in the neoclassical or even the habit formation model in the domain of losses. The much quicker reduction in consumption towards the new steady state level, following a sticky

[22]Although this is true for the chosen model calibration, Figure A.2 shows that the impact will depends on whether $\epsilon < 1$.

consumption response in the short run, suggests that reference dependence households' losses are focused to a smaller set of periods than neoclassical households. This observation is consistent with the models of Foellmi et al. (2011) and Bowman et al. (1999), although in the prior, as the time periods are much longer intervals, the losses are focused to a single period.

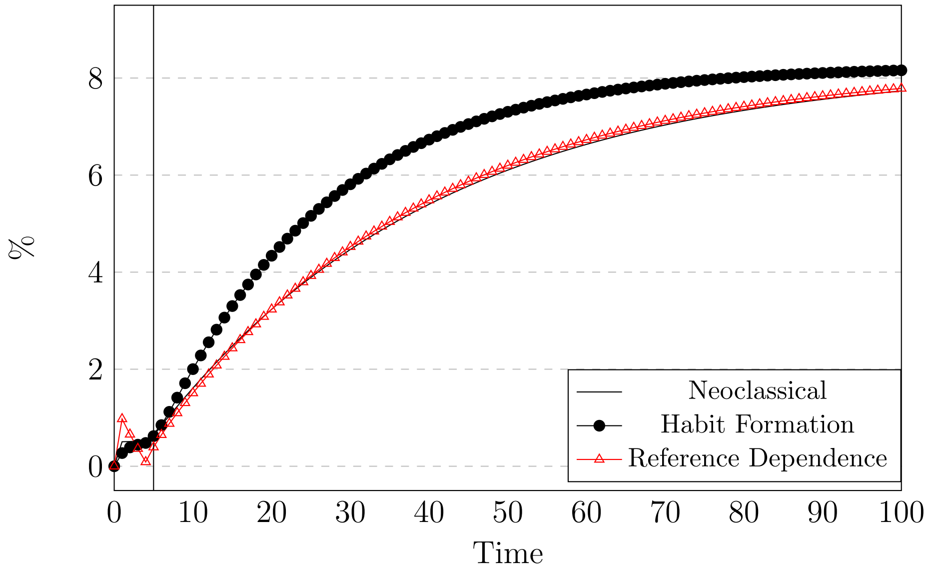
Overall, Figure 2.2 demonstrates that the habit formation and reference dependence models may lead to different short run consumption responses to unanticipated permanent TFP shocks. In the case of the habit formation model, short-run consumption responses may be overestimated whilst adjustment speeds to the new equilibrium may be underestimated. The precise impact will depend on the EIS value and the estimate of habit formation chosen. If households are reference-dependent, then neoclassical consumption models will fail to capture the asymmetry in consumption responses to shocks of opposing signs. Households will resist decreasing consumption in the short run in response to unanticipated negative shocks and the speed of adjustment to the equilibrium in the domain of losses will be much faster than in the domain of gains.

Although in the short to medium run, IRFs will vary drastically depending on the model chosen, all models eventually converge to the same steady state even in an open economy setting.[23] This suggests that the long-run results of CGE simulations will not be affected by consumption model choice, as had previously been found by Lecca et al. (2013).

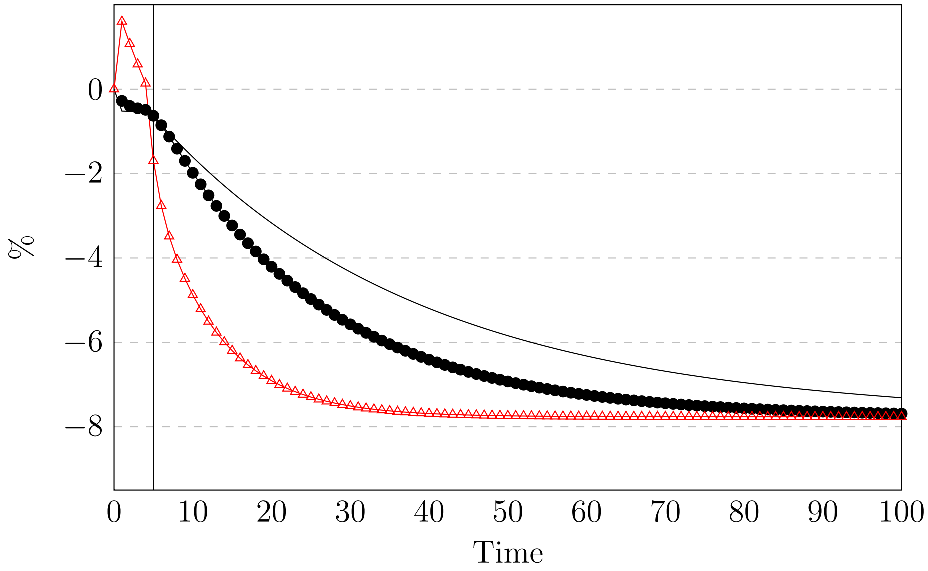
[23]As demonstrated in Appendix A.4.

2.5.3 Permanent anticipated shock

Figure 2.3 presents the results of the permanent anticipated TFP shocks. Whereas the shocks occur in period 1 in Figure 2.2, they occur in period 5 in Figure 2.3. This means that households have time to adjust their behaviours to maximise the benefits of the positive shock and minimise the costs of the negative shock.



(a) Positive TFP shock (+2%)



(b) Negative TFP shock (-2%)

Figure 2.3: Consumption IRF for anticipated permanent TFP shock ±2%: Classical model $\epsilon = 0.3$; Abel (1990) habit formation model $\gamma = 0.6$; Reference dependence model $\lambda_G = 1.1$, $\lambda_L = 0.2$

The anticipation effects of the TFP shock are symmetric for neoclassical households. That is, the magnitude of the anticipation effect is the same whether the anticipated impact is positive or negative. When consumption is expected to increase (decrease) in future periods, households begin increasing (decreasing) consumption before the (negative) positive TFP shock. This is because households have a preference for consumption smoothing as predicted by the PIH and LCH (Friedman, 1957; Modigliani, 1966). The anticipation effects are relatively small as consumption increases (decreases) by 0.5% in periods 1-4. Following the anticipated shock, the consumption IRFs of the neoclassical consumption model are almost identical to those of the unanticipated shock.

Habit-forming households also respond symmetrically to the anticipation of future TFP shocks. In line with neoclassical consumption, habit formation consumption increases (decreases) in anticipation of the positive (negative) TFP shock. In contrast to neoclassical households, the increases (decreases) in consumption between periods 1 and 4 are much more progressive. Consumption increases (decreases) quasi-linearly from 0.25% to 0.55% in periods 1-4. This occurs as habit-forming households have a higher preference for consumption smoothing due to the time dependence of their utility function. Following the shock, the qualitative features of the habit formation IRFs are very similar to those of Figure 2.2. The speed of adjustment to equilibrium is faster for habit-forming households than for neoclassical households.

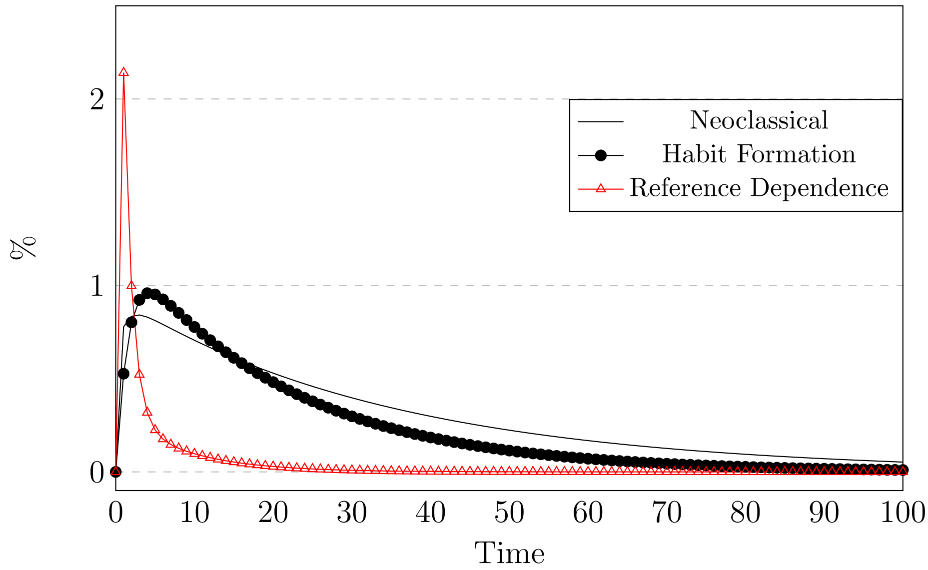
Whereas neoclassical and habit formation consumption IRFs are symmetric for anticipated shocks, this is not true in the case of the reference dependence model. In anticipation of the negative TFP shock, households consume above their reference points to achieve a higher relative utility contemporaneously whilst depleting capital stocks more quickly. This implies that losses are focused on a smaller set of periods than in the other consumption models. Through this initial overconsumption in anticipation of the shock, savings decrease. Consequently, households reduce consumption following the shock much more quickly than in the case of unanticipated shocks. These observations are in line with Bowman et al. (1999) who argue that households respond much more strongly to expected reductions in their income than they do to unexpected ones.

When the anticipated TFP shock is positive, reference-dependent households increase consumption in period 1 beyond the reference point in anticipation of the shock in period 5. This leads to an immediate increase in reference utility but pushes households to the domain of losses relative to previous periods' consumption in periods 2-4. This decreases the reference point so that when the shock occurs in period 5, the reference utility will increase once more. After the initial anticipation effects, the IRF of the reference-dependent household mirrors that of the neoclassical household closely from period 5 onward.

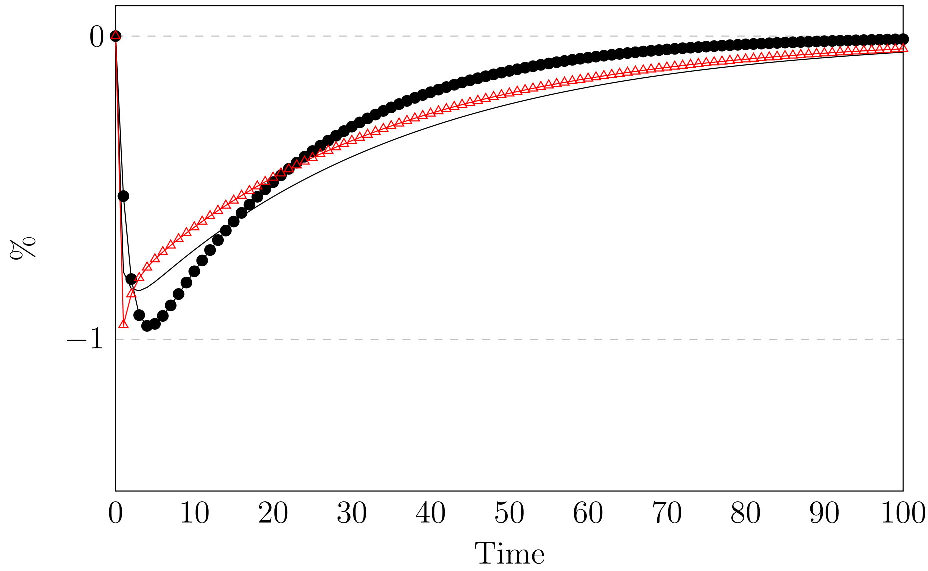
2.5.4 Temporary unanticipated shock

Figure 2.4 demonstrates the IRFs of the consumption models for an unanticipated temporary shock. Both positive and negative TFP shocks are considered and as $\rho_A = 0.4$, the unanticipated shock dissipates progressively from period 1 onwards.

Neoclassical and habit-forming households respond symmetrically to TFP shocks as was found for all other shocks evaluated. In response to the unanticipated temporary positive (negative) shock, neoclassical consumption increases (decreases) by 0.8% in the first two periods after the shock. Thereafter, consumption decreases (increases) monotonically towards the steady-state level.



(a) Positive TFP shock (+2%)



(b) Negative TFP shock (-2%)

Figure 2.4: Consumption IRF for unanticipated temporary TFP shock $\pm 2\%$: Classical model $\epsilon = 0.3$; Abel (1990) habit formation model $\gamma = 0.6$; Reference dependence model $\lambda_G = 1.1$, $\lambda_L = 0.2$

When households form consumption habits and a positive (negative) temporary TFP shock occurs, consumption increases (decreases) by 0.5% in the first period. This smaller change, relative to the neoclassical model, occurs as households have a stronger preference for consumption smoothing in the habit formation model. This means that savings increase (decrease) proportionally more (less) in the short run as compared with the neoclassical model following positive (negative) shocks.

Higher (Lower) savings lead to quicker capital accumulation (depreciation). Consequently, with larger (smaller) capital stocks, consumption in the medium run remains high (low) relative to the neoclassical consumption model. This observation is consistent with Fuhrer (2000) who finds hump-shaped consumption responses to demand and supply shocks. As households maintain higher (lower) consumption in the medium run in the habit formation model, the speed of adjustment back towards the steady state equilibrium increases.

In the reference dependence model, consumption IRFs are asymmetric. That is, in the domain of gains, consumption increases by over 2% immediately following the shock, whereas it only decreases by 1% in the domain of losses. This observation is consistent with the theoretical model of Bowman et al. (1999) as households resist increasing consumption less in response to good news than they resist decreasing consumption in response to bad news. In the domain of gains, the large increase in consumption implies that savings increase by less than they do in neoclassical and habit formation models. Consequently, as capital stocks increase much less in the reference dependence model, production capacities increase less in the medium run than in the other consumption models. This implies that the adjustment to the new steady state is much faster in the reference dependence model than in the other models in the domain of gains.

The disutility of losses looms larger than the utility of gains in the reference dependence model (Kahneman and Tversky, 1979). This is reflected by the greater resistance exhibited by reference-dependent households in reducing consumption in Figure 2.4 in the domain of losses. Indeed, after an initially small consumption contraction, households remain in the domain of gains in all future periods as the TFP shock dissipates. This response provides a stark contrast to the medium-run responses of the neoclassical and the habit formation models where consumption is decreasing in some of the early medium run periods. The empirical model of Bowman et al. (1999) captures a key feature of the loss aversion model of Foellmi et al. (2011). This is, in the domain of losses, household losses are focused on a small set of periods.

2.6 Sensitivities & limitations

The aim of this chapter is to introduce computationally feasible and tractable habit formation and reference dependence modelling frameworks to CGE models. Section 2.5 achieves this objective and demonstrates the difference in the qualitative features of the respective models using a set of stylised shocks. Although the simulations provide key insights into the importance of consumption modelling assumptions for short-run to medium-run analysis, these are conducted based on specific functional forms and assumptions on the values of the parameters.

2.6.1 Habit Formation model

In this chapter, we employ a KUJ habit formation model. This model is chosen instead of an internal habit formation model as it is simpler, however, Appendix A.2 demonstrates that representative agent internal and external habit formation models provide the same qualitative conclusions (as also found by Alvarez-Cuadrado et al., 2004). This suggests that CGE modellers can use external habit formation models to proxy for internal habit formation in representative household models.

Importantly, we also choose to use the Abel (1990) habit formation model rather than the Pollak (1970) habit formation model used by Ryder and Heal (1973) and Boyer (1983). Whereas Abel (1990) habits are multiplicative in the utility function, Pollak (1970) habits are additive. Abel (1990) habits are chosen for two reasons. First, these are easier to estimate empirically (See Havranek et al., 2017, for estimations of Abel (1990) habits). Second, most of the modern macroeconomic literature has moved towards the Abel (1990) form (See for instance Fuhrer, 2000; Carroll et al., 2000; Alvarez-Cuadrado et al., 2004; Turnovsky and Monteiro, 2007). Appendix A.3 demonstrates that the qualitative features of the models when permanent positive TFP shocks are introduced are broadly similar although the calibration of the models may not be directly comparable. As empirical estimations more commonly estimate Abel (1990) habits, CGE modellers may wish to use Abel (1990) rather than Pollak (1970) habits.

In the numerical simulations, the EIS is assumed to equal 0.3 following Havranek et al. (2015). As EIS estimates are sensitive to methodological choices and vary across countries (Havranek et al., 2015), sensitivities on the EIS are conducted as well in Appendix A.3. These sensitivities demonstrate that the shape of the habit formation IRFs and the speed of the adjustment towards equilibrium will depend critically on whether the EIS is less than or greater than 1. Although most empirical evidence suggests that the EIS is less than one (Hall, 1988; Yogo, 2004; Havranek et al., 2015; Thimme, 2017), if the EIS is greater than 1, the speed of adjustment towards equilibrium of habit formation models will be slower than that of neoclassical consumption models. This sensitivity highlights the importance of country-specific estimations of key behavioural parameters as consumption habits may have qualitatively heterogeneous effects depending on the value of the EIS.

Finally, in the simulations, the habit point was assumed to be the last period's consumption. Authors such as Fuhrer (2000) have assumed that habit levels are weighted averages of past consumption levels. Appendix A.3 summarises the numerical impact of increasing the level of habit memory demonstrating that longer habit memories affect the curvature of the IRF. As habit memory increases, changes in the curvature of the slope decrease. This decreases the speed of adjustment to the new consumption steady state. When habit memory is very high, consumption IRFs have a more pronounced hump shape overshooting the new equilibrium following positive permanent TFP shocks. Consumption then converges towards the new steady state in oscillations (an observation in line with Ryder and Heal, 1973). This sensitivity shows the importance of capturing the habit formation structure of the model.

2.6.2 Reference Dependence model

In this chapter, the empirical reference dependence model of Shea (1995a,b) and Bowman et al. (1999) is employed to proxy for reference dependence consumption behaviour. The empirical reference dependence model captures some of the key qualitative features of the theoretical reference dependence model of Bowman et al. (1999) however, it has four limitations.

First, the Bowman et al. (1999) model is a two-period model. This means that the predictions of the model may not hold fully to an infinite time framework such as that presented in ORCK. Second, the empirical reference dependence model is not derived directly from the theoretical model but rather designed to capture the key features of the model empirically. Third, one qualitative result of the empirical reference dependence model seems inconsistent with reference dependence. This is the consumption IRF in the domain of gains in Figure 2.3. Fourth, the empirical literature validating the Bowman et al. (1999) and Shea (1995a,b) reference dependence model is limited.

The first two limitations are more philosophical than technical. Although theoretical foundations of consumption models are very important to develop a nuanced understanding of economic transmission channels of shocks and policies and the behavioural characteristics of consumers, these models are limited by numerical and mathematical constraints. The classical reference dependence model of Kahneman and Tversky (1979) is extremely complicated to capture numerically for representative consumers as the utility function is concave in the domain of gains and convex in the domain of losses. Practically, this makes operationalising the model as a policy tool within a CGE model difficult. Technically, under the representative agent assumption, the model is solved by comparing the utility of dynamic binary choices growing exponentially with the number of time periods. An additional layer of complexity is added by the fact that corner solutions, such as choosing to consume exactly the reference point, may form a part of the consumption profile. Thus, using the empirically validated version of reference dependence consistent with the small-scale theoretical model of Bowman et al. (1999) may provide a first pass at incorporating reference-dependent consumption behaviour into CGE models. Inherently, this is an imperfect solution. However, the benefits of improving our understanding of asymmetric consumption responses in CGE models outweigh the costs of stubbornly maintaining theoretically consistent consumption theories which have been empirically invalidated.

For the third limitation, Figure 2.3 demonstrates that the reference dependence model must be introduced with caution. This is because, in anticipation of a positive shock, households are predicted to decrease consumption. This behaviour seems[24] to be inconsistent with the canonical reference dependence model Kahneman and Tversky (1979), which predicts that households should avoid losses entirely as these are disproportionately costly. This is the only clear theoretical inconsistency in the set of simulations, and all other results are broadly consistent with theory and empirical evidence. Consequently, if CGE modellers adopt reference dependence consumption models, these should verify that the results of

[24] As no dynamic backwards-looking reference dependence model exists when depreciation rates are less than 1, there is no way to verify what the actual response should be.

the empirical reference dependence model are consistent with the predictions of Bowman et al. (1999). More, such analyses should compare consumption results with neoclassical or habit formation consumption baselines.

For the fourth limitation, it is important to note that few authors have replicated the estimation of the empirical reference dependence model since its estimation by Shea (1995a,b) and Bowman et al. (1999). Future research should replicate the estimations to more countries and for modern data to ensure that the values estimated by Shea (1995a,b) and Bowman et al. (1999) are consistent across time and countries. We leave this for future empirical research.

2.7 Conclusion

This chapter contributes to the CGE literature by developing tools to tractably and computationally feasibly introduce habit formation and reference dependence models to consumption equations of CGE models. All consumption models are developed in the software package GAMS and are generalisable to larger-scale CGE models.

To demonstrate the qualitative features of the models, a model named ORCK is developed extending the RCK model to an open economy setting. ORCK is calibrated to an equilibrium based on a simplified Social Accounting Matrix and provides an ideal stylised framework to compare the implications of the behavioural models to neoclassical consumption models.

By comparing neoclassical, habit formation and reference dependence model IRFs in a simple CGE model, three key stylised conclusions can be drawn. First, regardless of which of the models is employed, long-run results should not be affected.

As the research focus of many CGE modelling applications is to capture long-run impacts, this suggests that such analyses should not be concerned with intertemporal household consumption behavioural assumptions. This evidence is consistent with Lecca et al. (2013), who find that long-run results of CGE simulations are unaffected by intertemporal household consumption modelling choices when households are either myopic or forward-looking. Although long-run results are identical regardless of the consumption model, Keynes famously stated that the “long run is a misleading guide to current affairs. In the long run we are all dead”. This quote is particularly pertinent to many CGE analyses. For instance, medium-run behaviours such as overconsumption of environmentally harmful products may have long-run environmental impacts. This leads us to the second stylised conclusion.

Second, when short-run or medium-run responses are important outcomes in the research, the choice of the intertemporal consumption modelling framework is crucial to the qualitative and quantitative results. In the presence of consumption habits, the amplitude of consumption IRFs may increase in the medium run in response to temporary shocks. This means that the magnitude of consumption responses in the short run is overestimated whilst being underestimated in the early periods of the medium run, as compared with neoclassical consumption models. Moreover, treating positive and negative shocks equivalently is inconsistent with the empirical evidence of Bowman et al. (1999) and Shea (1995a,b). In the Bowman et al. (1999) and Shea (1995a,b) models, consumption responds much more to unanticipated shocks in the short run when shocks are positive than when shocks are negative. The speed of adjustment to the new equilibrium will be drastically different depending on whether households are in the domain of gains or losses and on whether the shock is temporary or permanent.

Third, CGE modellers should consider the choice of consumption modelling assumptions when shocks are anticipated. In the case of the reference dependence model, the initial household consumption response in the domain of losses is very sensitive to whether the shock is anticipated or unanticipated. When the shock is anticipated, households reduce consumption much more aggressively to reduce future reference points. If the shock is unanticipated, the consumption response is very small. These drastically different responses highlight the importance of classifying shocks for CGE analyses. For trade policies such as Brexit, which had a long anticipation period, this choice may have large effects on short- to medium-run results.

Future research should consider further contexts in which the habit formation and reference dependence models could be applied for CGE research. CGE modellers should determine whether the long-run predictions of habit formation and reference dependence models coincide with neoclassical/ Keynesian consumption functions when a model is calibrated to a balanced growth path rather than a steady state. Researchers should extend this framework to consider intertemporal behavioural heterogeneity in multiple-household settings.

Chapter 3

Growth, household behaviour and inequality: How do heterogeneity in habits and loss aversion affect the income distribution during growth?

3.1 Introduction

Growth theory elucidates the crucial role of capital accumulation and technological progress in determining economic growth. In his seminal work, Robert Solow (1956), the father of growth theory, reveals how differences in initial capital endowments explain cross-country wealth differentials. Assuming diminishing returns to capital, GDP per capita convergence occurs if technology is non-rivalrous (Solow, 1956). Cass (1965) and Koopmans (1963) criticise Solow's use of Keynesian consumption functions highlighting the importance of households' savings in capital accumulation. Extending the Solow growth model to contain Ramsey's (1928) forward-looking consumption model, Cass (1965) and Koopmans (1963) demonstrate the critical impact of savings decisions on long-run economic outcomes (collectively, Ramsey (1928), Cass (1965) and Koopmans (1963) are referred to as RCK). Romer (1990) extends the ideas of Solow (1956) and RCK to consider how endogenous human capital accumulation and the excludability of technology can affect economic growth showing that investments in research and development are key contributors to economic growth.

Following the pioneering works of Solow (1956), RCK and later Romer (1990), behavioural elements are incrementally introduced into growth models. Building on Duesenberry (1949), internal habit formation models, where habits are formed based on past consumption, are introduced into representative agent RCK models (Pollak, 1970; Ryder and Heal, 1973; Boyer, 1983; Carroll et al., 2000). The convergence speed to the steady state/ balanced growth path depends on the degree of habit persistence (Pollak, 1970; Ryder and Heal, 1973; Carroll et al., 2000). In some cases, Ryder and Heal (1973) indicate that the convergence occurs in decaying oscillations. Carroll et al. (2000) adopt the internal habit formation framework in a Romer (1990) model to explain the positive correlation between growth and savings.

Extending beyond internal habit formation models, a strand of the literature focuses on external habits, the Keeping up with the Joneses (henceforth KUJ) literature. Instead of having one's own consumption as a habit, the KUJ literature assumes that past average consumption in the economy forms the habit. Households consuming less than the average in the economy aim to keep up/ catch up.

Dupor and Liu (2003), Alvarez-Cuadrado et al. (2004) and Turnovsky and Monteiro (2007) investigate KUJ effects in identical multiple-household models. Dupor and Liu (2003) find that jealousy will lead to aggregate consumption exceeding the socially optimal level as households do not internalise the effects of their consumption on others. Alvarez-Cuadrado et al. (2004) extend the model of Ryder and Heal (1973) to compare time-separable utility and non-time-separable utility formation considering both "internal" and "external" habit formation processes. Using this framework, Alvarez-Cuadrado et al. (2004) find that the convergence speed is affected by the level of habits however, internal and external habits have similar qualitative conclusions.[1] Turnovsky and Monteiro (2007) extend the work of Alvarez-Cuadrado et al. (2004) to a Romer (1990) model considering the role of endogenous labour supply. Turnovsky and Monteiro (2007) suggest that habits do not affect the long-run equilibrium if labour supply is inelastic. If labour supply is elastic, consumption, output, labour supply and capital become sub-optimally large. Hori (2011) assumes there is a level of skill heterogeneity within households (but not across) in a multi-sector growth model by Doi and Mino (2008). In the spirit of Ravn et al. (2006), the model includes sector-specific habits.

[1] As also demonstrated in Appendix A.2.

Only Foellmi et al. (2011) considers the role of reference dependence consumption behaviour in a representative agent RCK growth model. Foellmi et al. (2011) demonstrate that economies may remain in sub-optimal equilibria with low consumption and capital if households are reference-dependent.

Despite the influx of behavioural economics theories into growth models, authors have not considered the impact of behavioural heterogeneity or reference dependence consumption behaviour across households. Indeed, all of the literature cited above employs either the representative household or homogeneous preference assumptions. Therefore, there is no literature on how behavioural characteristics affect consumption and income distributions within a country during economic growth. Indeed, most of the literature on growth and the income distribution focuses on structural characteristics such as tax structures, capital incomes, labour markets and education systems (Roine and Waldenström, 2015). Yet understanding how behavioural heterogeneity may impact consumption and income distributions during growth provides crucial insights complementing the current state of the literature. This information is particularly important for policymakers that are concerned with the distributional impacts of economic fluctuations and policy interventions, making them aware of potential inequality effects during growth and appropriate policy measures to address these.

Thus, in this chapter, the role of intertemporal preference heterogeneity and reference dependence consumption behaviour across households are considered in a multiple-household RCK model (a constrained version of ORCK). KUJ and reference dependence consumption behaviour are both examined. Mathematical proofs and numerical simulations are presented. Four key stylised conclusions are drawn.

First, if the elasticity of intertemporal substitution (EIS) is not equal to 1, differences in Abel (1990) style KUJ habit persistence will unambiguously lead to changes in the consumption and income distribution during economic growth. These distributional effects are independent of the initial capital and labour allocations of the households. If the EIS is less (greater) than 1, households with stronger habits will become relatively richer (poorer) in the long run. Second, the short-run distributional effects will be the opposite of the long-run effects in the KUJ model. This is because households with higher consumption growth, in the long run, can only sustain this growth through short-run increases in savings exceeding those of low consumption growth households. Third, if households form rational expectations and are loss-averse, economic growth will be associated with reductions in consumption and income inequality. Fourth and last, if loss-averse households in the domain of losses fail to anticipate being in the domain of losses in the future, they will overconsume increasing consumption and income inequality in perpetuity. This occurs regardless of the state of the economy.

3.2 Model, data and shock

A closed economy version of ORCK, the model presented in Chapter 2 Section 2.3, is utilised to investigate how behavioural heterogeneity affects the consumption and income distribution during growth. ORCK's equations are summarised in Chapter 2 Table 2.1. In contrast to Chapter 2, this version of the model contains multiple households. Mathematical proofs and numerical simulations are employed to illustrate how heterogeneity in household behaviour drives the consumption and income distribution following aggregate shocks. Although the mathematical proofs are designed to be generalisable, the numerical simulations' SAM and parameters must be predefined. Hence, all simulations are built on fictitious[2] data presented in Table 3.1.

Table 3.1: ORCK Social Accounting Matrix

	F	**K**	**L**	**H1**	**H2**	**S**	**ROW**
F	0	0	0	$1.6 \cdot w_{c,1}$	$1.6 \cdot w_{c,2}$	0.4	0
K	1.5	0	0	0	0	0	0
L	0.5	0	0	0	0	0	0
H1	0	$1.5 \cdot w_{k,1}$	$0.5 \cdot w_{l,1}$	0	0	0	0
H2	0	$1.5 \cdot w_{k,2}$	$0.5 \cdot w_{l,2}$	0	0	0	0
S	0	0	0	$0.4 \cdot w_{k,1}$	$0.4 \cdot w_{k,2}$	0	0
ROW	0	0	0	0	0	0	0

F= Firms, K= Capital, L= Labour, Hi= Household i, S= Capital formation, ROW= Rest of the World

In the numerical simulations, there are two representative households denoted by H1 and H2. $w_{k,h} \in [0,1]$, $w_{l,h} \in [0,1]$ and $w_{c,h} \in [0,1]$ are household h's share of labour income, capital income and consumption where $\sum_h w_{l,h} = \sum_h w_{k,h} = \sum_h w_{c,h} = 1$. With the exception of the household disaggregation, the structure of the SAM is identical to that presented in Chapter 2. On aggregate, households receive 1.5 units of capital income and 0.5 units of labour income consuming 80% and saving the remaining 20%.

In the habit formation section, $w_{l,h} = w_{k,h} = w_{c,h} = 0.5$. Therefore, the households have identical income and consumption patterns in the baseline. This means that any difference in long run results will be driven by behaviour rather than the difference in structure of the household accounts.

[2]As the simulations are designed to illustrate the graphical interpretation of the proofs, the exact structure is of second-order importance.

In the reference dependence section, $w_{l,1} = w_{k,1} = w_{c,1} = 0.75$. Therefore, H1 is richer than H2. As average consumption in the economy is assumed to be the reference point in the reference dependence section, this ensures that loss aversion will be a driving factor in the behaviour of H2. To minimise the effects of the structural characteristics of the household accounts, the capital-to-labour and consumption-to-savings ratios are identical across household groups.

Each group contains half of the population. Households are too small to affect future external habit/reference points and thus do not aim to optimise these. The depreciation rate is set to 10% (Jorgenson, 1996).[3] For simplicity, the TFP growth rate and labour growth rates are set to 0 ($\overline{g} = n = 0$).

In the subsequent illustrative numerical simulations, a permanent unanticipated TFP increase of 2% is introduced in the first period. Thus, $A_t = A_0 \cdot (1+0.02) \forall t > 0$. Consumption impulse response functions (IRFs) are then compared depending on the behavioural assumptions employed.

3.3 Keeping up with the Joneses with habit heterogeneity

Consider a multiple-household version of ORCK.[4] There are N households with identical endowments, savings and consumption patterns in the baseline. That is, $K_{h,t} = k > 0 \ \forall \ h \in N$, $L_{h,t} = l > 0 \ \forall \ h \in N$, $C_{h,t} = c > 0 \ \forall \ h \in N$ and $S_{h,t} = s > 0 \ \forall \ h \in N$. Marginal utility is defined by eq. (2.36) presented in

[3]This is approximately the average depreciation rate estimated by Jorgenson (1996) across multiple industries in the US.
[4]Formally defined in Section 2.4, Chapter 2.

Chapter 2. Combining Chapter 2 eq. (2.36) and (2.29) we get:

$$\left(\frac{C_{h,t}}{H_t^{\gamma_h}}\right)^{-\frac{1}{\epsilon}} \cdot H_t^{-\gamma_h} = \frac{\beta}{p_t} \cdot \mathbb{E}_t \left(\frac{cpi_{h,t}}{cpi_{h,t+1}} \cdot \left(\frac{C_{h,t+1}}{H_{t+1}^{\gamma_h}}\right)^{-\frac{1}{\epsilon}} \cdot H_{t+1}^{-\gamma_h} \cdot (r_{t+1} + p_{t+1} \cdot (1-\delta)) \right). \tag{3.1}$$

Note that a household subscript is added to γ meaning that $\gamma_h \in [0, 1)$ is the level of habit persistence of household h. In a deterministic environment, the expectations operator can be dropped. As we are interested in household behaviour rather than consumption basket composition,[5] assume that $cpi_{h,t} = cpi_t \ \forall \ h$.[6] Under these assumptions, we can log-linearise and manipulate eq. (3.1) to get:

$$\ln\left(\frac{C_{h,t+1}}{C_{h,t}}\right) = (1-\epsilon) \cdot \gamma_h \cdot \ln\left(\frac{H_{t+1}}{H_t}\right) + \vartheta_t. \tag{3.2}$$

In eq. (3.2), $\vartheta_t := \epsilon \cdot \left(\ln(\beta) - \ln(p_t) + \ln(r_{t+1} + p_{t+1} \cdot (1-\delta)) + \ln\left(\frac{cpi_t}{cpi_{t+1}}\right)\right)$. Importantly, when $\gamma_h = 0 \ \forall \ h$, eq. (3.1) collapses to the neoclassical consumption model (in log-linear form).[7] In this case, there is no behavioural heterogeneity and aggregate shocks have symmetric impacts across the households.

Eq. (3.2) holds between all periods except in the short run which is defined as the transition from period $t = 0$ to period $t = 1$ when the shock occurs. This is because, in $t = 1$, the economy changes unexpectedly and hence the optimal consumption path predicted in $t = 0$ does not coincide with the optimal consumption path from $t = 1$. More, in period $t = 1$, capital stocks are fixed meaning that households have no direct influence on production capacity.

[5]Consumption basket composition will affect the distributional effects of aggregate shocks in ORCK and may be affected indirectly by habit persistence.

[6]In a closed economy, this assumption is not necessary as the domestic price level is the numéraire, meaning that $cpi_{h,t} = cpi_t = p_t = p_{t+1} \ \forall \ h$ and $\theta_t = 1$.

[7]In a closed economy, this is identical to the Ramsey (1928) household problem in log-linear form.

Proposition 1:

Suppose $\epsilon = 1$. Then, following aggregate shocks,[8] percentage changes in consumption will be identical across the households.

Proof:

When $\epsilon = 1$:

$$\ln\left(\frac{C_{h,t+1}}{C_{h,t}}\right) = \vartheta_t.$$

As ϑ_t is constant across households, aggregate changes will have symmetric impacts on consumption growth from period $t = 2$ onwards. As, by assumption, households are identical in the baseline, this is only possible if the households' short-run consumption responses are also identical. □

Proposition 1 suggests that contemporaneous and future habit persistence effects cancel each other out when the EIS is one. In this case, regardless of whether habit persistence is heterogeneous across the distribution, economic growth will not affect the consumption distribution.[9]

Corollary 1:

Suppose $\epsilon = 1$. Then, following aggregate shocks, percentage changes in income will be identical across all households.

As percentage changes in consumption will be identical across the income distribution and households are initially identical, percentage changes in savings will also be identical across the income distribution. Consequently, percentage changes in

[8]Defined as any demand or supply shock affecting households symmetrically.

[9]In the period immediately following the shock, consumption growth may be heterogeneous across households if the respective capital-to-labour income ratios are different across households. As the focus is on behavioural heterogeneities, this case is not considered.

incomes will be identical across the income distribution and corollary 1 will hold.[10]

Proposition 2:

Suppose $\gamma_h = \gamma \; \forall \; h$. Then, following aggregate shocks, percentage consumption changes will be identical across households.

Proof:

When $\gamma_h = \gamma$:

$$\ln\left(\frac{C_{h,t+1}}{C_{h,t}}\right) = (1-\epsilon)\cdot\gamma\cdot\ln\left(\frac{H_{t+1}}{H_t}\right) + \vartheta_t.$$

Comparing households h and k we get:

$$\ln\left(\frac{C_{h,t+1}}{C_{h,t}}\right) - \ln\left(\frac{C_{k,t+1}}{C_{k,t}}\right) = 0.$$

As the right-hand-side (RHS) is 0, percentage consumption changes following aggregate shocks will be identical across households in the medium to long run. As households are identical in all respects except their level of habit persistence, the only way this is possible is if the short-run consumption change is identical across households as well. Hence, following aggregate shocks, percentage consumption changes will be identical across households. □

Corollary 2:

Suppose $\gamma_h = \gamma \; \forall \; h$. Then, following aggregate shocks, percentage income changes will be identical across households.

Proposition 2 demonstrates that when households have identical behavioural characteristics, aggregate shocks will not affect the consumption distribution. Proposi-

[10]If capital-to-labour ratios are heterogeneous across the income distribution, this does not hold.

tion 2 implies Corollary 2 by the same reasoning as Proposition 1 implies Corollary 1. Thus, the same conclusion holds for the income distribution.

Proposition 3:

Suppose $\exists\ h,\ k$ such that $\gamma_h > \gamma_k$. Then, if $\epsilon < 1$ ($\epsilon > 1$), household h's consumption will grow proportionally faster (slower) than household k's in the medium to long run following positive aggregate shocks.

Proof:

For households h and k, we know that:

$$\ln\left(\frac{C_{h,t+1}}{C_{h,t}}\right) - \ln\left(\frac{C_{k,t+1}}{C_{k,t}}\right) = (1-\epsilon)\cdot(\gamma_h - \gamma_k)\cdot\ln\left(\frac{H_{t+1}}{H_t}\right).$$

Following positive aggregate shocks, households are strictly better off on aggregate as factor incomes increase. Therefore, aggregate consumption will increase in the long run. As aggregate consumption increases, $H_{t+1} > H_t$.

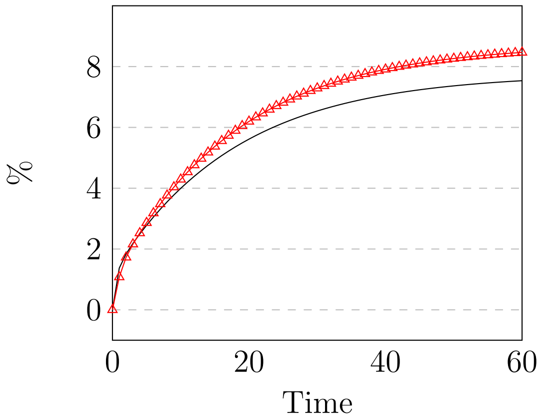
Suppose $\gamma_h > \gamma_k$. As $\ln(x) > 0\ \forall\ x > 1$, we deduce that $(\gamma_h - \gamma_k)\cdot\ln\left(\frac{H_{t+1}}{H_t}\right) > 0$. Hence, the sign of the RHS is entirely determined by the sign of $(1-\epsilon)$.

When $\epsilon < 1$ ($\epsilon > 1$), the RHS is positive (negative). This implies that household $h's$ consumption growth is greater (less) than household $k's$. □

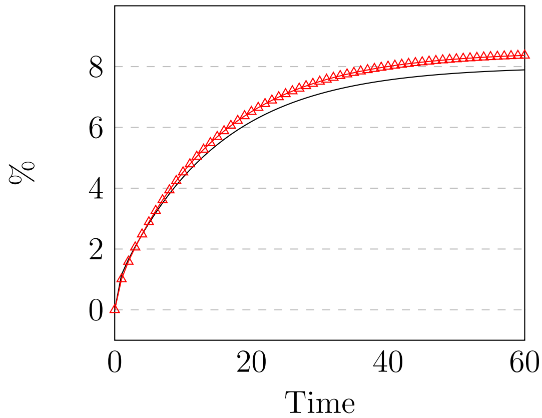
Corollary 3:

Suppose $\exists\ h,\ k$ such that $\gamma_h > \gamma_k$. Then, if $\epsilon < 1$ ($\epsilon > 1$), household h's income will grow proportionally faster (slower) than household k's in the medium to long run following positive aggregate shocks.

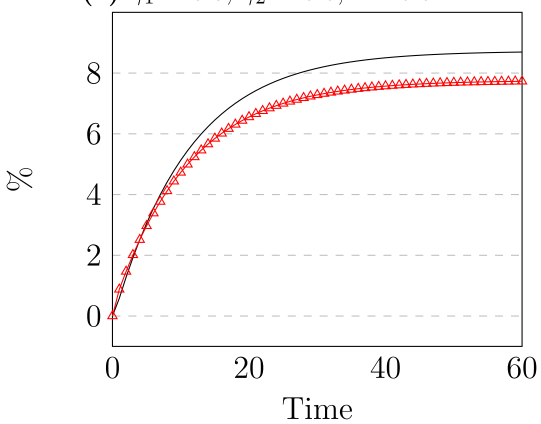
Proposition 3 suggests that long-run changes in consumption inequality between household groups are related to the difference in the strength of habits scaled by the EIS. Very small or large values of ϵ lead to larger changes in relative consumption than values of ϵ closer to 1. Importantly, Proposition 3 implies that relative medium to long-run consumption growth rates are unaffected by initial relative incomes or endowments. Only differences in short-run consumption growth rates will be affected by heterogeneities in endowments and or consumption basket composition. Corollary 3 follows directly from Proposition 3. Persistently higher consumption growth is only achievable through higher income growth in the medium to long run. An important implication of Proposition 3 and Corollary 3 is that even in an otherwise homogeneous economy, heterogeneity in behaviour will lead to the emergence of inequality.



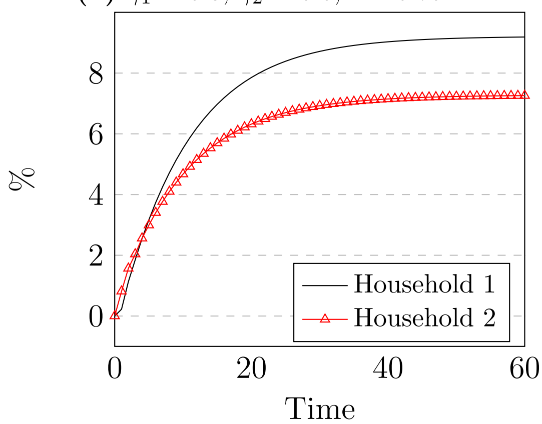
(a) $\gamma_1 = 0.3$, $\gamma_2 = 0.6$, $\epsilon = 0.5$



(b) $\gamma_1 = 0.3$, $\gamma_2 = 0.6$, $\epsilon = 0.75$



(c) $\gamma_1 = 0.3$, $\gamma_2 = 0.6$, $\epsilon = 1.5$



(d) $\gamma_1 = 0.3$, $\gamma_2 = 0.6$, $\epsilon = 2$

Figure 3.1: 2% increase in TFP: Household specific consumption IRFs

Figure 3.1 demonstrates the visual interpretation of Proposition 3. In the numerical simulations, household 1 has a level of habit persistence ($\gamma_1 = 0.3$) which is lower than household 2's level ($\gamma_2 = 0.6$). The numerical simulations demonstrate that when $\epsilon < 1$ ($\epsilon > 1$), household 2's consumption growth is greater (less) than household 1's. The difference in consumption growth rates increases as the distance between ϵ and 1 increases.

The value of the EIS is subject to debate in the academic literature. Authors such as Hall (1988), Yogo (2004) and Havranek et al. (2015) suggest that the EIS is equal to or less than 0.5 whereas Thimme (2017) summarises papers suggesting that the EIS is greater than 1. As many features of economic models such as the granularity of the data and the country evaluated to estimate the EIS have large effects on the results, no firm position is taken on which of the figures is most likely to represent reality. Havranek et al. (2017) summarise estimates of habit persistence for representative households. Depending on the model and data used, habit persistence levels differ significantly although the mean macro estimate is 0.6. The level of KUJ habit persistence across different household groups has not previously been estimated. Therefore, future research should aim to determine whether the level of habit persistence is heterogeneous across household groups.[11] This information will help policymakers determine the potential consequences of policies on different household groups *ex ante*.

[11] These characteristics could include household differentiation by income groups but also other observable characteristics such as age, gender, household size *etc.*

Proposition 4:

Suppose that the consumption growth rate of household h exceeds that of household k in the medium to long run. Then, in the short run, household k must increase consumption more than household h. Therefore, the distributional impact of any aggregate shock in the short run is the opposite of the distributional impact in the long run.

Proof:

As labour supply is exogenous and all markets clear, sustainable higher consumption growth can only be achieved through a relative increase in capital income. As capital accumulation is driven entirely by savings, households with higher consumption growth can only achieve this higher growth rate through an initial increase in savings exceeding that of low consumption growth households. This implies that in the short-run, consumption in the low-consumption growth household must increase proportionally more than that of high-consumption growth households. □

Propositions 1-4 provide crucial testable predictions describing how behavioural heterogeneity in habit persistence may affect short-run and long-run household consumption inequality following aggregate shocks such as TFP shocks. These propositions complement classical growth theory predictions providing nuanced insights about how heterogeneity in household behaviour may affect the consumption and income distribution.

3.4 Reference Dependence and Growth

Next, let's consider the case where households' preferences are determined by reference dependence. In this section, suppose that the reference point is the lag of average aggregate consumption and that we have a low- and high-income household. Thus, differences in consumption growth will be driven by reference dependence and loss aversion rather than behavioural heterogeneity. The reference dependence utility function is presented in eq. (3.3).

$$u_R(C_{h,t}|H_t) = \begin{cases} \frac{\epsilon}{\epsilon-1} \cdot C_{h,t}^{\frac{\epsilon-1}{\epsilon}} \text{ if } C_{h,t} \geq H_t \\ \frac{\epsilon}{\epsilon-1} \cdot C_{h,t}^{\frac{\epsilon-1}{\epsilon}} - \frac{\lambda}{\mu} \cdot (H_t - C_{h,t})^{\mu} \text{ if } C_{h,t} < H_t \end{cases} . \tag{3.3}$$

Eq. (3.3) extends eq. (2.4), presented in Chapter 2, to capture both absolute and relative utility. The reference point is the previous period's average consumption level in the economy H_t following the KUJ literature. For simplicity, reference utility is only considered in the domain of losses. Taking the first order condition with respect to $C_{h,t}$ assuming households are too small to influence H_t we get eq. (3.4):

$$u'_R(C_{h,t}|H_t) = \begin{cases} C_{h,t}^{-\frac{1}{\epsilon}} \text{ if } C_{h,t} \geq H_t \\ C_{h,t}^{-\frac{1}{\epsilon}} + \lambda \cdot (H_t - C_{h,t})^{\mu-1} \text{ if } C_{h,t} < H_t \end{cases} . \tag{3.4}$$

Households with consumption above (below) the average level consider themselves in the domain of gains (losses). For simplicity and without loss of generality, assume that $\mu = 1$ and $\lambda > 0$ meaning that reference utility is linear and households are loss averse.[12] Under these assumptions, the shape of the utility function is demonstrated in Figure 3.2.

[12] In this chapter, λ cannot be interpreted in the same way as Kahneman and Tversky (1979) where $\lambda > 1$ implies loss aversion. This is since reference utility in the domain of gains is removed for simplicity and without loss of generality.

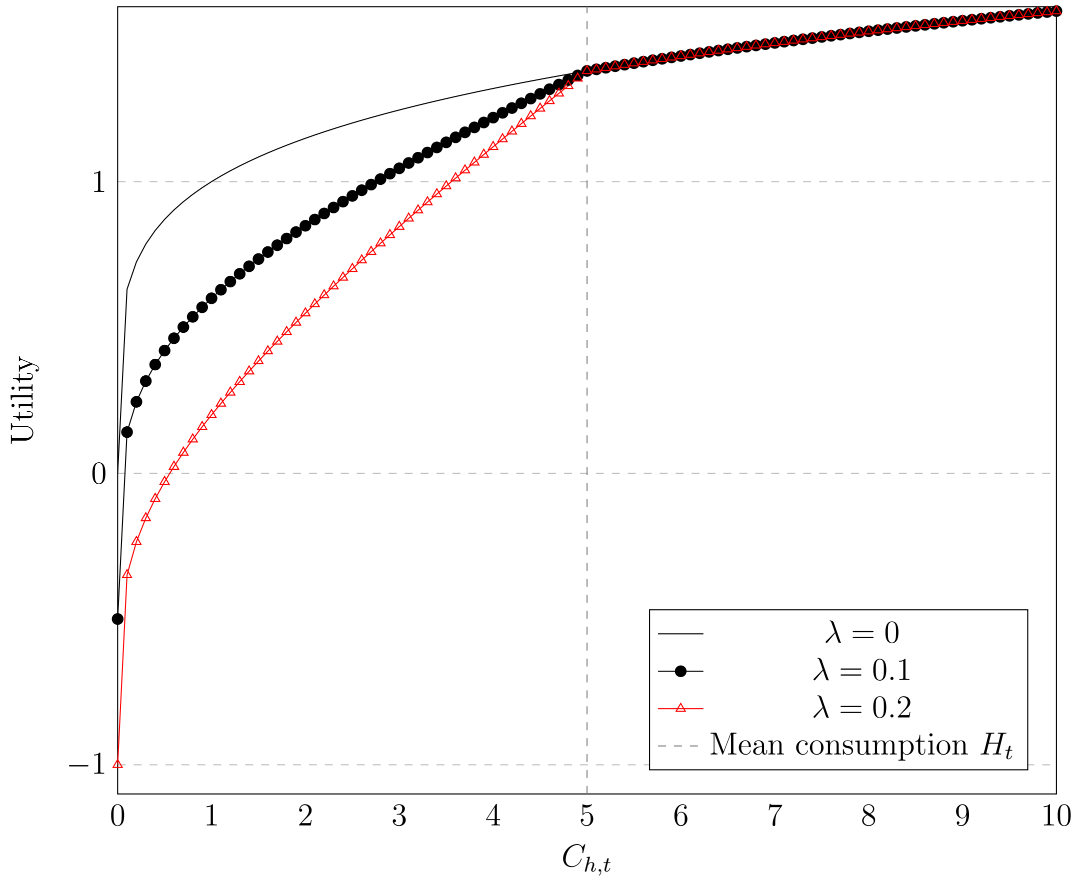


Figure 3.2: Theoretical loss aversion utility function: $\epsilon = 0.2$.

In Figure 3.2, the solid black line is a conventional concave utility function with an EIS of 0.2 to accentuate the qualitative features of the function. The black line with circular marks and the red line with triangular marks are the same utility function when loss aversion is captured with $\lambda = 0.1$ and $\lambda = 0.2$ respectively. The utility function is piece-wise linear, capturing both absolute utility and gain-loss utility (Kahneman and Tversky, 1979). The function is everywhere concave.[13]

As shown in Figure 3.2, the reference point is the mean consumption in the economy H_t. Households receive a disutility of consuming below the reference point represented visually as the vertical difference between the black line and the other

[13]For simplicity, we abstract away from diminishing sensitivity in the domain of losses.

lines in the domain of losses. Larger λ values are associated with greater disutilities of consuming below H_t as revealed by the fact that the $\lambda = 0.2$ line is below the $\lambda = 0.1$ line in the domain of losses.

As we are interested in how behaviour affects the consumption distribution, suppose $cpi_{h,t} = cpi_t \ \forall \ t$. Combining eq. (2.29) presented in Chapter 2 and eq. (3.4) in a deterministic setting, we get:

$$C_{h,t}^{-\frac{1}{\epsilon}} + \Omega_{h,t} = \frac{\beta}{p_t} \cdot \left(\frac{cpi_t}{cpi_{t+1}} \cdot \left(C_{h,t+1}^{-\frac{1}{\epsilon}} + \Omega_{h,t+1} \right) \cdot \left(r_{t+1} + p_{t+1} \cdot (1-\delta) \right) \right). \tag{3.5}$$

$$\Omega_{h,t} = \begin{cases} 0 \text{ if } C_{h,t} \geq H_t \\ \lambda \text{ if } C_{h,t} < H_t \end{cases}. \tag{3.6}$$

In the next proofs, suppose that there are two representative households. The difference in the households' consumption is sufficiently large such that the probability of switching between "loser" and "winner" states is 0 ($\Omega_{h,t} = \Omega_{h,t+1} \ \forall \ h$). This means that low consumption households are in the domain of losses persistently whereas high consumption households are in the domain of gains persistently.

Proposition 5:

Households in the domain of losses (gains) will attain higher medium- to long-run consumption growth rates than households in the domain of gains (losses) following positive (negative) aggregate shocks if an interior solution exists.

Proof:

Suppose there are two households. Household 1 is in the domain of gains and household 2 is in the domain of losses. Therefore, $\Omega_{1,t} = 0 \ \forall \ t$ and $\Omega_{2,t} = \lambda \ \forall \ t$. Define $A_t = C_{1,t}$, $x \cdot A_t = C_{2,t}$ and $\Delta_{h,t} = \left(\frac{C_{h,t+1}}{C_{h,t}} \right)$. Dividing the Euler equations of the respective households, we get:

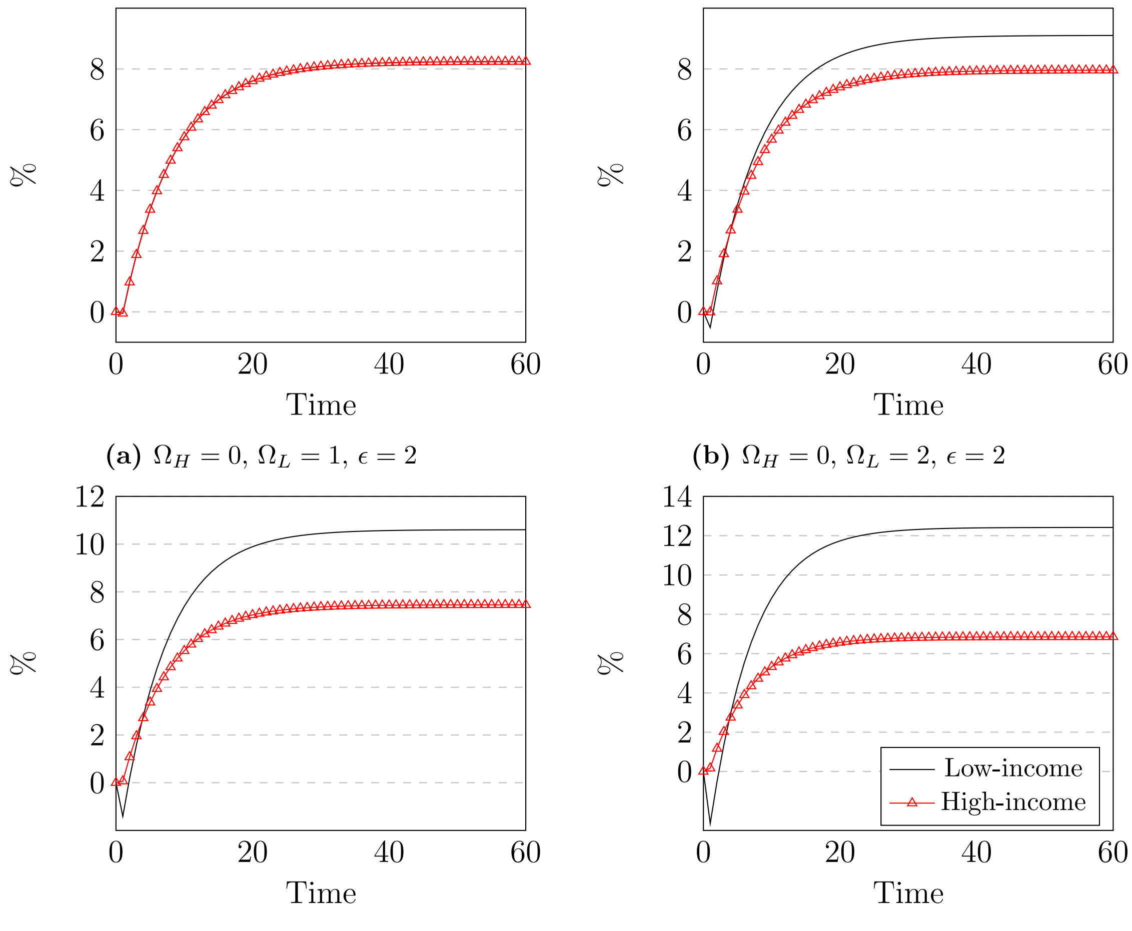
$$
\begin{aligned}
& \frac{C_{1,t}^{-\frac{1}{\epsilon}}}{C_{2,t}^{-\frac{1}{\epsilon}} + \lambda} = \frac{C_{1,t+1}^{-\frac{1}{\epsilon}}}{C_{2,t+1}^{-\frac{1}{\epsilon}} + \lambda}, \\
\implies & \frac{A_t^{-\frac{1}{\epsilon}}}{(x \cdot A_t)^{-\frac{1}{\epsilon}} + \lambda} = \frac{(\Delta_{1,t} \cdot A_t)^{-\frac{1}{\epsilon}}}{(x \cdot \Delta_{2,t} \cdot A_t)^{-\frac{1}{\epsilon}} + \lambda}, \\
\implies & A_t^{-\frac{1}{\epsilon}} \cdot \left((x \cdot \Delta_{2,t} \cdot A_t)^{-\frac{1}{\epsilon}} + \lambda \right) = (\Delta_{1,t} \cdot A_t)^{-\frac{1}{\epsilon}} \cdot \left((x \cdot A_t)^{-\frac{1}{\epsilon}} + \lambda \right), \\
\implies & (x \cdot \Delta_{2,t} \cdot A_t)^{-\frac{1}{\epsilon}} + \lambda = \Delta_{1,t}^{-\frac{1}{\epsilon}} \cdot \left((x \cdot A_t)^{-\frac{1}{\epsilon}} + \lambda \right), \\
\implies & (x \cdot \Delta_{2,t} \cdot A_t)^{-\frac{1}{\epsilon}} = \Delta_{1,t}^{-\frac{1}{\epsilon}} \cdot \left((x \cdot A_t)^{-\frac{1}{\epsilon}} + \lambda \right) - \lambda, \\
\implies & \left(\frac{\Delta_{1,t}}{\Delta_{2,t}} \right)^{\frac{1}{\epsilon}} = \frac{(x \cdot A_t)^{-\frac{1}{\epsilon}} + \lambda - \Delta_{1,t}^{\frac{1}{\epsilon}} \cdot \lambda}{(x \cdot A_t)^{-\frac{1}{\epsilon}}}, \\
\implies & \left(\frac{\Delta_{1,t}}{\Delta_{2,t}} \right)^{\frac{1}{\epsilon}} = 1 + \lambda \cdot (1 - \Delta_{1,t}^{\frac{1}{\epsilon}}) \cdot (x \cdot A_t)^{\frac{1}{\epsilon}}.
\end{aligned}
$$

Following a positive shock, factor incomes will increase. Thus, over time, aggregate consumption increases. Suppose that $\Delta_{1,t} > 1$. By definition $(\Delta_{1,t})^z > 1 \; \forall \; z > 0$. As $\frac{1}{\epsilon} > 0$, we can deduce that the RHS is less than 1 as $\lambda \cdot (1 - \Delta_{1,t}^{\frac{1}{\epsilon}}) \cdot (x \cdot A_t)^{\frac{1}{\epsilon}} < 0$. This implies that the LHS is less than 1. As labour supply is fixed exogenously and consumption can't be negative in the model, $\Delta_{h,t} \geq 0$. As $\Delta_{h,t} \geq 0$, the LHS can only be less than 1 if $\Delta_{2,t} > \Delta_{1,t}$. Hence, if an interior solution exists, where households in the domain of gains increase their consumption, households in the domain of losses will increase their consumption by a larger amount. □

Corollary 5:

Households in the domain of losses (gains) will attain higher medium- to long-run income growth rates than households in the domain of gains (losses) following positive (negative) aggregate shocks if an interior solution exists.

Based on Proposition 5, we expect the consumption distribution to narrow in the long run following positive aggregate shocks if an interior solution exists and households are loss-averse having external reference points determined by average consumption levels in the economy. Corollary 5 follows from Proposition 5 as persistently higher consumption growth rates are only achievable through persistently higher income growth. If income composition is identical, then higher consumption growth rates can only occur through proportionally higher increases in capital. Therefore, income growth of low-income households must exceed that of high-income households. By Proposition 4, we expect the consumption distribution effects to reverse from the short run to the long run.[14]



(a) $\Omega_H = 0$, $\Omega_L = 1$, $\epsilon = 2$

(b) $\Omega_H = 0$, $\Omega_L = 2$, $\epsilon = 2$

(c) $\Omega_H = 0$, $\Omega_L = 3$, $\epsilon = 2$

(d) $\Omega_H = 0$, $\Omega_L = 4$, $\epsilon = 2$

Figure 3.3: 2% increase in TFP: Household specific consumption IRFs

[14]This will arise if capital-to-labour ratios are identical.

Figure 3.3 provides a visualisation of Proposition 5. Subfigures 3.3a-3.3d demonstrate the results of 2% TFP shock as low-income households' level of loss aversion increases. As the degree of loss aversion increases, the consumption growth rate of low-income households increases relative to that of high-income households. This suggests that, in a deterministic environment, loss aversion drives income convergence during positive aggregate shocks.

Proposition 5 holds for an interior solution, however, sufficiently large values of λ may push the model towards a corner solution. This would imply that the Euler equations may not hold. Based on the numerical simulation presented in Figure 3.3, specifically panel 3.3d, this threshold is likely too high to be sensible in an economic model.[15] This is since a corner solution would imply that low-income households save all of their incomes in the period immediately after the shock. No empirical arguments would support such behaviour.[16]

Propositions 5 provides testable predictions describing how loss aversion will affect household consumption inequality following aggregate shocks such as TFP shocks. The reference dependence model predicts consumption growth of households in the domain of losses to exceed that of households in the domain of gains following aggregate positive shocks if an interior solution exists.

Proposition 5 and Corollary 5 imply that consumption and income will converge following positive aggregate shocks however, these rely critically on the assumption that households are rational and forward-looking. If households are not fully rational, for instance due to overconfidence (Caliendo and Huang, 2008), they may

[15] Appendix B.1 defines an implicit equation for this threshold.

[16] In the context of the model, λ must be scaled relative to the consumption level. Therefore, the thresholds are not universal but scale variant.

overestimate their ability to transition from the domain of losses to the domain of gains. In this context, Proposition 5 and Corollary 5 collapse.

Proposition 6:

If households in the domain of losses are unable to anticipate being in the domain of losses in future periods, their medium- to long-run consumption will grow proportionally less than that of households in the domain of gains.

Proof:

Suppose "loser" households overestimate their probability of transitioning to the domain of gains. Then, "loser" households' Euler equation is:

$$C_{L,1}^{-\frac{1}{\epsilon}} + \lambda = \frac{\beta}{p_1} \cdot \left(\frac{cpi_1}{cpi_2} \cdot \left(C_{L,2}^{-\frac{1}{\epsilon}} + \phi_{1,1} \cdot \lambda \right) \cdot \left(r_2 + p_2 \cdot (1-\delta)\right) \right),$$

$$\mathbb{E}_{t-1}\left(C_{L,t}^{-\frac{1}{\epsilon}} + \phi_{1,t}\lambda \right) = \frac{\beta}{p_t} \cdot \mathbb{E}_{t-1}\left(\frac{cpi_t}{cpi_{t+1}} \cdot \left(C_{L,t+1}^{-\frac{1}{\epsilon}} + \phi_{1,t+1}\lambda \right) \cdot \left(r_{t+1} + p_{t+1} \cdot (1-\delta)\right) \right),$$

$$\text{if } t > 1.$$

$\phi_{t,t'} \in [0,1]$, is the "loser" households' belief that they will transition to the domain of gains during period t' in period t. Dividing "winner" households' Euler equation between $t = 1$ and $t = 2$ by that of "loser" households, and maintaining the notation of the proof of Proposition 5, we get:

$$\frac{C_{W,t}^{-\frac{1}{\epsilon}}}{C_{L,t}^{-\frac{1}{\epsilon}}+\lambda}=\frac{C_{W,t+1}^{-\frac{1}{\epsilon}}}{C_{L,t+1}^{-\frac{1}{\epsilon}}+\phi_{1,1}\cdot\lambda},$$

$$\implies \frac{A_t^{-\frac{1}{\epsilon}}}{(x\cdot A_t)^{-\frac{1}{\epsilon}}+\lambda}=\frac{(\Delta_{1,t}\cdot A_t)^{-\frac{1}{\epsilon}}}{(x\cdot\Delta_{2,t}\cdot A_t)^{-\frac{1}{\epsilon}}+\phi_{1,1}\cdot\lambda},$$

$$\implies A_t^{-\frac{1}{\epsilon}}\cdot\left((x\cdot\Delta_{2,t}\cdot A_t)^{-\frac{1}{\epsilon}}+\phi_{1,1}\cdot\lambda\right)=(\Delta_{1,t}\cdot A_t)^{-\frac{1}{\epsilon}}\cdot\left((x\cdot A_t)^{-\frac{1}{\epsilon}}+\lambda\right),$$

$$\implies (x\cdot\Delta_{2,t}\cdot A_t)^{-\frac{1}{\epsilon}}+\phi_{1,1}\cdot\lambda=\Delta_{1,t}^{-\frac{1}{\epsilon}}\cdot\left((x\cdot A_t)^{-\frac{1}{\epsilon}}+\lambda\right),$$

$$\implies (x\cdot\Delta_{2,t}\cdot A_t)^{-\frac{1}{\epsilon}}=\Delta_{1,t}^{-\frac{1}{\epsilon}}\cdot\left((x\cdot A_t)^{-\frac{1}{\epsilon}}+\lambda\right)-\phi_{1,1}\cdot\lambda,$$

$$\implies \left(\frac{\Delta_{1,t}}{\Delta_{2,t}}\right)^{\frac{1}{\epsilon}}=\frac{(x\cdot A_t)^{-\frac{1}{\epsilon}}+\lambda-\Delta_{1,t}^{\frac{1}{\epsilon}}\cdot\phi_{1,1}\cdot\lambda}{(x\cdot A_t)^{-\frac{1}{\epsilon}}},$$

$$\implies \left(\frac{\Delta_{1,t}}{\Delta_{2,t}}\right)^{\frac{1}{\epsilon}}=1+\lambda\cdot(1-\phi_{1,1}\cdot\Delta_{1,t}^{\frac{1}{\epsilon}})\cdot(x\cdot A_t)^{\frac{1}{\epsilon}}.$$

Suppose that $\phi_{1,t}=0\ \forall\ t$. Then the RHS is unambiguously greater than 1 if $\lambda>0$. This means that expected consumption growth of "winner" households exceeds that of "loser" households from $t=1$ to $t=2$. Dividing the Euler equation of "winner" households by that of "loser" households in period $t=2$ onward we know that:

$$\mathbb{E}_\tau\left(\frac{C_{W,t}}{C_{L,t}}\right)=\mathbb{E}_\tau\left(\frac{C_{W,t+1}}{C_{L,t+1}}\right)\ \forall\ \tau<t+2.$$

Therefore, the only way that the expected period $t=1$ consumption growth of "winner" households exceeds that of "loser" households whilst expected consumption growth $\forall\ t>1$ is equal across households is if consumption growth of "loser" households exceeds that of "winner" households from $t=0$ to $t=1$. This only occurs if the initial savings of the "loser" households are lower than those of the "winner" households.

Although "loser" households expect not to be in the domain of losses in the following period, the expectation is false and thus, the problem in period $t+1$ is the same. Consequently, "loser" households' savings decrease each period relative to "winner" households, decreasing relative factor incomes of the "loser" households. Thus, in the medium to long run, "winner" households' consumption increases more than "loser" households. Importantly, even in the absence of shocks, this will ultimately lead to "loser" households entirely depleting their capital stocks in the absence of TFP growth. □

Proposition 6 suggests that households' relative loss aversion behaviour only leads to consumption and income convergence following positive shocks if households are forward-looking and rational. If "loser" households are unable to anticipate being in the domain of losses in future periods, the model predicts that these households will become relatively poorer regardless of the state of the economy. Ultimately, myopic "loser" households will entirely deplete their capital stocks driving increases in income and consumption inequality. Importantly, the proof of Proposition 6 demonstrates that the further $\phi_{1,1}$ is from 1, the more likely it will be that low-income households' consumption will grow less than high-income households following positive aggregate shocks.

3.5 Concluding remarks

This chapter contributes to growth theory by considering the role of behavioural heterogeneity across households in an RCK framework. A set of testable theoretical insights are derived and numerically feasible methods to introduce habit formation and reference dependence into general equilibrium models are applied. The chapter provides four crucial insights.

First, Abel (1990) style KUJ habit persistence heterogeneities across households will unambiguously lead to changes in the consumption and income distributions if the elasticity of intertemporal substitution is not equal to 1. Larger differences in habit persistence will lead to larger changes in the distribution. Whether long-run consumption inequality increases or decreases depends on whether the elasticity of intertemporal substitution is less than or greater than 1 and on which households have higher levels of habit persistence. Future research should jointly estimate habit persistence levels across households and elasticities of intertemporal substitution for regions of interest. This will help economists better understand how behavioural heterogeneities may affect consumption and income distributions during the growth process.

Second, following positive total factor productivity shocks in the multiple-household RCK framework, short-run and long-run consumption distribution effects will reverse. That is, if consumption inequality increases in the short run, it will decrease in the long run (*vice versa*). Third, rational loss aversion in a KUJ style reference dependence model will lead to consumption and income convergence during growth in the RCK model if an equilibrium exists. Combining the second and third insights suggests that loss aversion may help explain features of the Kuznets curve. This is because it would predict that countries in the early stages of growth/ catch-up witness increases in inequality. Once countries grow to the technological frontier, inequalities decrease. The driving mechanism in this case is loss aversion and the structure of the RCK model.

Forward-looking loss-averse behaviour may drive consumption and income convergence. Although this conclusion is true in a world of perfect foresight, the fourth stylised result demonstrates that when households are unable to predict being in the domain of losses in the future, "loser" households will systematically under-save. In a world where "loser" households are unable to anticipate their future relative losses, consumption inequality may increase. Thus, whether consumption convergence occurs will depend on the degree to which "loser" households can anticipate their future states and behaviour.

Future research should aim to extend this chapter. Considering the role of uncertainty and the possibility of switching between "loser" and "winner" states will be crucial extensions. Understanding the implications of heterogeneities in the elasticity of intertemporal substitution may also extend the analysis. Endogenising labour supply decisions will reveal further important insights into how habits and loss aversion may affect the consumption and income distribution in growth through labour markets. Finally, future research should investigate how behavioural heterogeneities combined with capital market frictions such as liquidity constraints may affect the consumption distribution.

Chapter 4

How should governments respond to energy price crises? A horse-race between fiscal policies.

4.1 Introduction

Beginning in 2021 the world has experienced a dramatic and sudden increase in energy prices. This 'energy crisis' (IEA, 2023) has been attributed to a variety of factors, including the rapid economic rebound following the Covid-19 pandemic and Russia's invasion of Ukraine in February 2022. Crucially, the energy crises has significantly impacted the cost-of-living. This is evidenced by the fact that global inflation increased from 3.1% in 2021 to 7.3% in 2022 whilst world output growth decreased from 6.2% to 3.4% (IMF, 2023). However, the consequences of this shock have not been felt evenly. On a geographical level, for instance, some countries such as Germany and Italy, have been more exposed due to their dependence on gas imports from Russia. Distributionally speaking, lower-income households have been disproportionately affected as they typically consume a larger proportion of their income on energy goods compared with higher-income households (Guan et al., 2023).

To contain the impact of this increase in the price of energy, governments across Europe have been implementing a litany of fiscal policies designed to address aggregate and distributional consequences of the shock (Sgaravatti et al., 2023). These included price subsidies, either to firms and households, to households only or targeted to low-income households, income subsidies, and tax reductions on energy. The policies have been mostly financed by public debt with some exceptions where the funding has come from taxing energy companies' extra profits[1], the so called 'windfall tax'. Whilst a broad empirical and theoretical literature exists, that quantifies the aggregate and distributional effects of energy shocks and the

[1]There is evidence that the hike in energy prices has led to a surge in profits for energy companies. For instance two of the largest oil and gas companies in the world, Shell and BP, saw record profits in 2022 (BP, 2023; Shell, 2023). (Jolly and Elgot, 2022) suggest that the profits of the 7 largest oil firms in the world exceeded £150bn in 2022.

effects of price subsidies, income subsidies, and tax reductions, there is limited ability to compare the welfare and distributional implications of such policies.

The aim of this chapter is to analyse and compare the implications of fiscal policies implemented by European governments to contain the increase in energy prices on output, prices, income distribution and welfare. To achieve a like-for-like comparison of the different policies we develop a dynamic Computable General Equilibrium (CGE) of Germany and the Rest of the EU using the 2020 FIGARO Input-Output database (Remond-Tiedrez and Rueda-Cantuche, 2019). The focus on Germany is purely illustrative of a country with a strong dependence on imported gas. The model considers the production activities of energy and non-energy industries where energy industries set energy prices in a monopolistic environment. Two household income groups are considered to investigate the distributional implications of the policies. Using the model, we simulate the introduction of five fiscal policies (general/ untargeted/ targeted price subsidies, income subsidies, and production tax reductions) representing the main policies introduced by European governments following an exogenous energy price shock. The simulations are performed by either assuming that the policies are entirely government debt financed or funded through a combination of debt and windfall taxes on energy profits. This allows us to compare the welfare implications of the two financing mechanisms.

Using the CGE model, some stylised conclusions can be drawn. First, targeted income and price subsidies best counteract short-run regressive impacts on consumption and provide the best long-run welfare outcomes following the energy shock. Second, households targeted and untargeted income and price subsidies achieve a greater reduction in inflation. Third, production tax reduction are the most effective policy to counteract downward pressure on aggregate output in the short run. Fourth and last, introducing a windfall tax is welfare-enhancing for all policies as long as households care sufficiently about the provision of public goods.

4.2 Background and Literature

An extensive economics literature starting with Hamilton (1983) has documented the contractionary and inflationary effects of energy price shocks (see for example Kilian, 2008; Ven and Fouquet, 2017, for a review and a historical analysis). The literature highlights how these shocks may hit energy importing countries more severely (Jiménez-Rodríguez and Sánchez, 2005; Jiménez-Rodríguez, 2008; Alexeev and Chih, 2021; Peersman and Robays, 2012), and that impacts may be heterogeneous at an industrial level (Jiménez-Rodríguez, 2008; Ahmed et al., 2023; Ferriani and Gazzani, 2023).

Researchers typically find that low-income households are more adversely affected by energy shocks (Michael, 1979; Hagemann, 1982; Pizer and Sexton, 2019; Williams et al., 2015; Metcalf et al., 2008; Guan et al., 2023; Celasun et al., 2022; Turner et al., 2022) for two main reasons. First, low-income households spend larger proportions of their income on energy and goods highly dependent on intermediate energy use. Second, low-income households own proportionally fewer assets than high-income households. Thus they are less likely to benefit from increased returns from energy companies' assets.

An emerging literature is concerned with the distributional impacts of the recent energy crisis (Celasun et al., 2022; Guan et al., 2023; Perdana et al., 2022; Turner et al., 2022). Specifically, Celasun et al. (2022) suggest that in 2022, European households' cost-of-living increased by 7%. Guan et al. (2023) use an international input-output framework and estimate total household energy costs to increase by

62.6–112.9% across the world. These effects are found to be distributed unevenly both within and across countries supporting evidence from Celasun et al. (2022). Perdana et al. (2022) evaluate the consequences of the trade sanctions on Russia using a CGE methodology, mainly from an environmental perspective, but also find reductions in GDP and Welfare in the EU. Finally, Turner et al. (2022) evaluate the implications of the cost-of-living crisis using a CGE model of the UK. They focus on the distributional impacts of £400 energy payments given by the UK Government to all households and find that the policy still leaves households on the lowest income £350 worse off than before the energy crisis.

Although all the papers above provide an assessment of the impact of the 2022 energy shock, none attempt to compare energy policies using a unified framework. Guan et al. (2023) and Perdana et al. (2022) provide insights on the aggregate and distributional impacts of the energy shock but do not present any fiscal policy measures. On the other hand Turner et al. (2022) analyse a specific policy introduced in the UK but do not compare alternative policies and do not consider windfall taxation. Celasun et al. (2022) provide the most detailed discussion on policy options however the discussion is not based on a single framework and is more qualitative than quantitative.

Thus with our work, we contribute to the above literature by systematically assessing the welfare and distributional impacts of the main fiscal policies implemented across Europe to counteract the impact of increased energy prices as reported in Sgaravatti et al. (2023). The analysis in this chapter provides a strong basis for the assessment of the strengths and weaknesses of each of the policies in addressing both welfare and distributional policy objectives under a unified framework. Although the paper is inspired by the current measures implemented across Europe, it is designed as a theoretical contribution. Thus, the focus will be on comparing the policies rather than precisely quantifying the effects of the energy crisis. Equally, the focus on Germany is purely illustrative of an energy import-intensive country. Germany makes the ideal case study as 90% of total crude oil, refined petroleum products and natural gas used in Germany was imported prior to the beginning of the Ukraine conflict (Eurostat, 2023c). Whilst the results from this chapter are specific to the German case, the methods developed are directly applicable to any other country. In addition, the results are relevant for countries with similar dependencies on imported energy or with similar economic structures and consumption patterns.

4.3 Model

We compare the welfare and distributional implications of the fiscal policies by developing and using a multi-region dynamic[2] Computable General Equilibrium (CGE) model of Germany and the rest of the EU. The model is used as a controlled environment to compare the fiscal policies (Freire-González and Ho, 2022). The key building blocks of the model are discussed below.[3]

4.3.1 Production

The model considers the production activities of 22 aggregated industries including energy industries (*ene*) and non-energy industries (*nene*). Importantly, energy industries are assumed to have an oligopoly structure with a small set of identical representative firms competing for the market implying that they have a degree of market power and therefore earn non-zero profits. Non-energy industries operate in perfectly competitive markets, therefore, earn zero profits.

[2]The model includes 50 periods which can be interpreted as years as these are based on annual IO accounts.

[3]The equations of the model are described in detail in Appendix C.1.

All industries are assumed to maximise profits from the production of output by using a combination of labour, capital and intermediate inputs. Capital and labour are country specific whereas intermediates can be either domestically produced or imported following the classical Armington (1969) assumption of imperfect substitution. The demand for intermediates $VR_{r,i,j,t}$ in every time period t by sector j from region r sector i is defined as:

$$VR_{r,i,j,t} = \left(\Psi_{i,j}^{V\ \rho_i^V} \cdot \alpha_{r,i,j}^{ARM} \cdot \frac{pv_{i,t}}{pd_{r,i,t}} \right)^{\frac{1}{1-\rho_i^V}} \cdot V_{i,j,t}. \tag{4.1}$$

In (4.1) $\Psi_{i,j}^{V}$ and $\alpha_{r,i,j}^{ARM}$ are CES productivity and share parameters respectively, $V_{i,j,t}$ is total intermediate use, $pv_{i,t}$ is the Armington composite price of good i and $pd_{r,i,t}$ is the domestic price of intermediates.

4.3.2 Household consumption behaviour and budget constraint

There are two representative aggregated household income groups[4]. Low-income households consist of the 75% of households in Germany with net incomes below €5,000/ month. High-income households consist of the remaining 25% of German households with net incomes exceeding or equal to €5,000/ month[5]. These groups are defined following the convention used in the "Continuous household budget surveys" available on the Federal Statistical Office website, Germany's main statistics collection agency (FSO, 2023b).

[4]The two-group assumption is made for narrative purposes. We expect the general conclusions to hold broadly for further household disaggregations as expenditure patterns are consistent with lower-income households consuming proportionately more energy and energy-intensive goods as demonstrated in Appendix C.2.

[5]The data used excludes households earning over €18,000, self-employed households and homeless households.

Each representative household maximizes the discounted value of time-separable utility functions following Devarajan and Go (1998) so that:

$$U_h = \sum_{t=0}^{\infty} \beta_h^t \cdot u_h(C_{h,t}^H). \tag{4.2}$$

In (4.2), $U_h : \mathbb{R}^\infty \rightarrow \mathbb{R}$ is the intertemporal utility function, $u_h : \mathbb{R}_+ \rightarrow \mathbb{R}$ is the time-separable household utility function, $C_{h,t}^H \in \mathbb{R}_+$ is households' aggregate consumption $h \in (low, high)$ is set for the two household groups low-income (low) and high-income (high) and $\beta_h \in (0,1)$ is a Samuelson (1937) discount factor. The time path of intertemporal consumption and savings is obtained by maximising eq. (4.2) subject to the households' budget constraint (4.3).

$$II_{h,t}^H = uck_t \cdot KS_{h,t}^H + w_t \cdot LS_{h,t}^H + \theta_h^\Pi \cdot \sum_{ene} \Pi_{ene,t} + TR_{h,t}. \tag{4.3}$$

Each household receives a capital income ($KS_{h,t}^H$) at rate (uck_t), wage (w_t) income from labour ($LS_{h,t}^H$) and transfers from the government ($TR_{h,t}$).[6] Crucially, only high-income households receive profits in the form of dividends from energy firms. That is: $\theta_{high}^\Pi = 1$ and $\theta_{low}^\Pi = 0$. Household gross income is taxed by the government at a constant rate.

In each time period, households consume goods and services from the 22 industries. This is represented using a Stone-Geary utility function (Stone, 1954; Geary, 1950) which captures the idea of sustenance consumption of certain necessity goods including energy[7]. Similarly to industries, households can either consume domes-

[6]For simplicity, we assume that wages change proportionately in both groups however, the initial labour endowment implies distinct wages across the groups.

[7]See eq. C.14 in Appendix C.1 for the functional form.

tically produced or imported goods (Armington, 1969) as follows:

$$CD^H_{h,r,i,t} = \left({\Psi^C_{h,i}}^{\rho^V_i} \cdot \alpha^C_{h,r,i} \cdot \frac{pc^T_{h,i,t}}{pd_{r,i,t}} \right)^{\frac{1}{1-\rho^V_i}} \cdot CT^H_{h,i,t}. \tag{4.4}$$

In eq. (4.4), $\Psi^C_{h,i}$ and $\alpha_{h,r,i}$ are CES productivity and share parameters.[8] ρ^V_i is a substitution parameter linked to the Armington elasticity. $CD^H_{h,r,i,t}$ and $CT^H_{h,i,t}$ are household h's consumption of good i from region r and the Armington consumption good for household h sector i. $pc^T_{h,i,t}$ is the Armington price of commodity i for household h and $pd_{r,i,t}$ is sector i's sellers price in region r.

4.3.3 Government

The government receives income from households' income taxes (T_t) and taxes on production ($T^F_{i,t}$).

$$G^Y_t = T_t + \sum_i T^F_{i,t}. \tag{4.5}$$

This income (G^Y_t) is either spent or saved. The government runs a balanced budget in each period, consumes fixed shares of each sector's output (Leontief) and views domestic and foreign goods as imperfect substitutes (Armington, 1969). The government's saving rate is fixed for simplicity.

4.3.4 The labour market

Employment supply is fixed with a pool of unemployed workers. In the short-run the nominal wage is assumed to be fixed. Following this, a wage curve determines an inverse relationship between the real take home wage and the unemployment rate (Blanchflower and Oswald, 1995b).

[8]The region subscript is dropped for simplicity on the right-hand-side.

4.4 Data

4.4.1 Social Accounting Matrices

The structural parameters for the model are based on the industry-by-industry Figaro 2020 input-output tables (Eurostat, 2023). These are aggregated to 22 sectors as displayed in Table 4.1. The Figaro data is supplemented by household saving rates and tax-to-GDP ratios for all EU countries to form the baseline Social Accounting Matrices (SAM). For the household savings rate, the 2020 "Gross household saving rate" for "Households; non-profit institutions" series is used (Eurostat, 2023b). Finally, household tax rates are calculated using the "Total receipts from taxes and social contributions" data (Eurostat, 2023a).

Table 4.1: Sectoral aggregation and ISIC codes (UN, 2008).

Label	**Code**
Agriculture, forestry and fishing	A
Mining and quarrying	B
Manufacture of coke and refined petroleum	C.19
Manufacturing (excluding C.19)	C
Electricity, gas, steam and air conditioning supply	D
Water supply; sewerage, waste management and remediation activities	E
Construction	F
Wholesale and retail trade; repair of motor vehicles and motorcycles	G
Transportation and storage	H
Accommodation and food service activities	I
Information and communication	J
Financial and insurance activities	K
Real estate activities	L
Professional, scientific and technical activities	M
Administrative and support service activities	N
Public administration and defence; compulsory social security	O
Education	P
Human health and social work activities	Q
Arts, entertainment and recreation	R
Other service activities	S
Activities of households as employers; undifferentiated goods- and services...	T
Activities of extraterritorial organizations and bodies	U

Table 4.2: Household Disaggregation

Type	Group	low	high
Income	Gross	48.0%	52.0%
	Capital	33.7%	66.3%
	Labour	41.4%	58.6%
	Profit	0.0%	100.0%
	Transfers	70.5%	29.5%
Expenditure	Consumption	57.0%	43.0%
	Savings	34.2%	65.8%
	Taxes	41.0%	59.0%
Other	Population weight	74.3%	25.7%

low= low-income households, high= high-income households
Calculations based on FSO (2023c)

4.4.2 Household income disaggregation

In order to parameterize the consumption block of the model, the Figaro dataset is disaggregated into the two households groups ('low' and 'high') by calculating shares of average gross income, net income, aggregate consumption, sectoral consumption, employment income, savings and taxes. These shares are used to separate the broad categories (e.g. gross income) into household-specific categories (e.g. gross income for low-income households). Average gross income, net income, aggregate consumption, employment income, savings[9], and taxes are estimated using the 2021 "Continuous household budget survey" (FSO, 2023c). To estimate the low-income group shares, average values in each income group are weighted by the extrapolated household weights provided in the "Continuous household budget surveys" (FSO, 2023b). As capital income is assumed to be proportional to savings in the model, the capital share equals the savings share. Assuming the profit rates and profits shares in energy firms, government transfers to households then act as a balancing element in the SAM. The key data used to define household shares is displayed in Table 4.2.

[9]Savings are defined as net income minus private consumption expenditure.

For sectoral consumption, the 2021 "Continuous household budget survey" is used (FSO, 2023a). The survey contains information on consumption on eleven broad categories. These categories are not all perfectly matched to the ISIC categories in the Figaro data. Therefore, a matching procedure is used to provide information on expected consumption by household and sector. When sectoral consumptions can't be matched, shares are estimated by removing matched category quantities from aggregate private consumption expenditure. The resulting shares then ensure that private consumption per household group is the sum of sectoral consumption for each group. The matched shares are presented in Appendix C.3.

4.4.3 Exogenous parameters

Table 4.3: Parameters

Parameter	Sector	Value	Source
σ_i^V	Agriculture	2.7	Zofio et al. (2020)
	Energy	2.9	
	Manufacturing	1.7	
	Other sectors	2.2	
σ_i^K	All	0.3	Gechert et al. (2022)
Profit share	Energy	$0.3 \cdot K_{r,i,0}$	Assumption
	Non-energy	0	
EIS: $\epsilon_{h,r}$	-	0.1	Yogo (2004)
Sustenance: $\gamma_{h,r,i}^{SG}$	Energy	$0.9 \cdot CT_{low,r,i,0}^H$	Assumption
		$0.8 \cdot CT_{high,r,i,0}^H$	
	Non-energy	$0.8 \cdot CT_{low,r,i,0}^H$	
		$0.8 \cdot CT_{high,r,i,0}^H$	

σ_i^V =Armington (1969) elasticity, σ_i^K= Elasticity of substitution between capital and labour, $K_{r,i,0}$= Initial capital demand by sector i. Households parameters; EIS= Elasticity of intertemporal substitution, $\gamma_{h,r,i}^{SG}$= Stone-Geary sustenance parameter, $CT_{h,r,i,0}^H$= Sector i Armington good for household h.

Four sets of behavioural parameters are imposed exogenously. These are the Armington elasticity of substitution between domestic and foreign goods (σ_i^V) (Armington, 1969), the elasticity of substitution between capital and labour (σ_i^K), the households' elasticity of intertemporal substitution (EIS) and the Stone-Geary sustenance parameters ($\gamma_{h,r,i}^{SG}$) (Stone, 1954; Geary, 1950). An additional assumption is made to calibrate the initial markup on energy price for the oligopolistic model.

The parameter values are reported in Table 4.3. The assumed values for the Stone-Geary sustenance parameters are set to reflect the fact that energy consumption is a necessity good especially for the low-income group. Sensitivity analysis is conducted on all assumed parameters.

4.5 Fiscal policy simulation scenarios

Table 4.4: Summary of Policy Simulation Scenarios

Policy	**Acronym**	**Channel**	**Recipient**
Tax Reduction	TR	Industry energy price	Industries
Untargeted Price Subsidy	UPS	Household energy price	All households
Targeted Price Subsidy	TPS	Household energy price	Lower income households
General Price Subsidy	GPS	Industry and household energy price	All households and industries
Targeted Income Subsidy	TIS	Households' income	Lower income households

To capture the impact of the initial energy price shock we introduce an illustrative 200% increase in the price of imported energy in both Germany and REU. We call this the no fiscal policies scenario (NFP). We then simulate five fiscal policies iteratively based on Sgaravatti et al. (2023) and summarised in Table 4.4.

In all the fiscal policy scenarios the government attempts to mitigate the increase in the energy price for one year using a subsidy τ_t for a total cost of 0.2% of GDP. The policies differ depending on whether they act through the industry energy price, household energy price or households' income, and on whether the direct recipients of the subsidy are industries, all households, low-income households only or both households and industries. The five policies scenarios are simulated under two financing mechanisms as explained in section 4.5.2. The technical implementation of the five policies is discussed in the sections below.

4.5.1 Modelling the policy scenarios

The production tax reduction (TR) policy is introduced according to the following expression:

$$\tau^P_{i,t} = \tau^P_{i,t=0} \cdot (1 - \tau_t \cdot \theta^{ENE}_i). \tag{4.6}$$

In (4.6), $\tau^P_{i,t} < 1$ is the production tax rate in sector i at time t,[10] $\tau^P_{i,t=0} < 1$ is the production tax rate in the baseline. $\theta^{ENE}_i \equiv \frac{\sum_{ene} V_{ene,i,t=0}}{X_{i,t=0}}$ is an index of the energy intermediate good cost $V_{ene,i,t=0}$ to total revenue $X_{i,t=0}$ for each sector introduced to ensure that the government targets tax rate reductions more toward energy-intensive sectors. In this scenario, τ_t is the endogenous tax rate reduction chosen based on the government's objective.

In the second fiscal policy scenario, the government introduces an untargeted energy price subsidy (UPS) to all households. This is modelled as a reduction to the price paid by households for energy.

$$CD^H_{h,r,i,t} = \left({\Psi^C_{h,i}}^{\rho^V_i} \cdot \alpha^C_{h,r,i} \cdot \frac{pc^T_{h,i,t}}{pd_{r,i,t} \cdot (1 - \tau_t \cdot \theta^H_{h,i})} \right)^{\frac{1}{1-\rho^V_i}} \cdot CT^H_{h,i,t}. \tag{4.7}$$

To simulate this, eq. (4.7) amends (4.4) to include a dummy $\theta^H_{h,i} \in [0, 1]$ which defines whether a household is eligible for a subsidy and whether the sector is an energy sector. In the UPS scenario, all households' groups receive the price

[10] In cases where the government subsidizes sectors, the sign of θ^{ENE}_i is reversed such that the policy increases the subsidy.

subsidy hence, $\theta^H_{h,ene} = 1$. In this scenario, τ_t is the percentage reduction in the household energy price chosen based on the government's objective.

In the targeted price subsidy (TPS) scenario we use the same expression used for the UPS (eq. 4.7) but set $\theta^H_{high,ene} = 0$ and $\theta^H_{low,ene} = 1$ so that the subsidy is only given to the low-income household group. In both TPS and UPS, the calculation of the CPI is adjusted to include the subsidized energy price.

The general energy price subsidy (GPS) is targeted to both firms and all households. For households we use eq. (4.7) again with $\theta^H_{h,ene} = 1$. An analogous equation for firm consumption is then introduced by amending eq. (4.1) as follows:

$$VR_{r,i,j,t} = \left({\Psi^V_{i,j}}^{\rho^V_i} \cdot \alpha^{ARM}_{r,i,j} \cdot \frac{pv_{i,t}}{pd_{r,i,t} \cdot (1 - \tau_t \cdot \theta^{GPS}_i)} \right)^{\frac{1}{1-\rho^V_i}} \cdot V_{i,j,t}. \tag{4.8}$$

In eq. (4.8), θ^{GPS}_i is a dummy defining whether sector i is an energy sector and $\theta^{GPS}_{ene} = 1$ and $\theta^{GPS}_{nene} = 0$. In the GPS, τ_t is the percentage reduction in the price of energy households and firms pay.

$$pv_{i,t} = \frac{\sum_{r,j} pd_{r,i,t} \cdot VR_{r,i,j,t} \cdot (1 - \tau_t \cdot \theta^{GPS}_i)}{\sum_j V_{i,j,t}}. \tag{4.9}$$

As $pv_{i,t}$ is influenced by the price subsidy, the intermediate good price index is modified to eq. (4.9).

Additionally, we assume that τ_t is equal for both household and firm subsidies. This ensures that the per unit energy price subsidy is identical regardless of the energy consumer.

Finally, the targeted income subsidy (TIS) is introduced by supplementing the 'low' household group's budget with an additional subsidy as follows:

$$II_{h,t}^{H} = uck_t \cdot KS_{h,t}^{H} + w_t \cdot LS_{h,t}^{H} + \theta_h^{\Pi} \cdot \sum_i \Pi_{i,t} + TR_{h,t} + \theta_h^{\Delta} \cdot \Delta_t. \tag{4.10}$$

Eq. (4.10) is an extension of eq. (4.3) where θ_h^{Δ} is a dummy capturing whether a household receives the income subsidy. $\theta_{low}^{\Delta} = 1$ and $\theta_{high}^{\Delta} = 0$. $\Delta_t \in \mathbb{R}_+$ is the lump sum transfer sent to low-income households in the period following the shock. As low-income households have high marginal utilities of consumption following unexpected payments (Agarwal et al., 2007; Parker et al., 2013), we assume that the marginal propensity to consume from the TIS is 1.[11]

4.5.2 Financing the fiscal policies

To gather funds for the fiscal policies, we assume that the government has two options. First, it can borrow at an interest rate ir. This is the risk-free interest rate assumed in the baseline. It is equal to the user cost of capital minus the depreciation rate. Alternatively, the government can use a combination of debt financing and a one-time windfall tax on excess profits of the energy companies following the shock to finance the expenditure side fiscal policies. Given that we are interested in the welfare implications of the policies under the two funding mechanisms we repeat the simulation of the five fiscal policies under the two financing options.

[11] We discuss the implications of this assumption in Section 4.7.

Debt financing

For the debt-financed revenue side fiscal policy, the government can borrow at ir during the first year following the shock and then repay this in the following 25 years by running a balanced budget and reducing spending.

$$\begin{aligned} G_t^Y &= T_t + \sum_i T_{i,t}^F - ir \cdot D_t^G - B_t, \\ D_t^G &= D_{t-1}^G - B_t, \\ B_t &= \frac{D_{t=1}^G}{dur}. \end{aligned} \tag{4.11}$$

Eq. (4.11) extends eq. (4.5) to capture interest payments and debt repayments. $D_t^G \in \mathbb{R}_+$ is the amount of additional debt accumulated by the government in period t. $B_t \in \mathbb{R}_+$ is the yearly debt payment. $dur \in \mathbb{N}_+$ is the number of periods the government will be repaying the debt and it is set to 25 years.

Windfall tax financing

The government can choose to accompany the debt financing with a windfall tax on the excess profits of energy firms. In this case the windfall tax revenue, $T_{t=1}^w \in \mathbb{R}_+$, is added to the government's budged eq. (4.11):

$$G_t^Y = T_t + \sum_i T_{i,t}^F - ir \cdot D_t^G - B_t + T_{t=1}^w. \tag{4.12}$$

In eq. (4.12), $T_{t=1}^w \in \mathbb{R}_+$ is the total amount of windfall tax revenue collected in period 1.

$$T_{t=1}^w = \sum_{ene} (RT_{ene,t=1} - RT_{ene,t=0}) \cdot \tau_{t=1}^{WT}. \tag{4.13}$$

Windfall tax revenue is defined in eq. (4.13) where $\tau_{t=1}^{WT} \in [0, 1]$ is the windfall tax rate set by the government on energy firms. The windfall tax rate is set to 90%

which is equal to the rate set in Germany for electricity.[12] Recall that this revenue is collected from high-income households only.[13]

4.5.3 Welfare

To compare the welfare implications of the five fiscal policies, we define intertemporal welfare as the discounted sum of intratemporal welfare. This is done using a welfarist approach (Sen, 1970; Boadway and Keen, 1999) whereby welfare is defined as the sum of households' utility from the consumption of both private and public goods.

$$U_{T,t} = (1 - \gamma_g) \cdot \sum_h \gamma_h \cdot u_h(C^H_{h,t}) + \gamma_g \cdot v(G_t). \tag{4.14}$$

In eq. (4.14), $\gamma_h \in (0, 1]$ is a population weight for household group h defined such that $\sum_h \gamma_h = 1$. $v(G_t)$ is the utility of public consumption for both households. γ_g is the weight placed on public good utility relative to private good utility. It is set equal to 0.42 in the baseline following Schram and van Winden (1989).

[12] This choice is made for narrative purposes and has no impact on the stylised results of the paper.

[13] We assume that energy companies are owned by domestic high-income households only.

4.6 Results

4.6.1 No fiscal policy scenario

Results from simulations are reported in Table 4.5 for the German case.[14] Following the 200% increase in the imported energy price, firms and households decrease their purchases of foreign energy and increase their demand for domestic and REU energy. This leads to crowding out of domestic and European energy supply so that the energy price increases by 23%.

Table 4.5: Aggregate Results

Variable	% change
Consumer price index	2.7
Energy price index	23.0
Non-energy price index	0.5
Output	-1.1
Energy Output	-2.5
Non-energy Output	-1.0

Short-run % deviations from baseline of key variables.

Average household energy consumption decreases by close to 3%. This is the result of a 2.9% increase in domestic demand and a 5.4% and 35.1% reduction in REU and ROW demand respectively. Industries increase their demand for domestic energy relative to ROW and REU energy as well. Overall, however, production costs increase and the demand for intermediate inputs, including energy, falls.

Domestic energy firms face more pressure to satisfy domestic demand both from households and from other firms. Sectors that are highly reliant on energy imports from the rest of the World (ROW) such as manufacturing of refined petroleum sharply increase their price by 59.1% whilst reducing output by 11.5%. On the

[14] Results for the rest of EU as an aggregate are comparatively similar to the German case, thus omitted for sake of brevity.

other hand, mining and quarrying, which has a more domestic supply chain, increases both output and prices by 68.8% and 58.4% respectively.

With higher domestic production costs, firms in most non-energy sectors decrease their demand for capital and labour. Hence, on aggregate output falls by 1.1%. Simultaneously, the consumer price index increases by 3.2% overall, mainly driven by energy price inflation. This reduces households' income and purchasing power.

The adverse aggregate consequences are not distributed evenly across household income groups as it has also been found by Celasun et al. (2022); Guan et al. (2023); Perdana et al. (2022) and Turner et al. (2022) amongst others. This is for two reasons. Firstly, low-income households spend a higher proportion of their income on energy and are closer to their sustenance levels of energy consumption so that energy consumption falls only by 2.64% depleting their disposable income for non-energy consumption. In contrast, high-income households are much further away from their sustenance levels and are able to reduce energy consumption by 4.57%. This asymmetric response across household types means that low-income households have less disposable income for non-energy consumption than high-income households.

Table 4.6: Household Results

Category	Low-income	High-income
Consumer price index	2.76	2.55
Real household income	-1.39	-1.15
Consumption	-1.63	-0.72
Energy consumption	-2.64	-4.57
Non-energy consumption	-1.54	-0.47
Real household savings	-0.89	-1.53

Short-run % deviations from trend of household variables

Secondly, high-income households reap the benefits of a 14.8% increase in energy firm profits. Payments of energy firm dividends to high-income households partly mitigate the reduction in gross income of high-income households which falls by 1.15% compared with the average household income reduction of 1.27%. Low-income households do not own shares in the energy companies and thus receive no benefits from the increasing profits. Hence, their income falls by 1.39%.

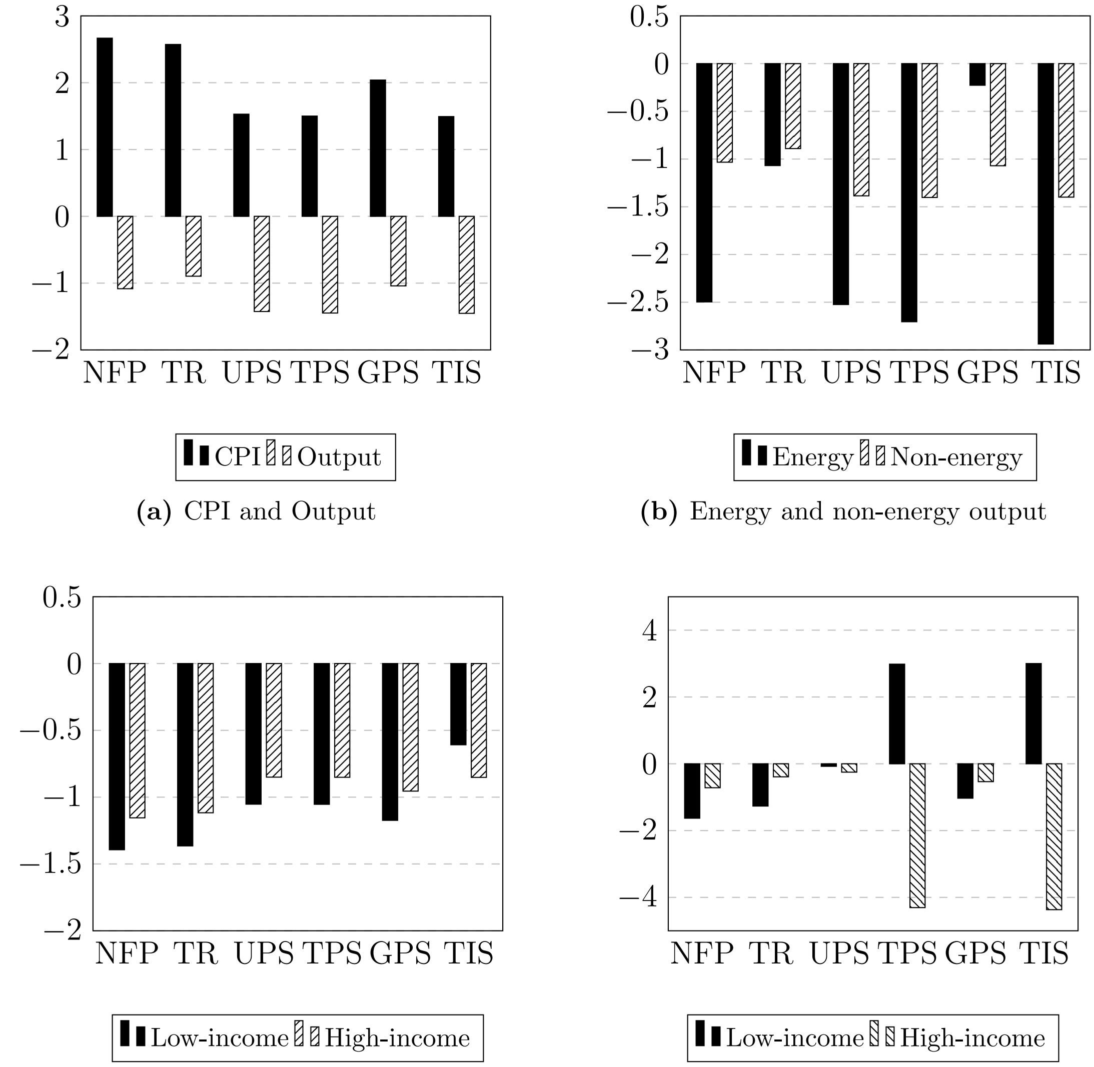
Overall, in the absence of a fiscal policy intervention, gross output falls whilst prices rise, a result consistent with other recent papers (Celasun et al., 2022; Guan et al., 2023; Perdana et al., 2022; Turner et al., 2022) and empirical observations (Eurostat, 2023b,a).

4.6.2 Debt financed policies

Following the energy shock, as discussed in Section 4.5, the government may choose to implement one of the following five fiscal policies: energy tax reduction (TR), untargeted and targeted price subsidies (UPS, TPS), general price subsidies (GPS) and targeted income subsidies (TIS).

Results from the simulated policies are summarised in Figure 4.1 for the debt-financed case.

We begin by discussing the impact of the five policies on aggregate output and CPI. As can be seen from panel a, Figure 4.1, the TR generates the greatest output recovery. In fact, in this scenario output recovers by 17.7% of the distance between the pre-shock equilibrium and the no fiscal policy scenario. The next closest aggregate output recovery is by 4.0% for the GPS. Both policies reduce the marginal cost of production by lowering energy costs proportionately to the pre-shock intermediate energy use. This stimulates demand and leads to a recovery in output.



(a) CPI and Output (b) Energy and non-energy output

(c) Real household income (d) Consumption

Figure 4.1: Short-run % deviations from a no-shock baseline for debt-financed policies; NFP = no fiscal policy, TR = firm tax reduction, UPS = untargeted price subsidy, TPS = targeted price subsidy, GPS = general price subsidy, TIS = targeted income subsidy.

The recovery is greater in the TR since this policy targets industries only whereas the GPS targets both industries and households. Interestingly, the output recovery of energy industries is greater for the GPS as can be seen in panel b, Figure 4.1. This is driven by the fact that both industries and households benefit from reduced energy prices both directly and indirectly in terms of energy embodied in production.

The policies targeted directly at households (UPS, TPS and TIS) slightly exacerbate the contraction in output compared to the no fiscal policy (NFP) scenario. This is explained by domestic households crowding out domestic energy and non-energy markets. Specifically, as households pay lower prices for energy compared to firms, more energy and non-energy goods are consumed as final demand rather than purchased as intermediate inputs. This puts upward pressure on energy prices and exacerbates the negative impact of the initial energy price shock.

All policies reduce the CPI, compared with no fiscal policy. UPS, TPS and TIS reduce the CPI by approximately 1.5 pp. Recall that these policies reduce directly the price of energy paid by households. The GPS reduce the CPI by over 0.6 pp by simultaneously targeting the households and industry energy price. The least disinflationary policy is the TR which achieves a reduction in inflation slightly under 0.1 pp but does not target households directly.

The aggregate output and CPI results would suggest that acting through the households' energy price is more effective at reducing the CPI whereas targeting the industry energy price achieves a greater recovery, with GPS achieving a good combination of both. If governments were not concerned about distributional impacts they may prefer GPS as it achieves a balanced outcome. However, a closer inspection of distributional impacts reveals a partly different story.

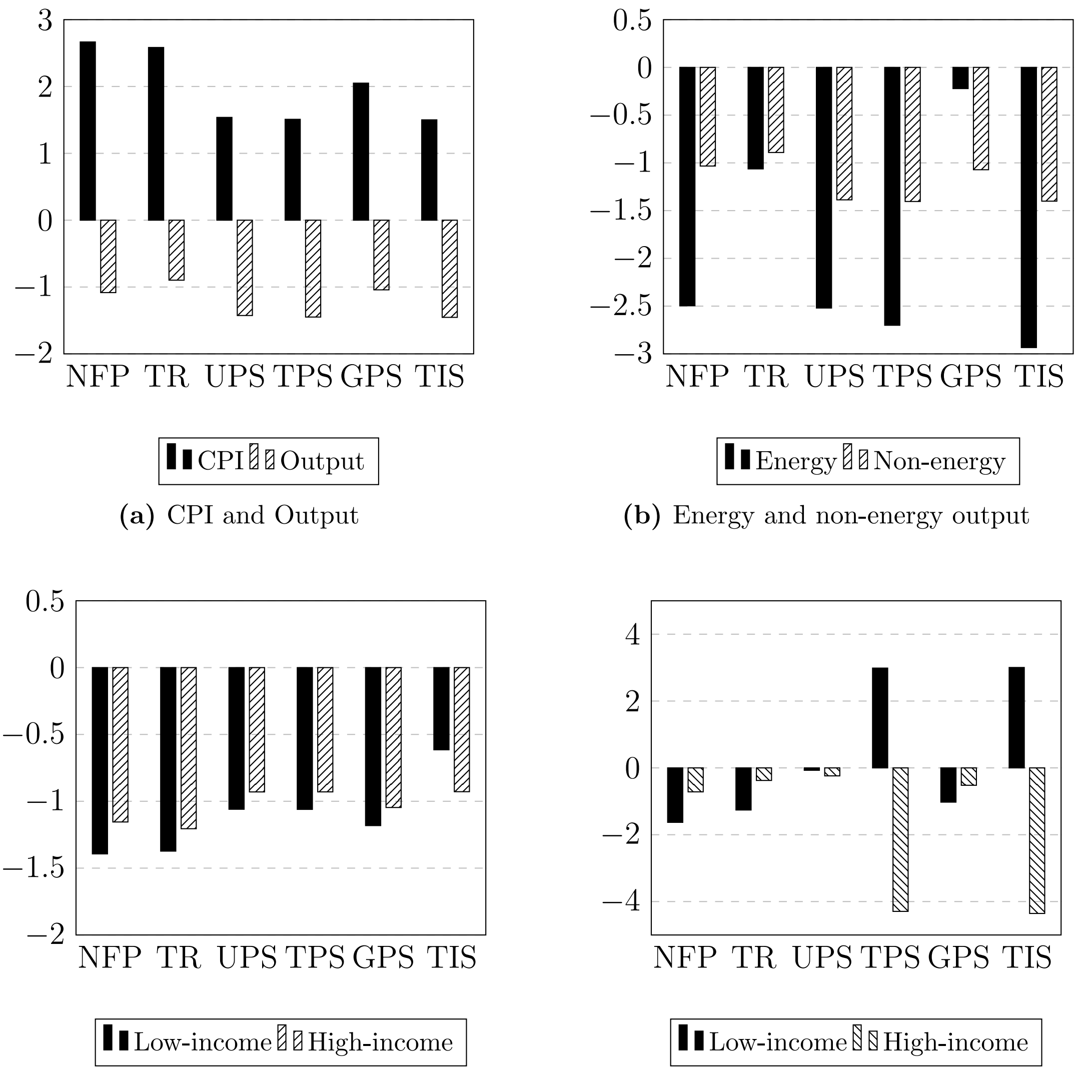
Panel c, Figure 4.1 presents real income by household group for each of the policies. The only policy that fully reverses the regressive effects of the initial energy shock is the TIS. This is since, unlike the price subsidies, this policy acts through income rather than the price of energy. As a result, although its effects on consumption are comparable to the TPS, its implications for real household income are very different. All policies except the TIS do little to address real income inequality. This is because none are designed to work through household incomes. Thus, the initial regressive effects on real household incomes of the energy price shock are mitigated but not reversed by the TR, UPS, TPS and GPS.

Panel d, Figure 4.1 summarises the short-run aggregate consumption by household group under each of the policies. The TR has relatively weak effects and only increases consumption by around 0.35 pp for both household groups. The GPS also has a relatively weak effect on consumption, and although it does not reverse the initial regressive outcome of the energy price shock it achieves a more progressive outcome than the TR. The UPS leads to much stronger consumption recoveries in both groups as consumption increases by around 0.5 and 1.5 pp respectively in the high-income and low-income consumption groups under both forms of financing. Despite the fact that the UPS is not targeted at low-income households, it entirely reverses the short-run regressive effect of the initial energy shock.

As is expected, the low-income household targeted policies have much greater redistributive effects on consumption than the untargeted policies. Indeed both the TPS and TIS fully reverse the regressive effects of the energy shock driving low-income households' consumption up by close to 3 pp relative to a no shock baseline whilst reducing high-income households' consumption by over 4 pp relative to a no shock baseline. This result demonstrates the effectiveness of these targeted policies at redistributing the losses from the energy shock. It also shows that this may lead to excessive redistribution towards the lower income households.

4.6.3 Windfall tax financed policies

In the windfall tax scenarios, between 18% and 21% of the funding for the five policies is financed by windfall taxes.[15] Figure 4.2 presents the results from the scenarios.



(a) CPI and Output

(b) Energy and non-energy output

(c) Real household income

(d) Consumption

Figure 4.2: Short-run % deviations from no-shock baseline of debt and windfall tax financed policies; NFP = no fiscal policy, TR = firm tax reduction, UPS = untargeted price subsidy, TPS = targeted price subsidy, GPS = general price subsidy, TIS = targeted income subsidy.

[15]Profits are endogenous and depend on energy but they are taxed at a fixed rate. For this reason the actual amount of tax funded policies varies depending on the policy.

The aggregate results of the purely debt-financed and partially windfall tax financed policies are very similar. In facts, the ranking of the policies in terms of impacts on output, CPI and redistribution are unchanged. The impact of the policies on output recovery and CPI is marginally smaller when the policies are financed by both windfall taxes and debt. Differences in household outcomes are more noticeable. Real household income of high-income households decreases by between 0.08 and 0.09 pp compared with purely debt-financed policies whereas that of low-income households decreases by less than 0.01 pp. Consumption of high-income households also falls proportionally more than that of low-income households. This is consistent with the fact that the windfall tax directly redistributes income from high-income households to low-income households.

Crucially, windfall taxation has relevant consequences for long-run impacts given that it is both an intertemporal and intratemporal redistributive policy whereas pure debt financing is an intertemporal redistributive policy exclusively. We discuss this more in detail in the following Section.

4.6.4 Welfare

To allow for a comparison of the policies that takes into account both the short-run benefits of the policies and the intertemporal costs through debt repayments and the effects of the policies we calculate welfare for all the policies according to expression 4.14. This is presented in Figure 4.3.[16]

From the Figure, it is clear that the TIS and TPS are the best policies given the welfare definition. This is expected as these policies drive the largest consumption redistributions. Since the marginal utility of consumption of low-income house-

[16]Welfare is normalised such that no fiscal policy is equal to 0 and the best policy equals 1.

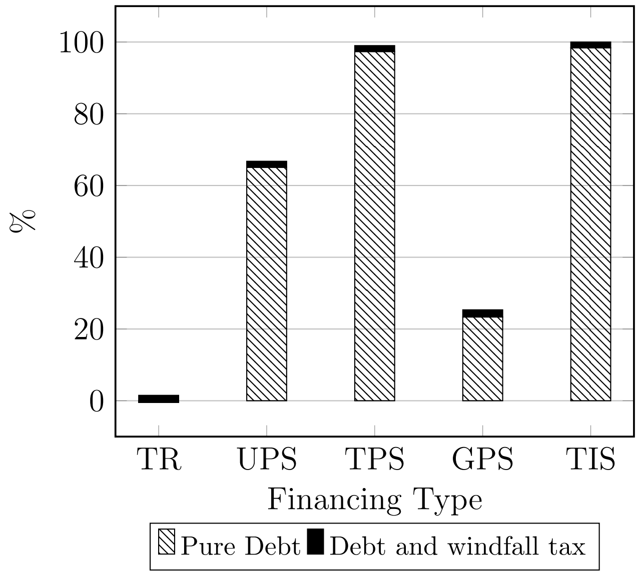


Figure 4.3: welfare under policies and financing when $\gamma_g = 0.42$; TR = firm tax reduction, UPS = untargeted price subsidy, TPS = targeted price subsidy, GPS = general price subsidy, TIS = targeted income subsidy.

holds is higher than that of high-income households, the redistributive policies lead to large increases in welfare. The UPS improves welfare by around 65% compared to the no fiscal policy scenario and the TIS under debt financing. This welfare improvement is relatively strong given that the UPS has no direct redistributive effects. In comparison, the GPS and TR lead to a 23% increase and a -0.5% decrease in welfare under debt financing. This result suggests that these policies are relatively ineffective at supporting households during energy shocks.

Importantly, whilst the ranking of the policies is identical, welfare is improved for all policies if windfall taxes are employed as long as the relative weight on the public good $\gamma_G \geq 0.14$, as presented in Table 4.7. The reasons for this are two-fold. First, windfall taxation leads to a direct redistribution of resources under all policies. As a result, regressive effects are counteracted under windfall taxation. Second, the financing collected through windfall taxation has no intertemporal cost to the government. Thus the government will need to repay a smaller debt and can afford a higher public good provision in the following periods. This implies that, as long as households value the provision of public goods sufficiently and even when the interest rate on debt is low, windfall taxation is preferable to debt financing.

Table 4.7: Public Good Critical Values

Policy	Debt preferred	Indifferent	Windfall tax preferred
Tax Reduction (TR)	$\gamma_g < 0.13$	$\gamma_g = 0.13$	$\gamma_g > 0.13$
Untargeted Price Subsidy (UPS)	$\gamma_g < 0.14$	$\gamma_g = 0.14$	$\gamma_g > 0.14$
Targeted Price Subsidy (TPS)	$\gamma_g < 0.14$	$\gamma_g = 0.14$	$\gamma_g > 0.14$
General Price Subsidy (GPS)	$\gamma_g < 0.13$	$\gamma_g = 0.13$	$\gamma_g > 0.13$
Targeted Income Subsidy (TIS)	$\gamma_g < 0.14$	$\gamma_g = 0.14$	$\gamma_g > 0.14$

Critical value of the government weight parameter in the Welfare function

4.7 Summary and sensitivity analysis

We summarise the key results of our simulation in Table 4.8 and the rank of the policies to show their effectiveness at increasing gross output, reducing the CPI, improving consumption distribution and increasing welfare compared to a situation where no fiscal policies are implemented.

Table 4.8: Policy Ranking

Policy	Output	CPI	Distribution	Welfare
Tax reduction (TR)	1	5	5	5
Untargeted price subsidy (UPS)	3	3	3	3
Targeted price subsidy (TPS)	4	2	2	2
General price subsidy (GPS)	2	4	4	4
Targeted income subsidy (TIS)	5	1	1	1

Rank of the policies for each target compared to no policy scenario

The second column in Table 4.8 shows that supply-side policies that affect the industry energy price directly (tax reductions and general price subsidies) are more effective at mitigating output losses. Energy firms in Germany are relatively upstream[17] and the reduction in cost of energy used in production driven by the supply side policies is passed more to the other industries than to consumers. On the other hand, the third column in Table 4.8 shows that demand-side policies (untargeted price subsidy, targeted price subsidy and targeted income subsidy) are more effective at lowering the CPI. We also note that the CPI ranking is the reverse of the output ranking for all policies. Thus, although all policies reduce the CPI compared to a situation where no policies are implemented, the increase in output acts in the opposite direction. Hence, in the central case, demand-side policies reduce CPI more than supply-side policies.

The fourth and fifth columns in Table 4.8 show that the policies targeted at low-income households counteract adverse consumption distribution effects most effectively and improve long-run welfare outcomes more than all other policies. Although TISs are ranked first for distributional and welfare outcomes, the effectiveness of these policies is dependent on a high marginal propensity to consume out of the unexpected subsidy. Finally, the rankings are unaffected by whether the policies are purely financed by government debt or by a combination of government debt and windfall taxation.

We test the sensitivity of our results to the assumed values for the Stone-Geary sustenance parameter and the profit share for energy industries reported in Table 4.3. For the Stone-Geary parameter, we explore the limiting case where the sustenance parameter is set to 0 for all households[18] and the case where the intra-temporal utility function is a Leontief.[19] When the sustenance parameter is set to

[17]We have calculated the upstreamness index according to Antràs et al. (2012). Out of 22 aggregated industries Coke and refined petroleum, Electricity, gas stream and air conditioning supply have the 12^{th},17^{th} and 22^{nd} highest upstreamness respectively.

[18]Implying a Cobb-Douglas intra-temporal utility function.

[19]See full results in Figures C.2 and C.3.

0 for all households the utility function reduces to a Cobb-Douglas which implies an elasticity of substitution of 1. In this case, the demand-side policies become more expansionary than the supply-side policies and therefore less effective at lowering the CPI. With a high elasticity of substitution and no constraint to maintain a sustenance level of energy consumption, households substitute energy with non-energy goods and this drives a strong recovery for non-energy industries. It is important to note that such high elasticity is unlikely to be realistic in the short run, especially for low-income households. Despite this, the ranking of the policies in terms of distributional outcome and welfare is unaffected by the change in this parameter. Setting the utility function to Leontief implies an elasticity of substitution of 0. In this case, none of the rankings change.

To test the sensitivity of our results to the initial value of profit shares we test the consistency of the results under higher and lower profit shares. As can be seen from the results presented in Appendix C,[20] this has no impact on the rankings. However, we note that the welfare impacts of windfall taxation are positively related to the size of the initial profit share.

Finally, in our modelling of debt policies, we assumed that governments borrow at a riskless rate. Under higher sovereign default risks, we may expect interest rates on government debt to increase. Thus, we expect that the windfall tax will become relatively more attractive the higher the initial sovereign default risk is.

[20]See Figures C.5 and C.6 for results under lower and higher profit rates.

4.8 Conclusion

In this chapter, we assess the short-run aggregate and distributional implications as well as the long-run welfare effects of a set of fiscal policies used to respond to energy price shocks. A 2-region dynamic CGE model is used to capture the impact of these policies using Germany as an illustrative example. A shock to the price of imported energy is introduced and the government is assumed to have a fixed budget available for all policies aimed at counteracting this initial shock. This budget could be financed through debt or a combination of debt and windfall taxation.

Using this model, we find that targeted policies such as targeted income subsidies (TIS) and targeted price subsidies (TPS) best address inflation, distributional and long-run welfare outcomes. Indeed, TIS and TPS entirely reversed the regressive effects of the initial energy shock and increased long-run welfare much more than the general price subsidy (GPS), untargeted price subsidy (UPS) and tax reduction (TR). Although the TIS and TPS counteract the regressive effects of the energy shock effectively, these have crowding out effects on output due to the additional pressure that households demand puts on domestic energy industries. Supply-side policies such as GPS and TR are less effective at reducing the consumer price index and achieve a lower welfare. However, these policies are more effective in reversing output losses.

Importantly, the ranking of policies does not change when windfall tax financing is introduced. However, with windfall taxation welfare is improved as long as households care sufficiently about public good provision or interest rates on debt are not risk-free and this is achieved with a relatively small cost on aggregate output. This result holds even when government debt is riskless and when consumers value public good provision very little. The fact that the aggregate output impacts and inflationary impacts are only slightly lower under windfall taxation implies that the redistribution has expansionary effects itself as lower-income households have a higher marginal propensity to consume than high-income households.

From a policy perspective, if governments are concerned about output recovery, supply-side policies such as TR and GPS should be preferred. A combination of such policies should provide the government's desired output inflation trade-off. However, if the priority is income equality and welfare, demand-side policies should be preferred. Targeted policies are especially effective as with relatively low debt and or windfall tax financing, these can entirely reverse the regressive effects of energy shocks.[21] These should however be carefully chosen so as not to crowd out the consumption of non-targeted groups.

If possible, governments could also use windfall tax financing to supplement their budgets as this is welfare-enhancing for all policies considered as long as households value public good provision a bit. Even in the absence of public good utility, windfall taxation may be preferred if governments pay more than a riskless rate on debt and/or if energy firm profits are owned by foreign households.

Results presented in this chapter provide a starting point for governments of countries with similar dependence on imported energy. However, economic structure may play an important role in defining what policies are ultimately better for any specific country. The methods used are directly applicable to other countries, provided that similar data is available. Future research should consider the replication of this analysis using a different set of countries to consider the extent to which economic structure drives the impact of the fiscal policies. Further research may also consider comparing the environmental implications of the policies.

[21] Targeted policies may be difficult to implement especially in a short time period due to lack of information.

Chapter 5

The UK Wage Curve Puzzle. Has the Wage Curve flattened since the Global Financial Crisis?

5.1 Introduction

This thesis aims to develop and apply methods to capture household behaviours and decisions better. While previous chapters have focused on intertemporal and intratemporal consumption modelling, this chapter extends beyond consumption modelling to consider labour market behaviour through the lens of the theory of the wage curve. Although consumption is the largest component of GDP, labour markets are key determinants of economies' production capacity and understanding the real wage - unemployment nexus is crucial to the solutions of general equilibrium models.

The wage curve refers to the empirically observed negative relationship between real wages and unemployment rates (Blanchflower and Oswald, 2017). It was considered an "empirical law of economics" (Card, 1995, p.25) upon the release of Blanchflower & Oswald's influential The Wage Curve textbook. This is because the relationship was stable over time and across many countries including the UK where the long-run unemployment elasticity of wages was negative with a value around -0.1.

Since the Global Financial Crisis, disruptions to the real wage - unemployment nexus have become increasingly apparent. Evidence suggests that the relationship between wages and unemployment rates has flattened in the US and in many developed countries (Barnichon and Mesters, 2021; Ball and Mazumder, 2011; Galí and Gambetti, 2019; Negro et al., 2020; Blanchflower et al., 2024). Despite this evidence, there is limited research evaluating how the UK wage curve may have changed following the financial crisis.

This chapter fills the gap in the literature by examining the real wage – unemployment relationship in the UK between 1992 and 2019. Yearly and monthly UK wage curves are estimated using the Bell et al. (2002) two-stage aggregation bias correction method and two separate datasets; namely the combined British Household Panel Survey & Understanding Society datasets[1] and the Annual Population Survey (APS) dataset. The analysis dissects pre- and post-financial crisis sub-periods to determine how the slope of the wage curve changed over time.

Evidence from 1992 to 2019 suggests that the yearly wage curve may have flattened. The long-run unemployment elasticity of wages ranges from -0.04 to -0.01 and is imprecisely estimated. Evidence from the monthly wage curve estimates between 2005 and 2019 using APS data suggests that the long-run unemployment elasticity of wages is zero or even positive. Some of this chapter's evidence suggests that the flattening of the wage curve may be driven by a structural change coinciding with the financial crisis as post-financial crisis unemployment elasticities of wages are lower for most results summarised. The evidence is not conclusive as many differences estimated are not statistically different from zero. Contrary to evidence from the US (Blanchflower et al., 2024), neither discouraged workers nor underemployed workers are driving the change in the unemployment elasticity of wages.

Crucially, the flattening of the slope of the wage curve has substantive implications for general equilibrium predictions. Increasing the long-run unemployment elasticity of wages from -0.1 to values close to 0 implies much stickier wages and much larger changes in unemployment. Consequently, output deviations following shocks more than double in magnitude. In such cases, the impacts of trade shocks

[1] These will collectively be labelled UKHLS.

such as Brexit, may be much larger for the UK than predicted under unemployment elasticities of -0.1.

The rest of this chapter is structured as follows: Section 5.2 summarises theory and literature related to the wage curve; Section 5.3 describes the methods employed to estimate the unemployment elasticity of wages; Section 5.4 explains the data used; Section 5.5 presents the results of the wage curve estimation between 1992 and 2019; Section 5.6 provides analysis of the wage curve across sub-periods; Section 5.7 tests potential explanations for the flattening of the wage curve; Section 5.8 demonstrates how the new wage curve estimates influence General Equilibrium (GE) modelling results; Section 5.9 concludes the chapter.

5.2 Theory and related literature

5.2.1 Theory

The wage curve started as an empirical relationship however, Blanchflower and Oswald (1995a) provide two main theoretical foundations for the model which have gained support in the broader literature. These are an efficiency wage model using a Shapiro and Stiglitz (1984) style no-shirking condition and a bargaining and competition model based on a Nash bargaining problem.[2]

Blanchflower and Oswald (1995a) suggest that the relationship between real wage and unemployment is bi-directional and should not be interpreted as causal. The efficiency wage model is built on a no-shirking condition. In regions with higher unemployment rates, the wage required to dissuade workers from shirking is lower

[2]These are derived and described in detail in Blanchflower and Oswald (1995a) pages 37-98. Note that the "labor contract model" built on the ideas of Baily (1974) and Azariadis (1975) is not included as it relies on the assumption that employment is the inverse of unemployment; an assumption which has been more scrutinised (Card, 1995).

than in low-unemployment regions. This argument implies a downward-sloping wage curve. The bargaining model builds on a Nash bargaining problem in which employers and employees each have a degree of wage-setting power. As regional unemployment rates increase, wage-setting power shifts towards employers implying a downward-sloping wage curve.

5.2.2 Related literature

Before Blanchflower and Oswald (1995a), Adam Smith's compensating differentials theory prevailed as the leading theory explaining the real wage - unemployment relationship.[3] The principle argument of compensating differentials is that higher unemployment rates should be offset by higher expected real wages to attract workers to a given region. This would imply a positive relationship between real wages and unemployment rates. This view is supported by seminal works in the 1970s, by Harris and Todaro (1970), Hall et al. (1970), Hall (1972), and Reza (1978). Harris and Todaro (1970) develop a rural-urban migration model, predicting compensating differentials in developing countries while Hall et al. (1970), Hall (1972) and Reza (1978) find modest evidence of an upward-sloping relationship between wages and unemployment in US cities.

In the late 1980s, a series of influential studies, notably synthesized in Blanchflower and Oswald (1995a), challenge the empirical validity of the compensating differential theory in regional wage and unemployment dynamics. Authors such as Blackaby and Manning (1987, 1990b,a,c, 1992), Card (1990), Freeman (1988), Holmlund and Skedinger (1988), Pissarides and McMaster (1990), Bartik (1991), Eberts and Stone (1992), and Blanchard and Katz (1992) all find evidence contradicting the theory of compensating differentials. A notable methodological in-

[3] See Dorman (1996) for discussion on Adam Smith's compensating differentials theory.

novation occurs in this period as many authors employ microeconomic data. This empirical shift, detailed in Blanchflower and Oswald (1995a), is widely embraced as the wage curve's estimated slope across many developed countries is approximately -0.1, signalling a significant departure from compensating differentials in the literature.

Table 5.1: Key Literature

Key Literature	**Dataset**	**Sample**	ε
Blackaby and Manning (1990a)	GHS	1975-1982	-
Blackaby and Manning (1990b)	NES	1970-1986	-
Blanchflower and Oswald (1994)	GHS	1973-1990	-0.09
Collier (2000)	BHPS	1991-1998	-0.1
Bell et al. (2002)	NES	1976–1997	-0.11
Johnes (2007)	BHPS	1992-2003	-0.05
Longhi (2012)	QLFS	1997-2006	-0.04
Brown and Taylor (2015)	BHPS	1992-2008	-0.04

$\varepsilon :=$ unemployment elasticity of wages

Selected estimates of the UK unemployment elasticity of wages (ε) are summarised in Table 5.1. In the UK, Blackaby and Manning (1990a,b) provide early evidence of a negative relationship between regional earnings and unemployment rates, although a formal wage curve is not established. Blanchflower and Oswald (1994) formalise this by estimating the unemployment elasticity of wages in the UK at approximately -0.09, using microeconomic data from the General Household Survey (GHS). However, concerns about potential aggregation bias prompt methodological developments.

Developments are proposed by Collier (2000) and Johnes (2007) who both employ the British Household Panel Survey (BHPS). Collier (2000) argues that the inclusion of individual fixed effects alleviates some of the aggregation bias, reporting a -0.14 unemployment elasticity of wages for males and a much lower unemployment elasticity for females. Johnes (2007) proposes an aggregation bias correction through a random-effects model. This yields volatile and imprecise unemployment elasticity estimates of approximately -0.05. As the random-effects estimator relies on the unlikely-to-hold assumption that the independent variables are uncorrelated with the individual unobserved heterogeneity, the method is not widely adopted. Instead, Bell et al. (2002) prevail as the gold standard in controlling for aggregation bias. Using a two-stage approach and the New Earnings Survey (NES), Bell et al. (2002) estimate an unemployment elasticity of wages of approximately -0.11.

Bell et al's. (2002) method is employed in more recent studies by Longhi (2012) and Brown and Taylor (2015). Longhi (2012) uses Quarterly Labour Force Survey data between 1995 and 2006, finding evidence that the wage curve is robust to alternative definitions of job competition (e.g. labour market tightness and sector-specific unemployment rates). However, the estimated unemployment elasticity of wages is closer to -0.04. On the other hand, Brown and Taylor (2015) estimate a reservation wage curve for the UK between 1991 and 2008, indicating an unemployment elasticity of reservation wages between -0.03 and -0.05.

Recent research has documented a flattening of both the price and wage Phillips curves in the United States. Barnichon and Mesters (2021) employs an instrumental variable method on quarterly data from 1975 to 2007, revealing decreasing Phillips multipliers in the US and the UK. The reduction in the Phillips multiplier occurs between 1990-2007 which coincides with evidence of a flatter wage curve in the UK (Johnes, 2007; Longhi, 2012; Brown and Taylor, 2015). A flatter US price Phillips curve is also observed by Ball and Mazumder (2011), using a model allowing for a time-varying slope between 1985 and 2010. This evidence is supported by Negro et al. (2020) and Galí and Gambetti (2019) who both identify a flattening in the US Phillips curve post-2007. Importantly, Galí and Gambetti

(2019) observe this flattening using a wage Phillips curve, emphasising a shift in wage-unemployment dynamics following the financial crisis.

Extending research on post-crisis labour markets, Blanchflower et al. (2024) estimate a US wage curve for 2008-2020 and find that unemployment rates are no longer a key factor in wage determination. Instead, other measures of labour market slack, namely underemployment and non-employment rates have a stable relationship with wages between 1980-2020.

Building on recent evidence of a flattening US wage curve (Blanchflower et al., 2024), this chapter extends the analysis to consider the case of the UK evaluating both the pre- and post-crisis period. This analysis is pivotal for discerning whether the observed flattening in the US wage curve is a unique phenomenon or extends to the UK. Moreover, this analysis will provide valuable insights into the mechanisms driving changes in the wage-unemployment relationship and whether these are consistent between the US and the UK.

5.3 Method

This chapter uses the two-stage wage curve estimation procedure proposed by Bell et al. (2002) following recent papers in the UK literature (Longhi, 2012; Brown and Taylor, 2015). This approach captures individual-level data whilst correcting for aggregation bias, which was not corrected in the early wage curve literature.[4] More, this approach does not rely on as strong assumptions as the random effects estimator proposed by Johnes (2007).[5]

[4]For instance Blanchflower and Oswald (1994) and Blackaby and Manning (1990b).

[5]The assumptions of the random effects estimator are tested using a Hausman (1978) test. The null hypothesis is rejected for all measured Johnes (2007) models implying the assumptions of the random effects model do not hold in the UKHLS and APS datasets.

The first stage of the Bell et al. (2002) method involves the estimation of a Mincer-style wage equation at the individual level (Mincer, 1958). Two approaches can be employed to estimate the first stage. The first is a panel approach presented in eq. (5.1).

$$\ln\left(\frac{w_{irt}}{p_{rt}}\right) = \alpha_i + \alpha_{rt} + \sum_{k=1}^{K} x_{kirt} \cdot b_{kr} + u_{irt}. \tag{5.1}$$

In eq. (5.1), $\frac{w_{irt}}{p_{rt}}$ is the real hourly wage of individual i in region r at time t. x_{kirt} are a set of k time-varying covariates such as age, industry and occupational category; formally defined in Section 5.4. α_i is an individual fixed effect capturing individual-level time-invariant heterogeneity. α_{rt} are region and time fixed effects which are interpreted as composition corrected wages. b_{kr} are the coefficients associated with x_{kirt}. Finally, u_{irt} is a random error term.

Alternatively, the first-stage Mincer equation can be estimated using a cross-section approach as presented in eq. (5.2).

$$\ln\left(\frac{w_{irt}}{p_{rt}}\right) = \alpha_{0t} + \alpha_{rt} + \sum_{k=1}^{K} x_{kirt} \cdot b_{kt} + \delta_{irt} \tag{5.2}$$

The key difference between eq. (5.1) and (5.2) is in the assumption made about the b_{kr} and b_{kt} parameters respectively. In the panel approach, b_{kr} has a region subscript implying that the parameters on the controls are region-specific but time-invariant. In eq. (5.2), the b_{kt} coefficients are time-varying but constant across regions. Each approach has advantages as eq. (5.1) controls for individual time-invariant heterogeneity which accounts for many unobserved factors in the dataset whereas eq. (5.2) allows for time-varying effects of the covariates such as changing wages across industries over time. For this reason, both approaches are employed in this chapter to ensure that the results are robust to this choice.

Following the first stage estimation, composition corrected wages ($\hat{\alpha}_{rt}$) are stored for the second stage. A region-level wage curve is then estimated following eq. (5.3).

$$\hat{\alpha}_{rt} = \omega_t + \omega_r + \sum_{x=0}^{X} \Psi_x \cdot \ln(U_{r,t-x}) + \sum_{y=1}^{Y} \varphi_y \cdot \hat{\alpha}_{r,t-y} + \sum_{j=2}^{J} (\gamma_j' \cdot D_j) \cdot t + \upsilon_{rt}. \quad (5.3)$$

In eq. (5.3), ω_t and ω_r are time and region fixed-effects respectively. These capture time trends in wage adjustment and region-specific differences. Ψ_x are coefficients on the contemporaneous and lagged values of the unemployment rate. Note that Ψ_0 is the short-run unemployment elasticity of wages. φ_y are autoregressive parameters capturing the dynamics of wage adjustment.[6] D_j is a region dummy. t is a trend. γ_j' is the coefficient of the regional trend. Finally, υ_{rt} is a random error term.[7]

Through a simple algebraic manipulation, the long run unemployment elasticity of wages is defined following eq. (5.4).

$$\varepsilon = \frac{\sum_{x=0}^{X} \Psi_x}{1 - \sum_{y=1}^{Y} \varphi_y}. \quad (5.4)$$

To allow for the possibility of compensating differentials, the null hypothesis which is tested in this chapter is that log real wages have a non-zero relationship with the log of unemployment rates.

$H_0 : \varepsilon = 0$; $H_1 : \varepsilon \neq 0$

[6] Importantly, when the granularity is low, only the contemporaneous unemployment rate and one lag of the composition corrected wage is included.

[7] The Levin et al. (2002) test is used to verify that $\upsilon_{r,t}$ is stationary. In all Bell et al. (2002) models, the null hypothesis of the Levin et al. (2002) panel unit root test is rejected. Thus, there is no unit root and the estimates are reliable.

H_0 implies that the wage curve is flat. H_1 implies that log real wages have a non-zero relationship with the log of unemployment rates.

If the p-value associated with ε is larger than the two-tailed test critical value at the 5% level, we fail to reject H_0 and confirm that there is no relationship between the log of real wages and the log of the regional unemployment rates. If the p-value associated with ε is larger than the critical value at the 5% level, we reject H_0 in favour of H_1 and confirm that there is evidence of the existence of a relationship between the log of real wages and the log of the regional unemployment rates. In this case, if $\varepsilon < 0$ then we have evidence supporting a Blanchflower and Oswald (1995a) style wage curve whereas if $\varepsilon > 0$ then we have evidence supporting compensating differentials.

5.4 Data

In this chapter, both Bell et al. (2002) first-stage estimation procedures are employed to verify the robustness of the conclusions to methodological decisions. Hence, micro-economic data is collected to estimate both eq. (5.1) and eq. (5.2). The variables chosen are summarised in Table 5.2. Eq. (5.3) is then estimated using composition-corrected wages from the first-stage and region-level data.

As the UKHLS dataset (ISER, 2023) has a panel structure, it is used to estimate both eq. (5.1) and (5.2).[8] As the UKHLS dataset has a much smaller sample size than the Annual Population Survey (APS) (ONS, 2023), the latter is used to estimate eq. (5.2).[9] This choice allows for the estimation of a monthly wage curve and for the inclusion of important covariates which are inconsistently estimated in

[8]This is the same dataset used by Collier (2000), Johnes (2007) and Brown and Taylor (2015).

[9]This is in line with Longhi (2012) who uses the quarterly LFS data which is summarised in the APS.

Table 5.2: Variable overview

Variable/ Dataset	UKHLS	APS
Gross wage	fimnlabgrs	grsswk & grsswk2
Net wage	fimnlabnet	netwk & netwk2
Hours	jbhrs	bushr
Age	dvage/ age	age
Gender	sex	sex
Region	gor	govtof
Interview month	istrtdatm	refwkm
Interview year	istrtdaty	refwky
Part-time	jbft	ftpt
Self-employed	jbsemp	statr
NS-SEC	jbnssec5	nsecmj10/ nsecmmj
Marital Status	mastat/ marstat	amarstt
Industry	-	indsect/ inde07m
Temporary contract	-	jobtyp
Experience	-	conmpy
Public sector	-	publicr

This table sets out variable names in the British Household Panel Survey & Understanding Society (UKHLS) and Annual Population Survey (APS)

UKHLS (e.g. years of professional experience). Regional data on monthly regional unemployment rates starting in 1992 is collected from the NOMIS data repository (Office for National Statistics, 2023).

5.4.1 First-stage dependent variable

As Bratsberg and Turunen (1996) and Blanchflower and Oswald (1995a) highlight the importance of using real hourly wages as the dependent variable in wage curve estimations, nominal monthly wages are deflated by the consumer price index and adjusted by dividing by the number of hours worked. To define hourly wages in the UKHLS dataset, the gross labour income variable (ISER, 2023) is adjusted to represent an hourly rate (instead of a monthly one) using the variable number of hours worked variable.[10] The sum of gross usual pay, gross self-employment income and gross pay in the second job is chosen as a dependent variable as it

[10]People working fewer than 6 hours are removed from the samples. This decision is made to avoid introducing bias due to extreme observations for individuals working fewer hours.

is available throughout the UKHLS datasets as opposed to "fimnlabnet" which is only available from 2009.[11] In the APS dataset, both gross and net wages in the primary and secondary job are summed up and divided by the number of hours to create the hourly gross and net nominal wages.[12]

In the absence of reliable regional consumer price index data spanning 1990-2020, nominal wages are adjusted by the national consumer prices index including owner occupiers' housing costs (CPIH) for the month and year of the interview to form real wages (Beckett, 2023).[13] It is important to note here that the use of a national deflator for regional data may induce some bias. As regional price indices are not publicly available in the UK for the period in question, no attempt is made to design a regional price index.

5.4.2 First-stage independent variables

For the Mincer (1958) style wage equations, a set of relevant control variables used in the UK literature are added to the central regressions (Blanchflower and Oswald, 1994; Bell et al., 2002; Johnes, 2007; Longhi, 2012; Brown and Taylor, 2015). Controls for age, age-squared, gender, region dummies, part-time status, self-employment status, marital status and the five-category version of the National Statistics Socio-economic Classification (NS-SEC) are included in eq. (5.1) and (5.2). Additional controls are included in eq. (5.2) as the APS contains consistent information on SIC[14] industries, temporary contracts, experience in the current job and whether the individual works in the private or public sector.

[11]It is important to note that this is a gross labour income variable and thus does not control for income tax and national insurance.

[12]The ratio is divided by 4.34 the average number of weeks in a month for both datasets.

[13]This is done by defining a discount factor equal to 1 in January 2015 and adjusting the wages such that these are represented in real terms relative to January 2015.

[14]In this chapter, these are aggregated to the 21 broad industries.

5.4.3 Second-stage independent variable

The independent variable of interest is the unemployment rate. This variable is obtained from the NOMIS data repository (Office for National Statistics, 2023). For the UKHLS dataset, yearly regional unemployment rates are matched. Monthly regional unemployment statistics are matched for the APS dataset.

As Blanchflower et al. (2024) suggest that the wage curve holds with non-employment rates and underemployment rates in the US, data is collected for these variables. Monthly regional non-employment rates are from NOMIS (Office for National Statistics, 2023). Underemployment rates are defined following Bell and Blanchflower (2013) using the APS data's "ovhrs" (how many fewer hours would you like to work) and "undhrs" (Extra hours wished to work) variables.

5.4.4 Additional controls

As labour union coverage may affect the wage curve, regional trade union statistics are collected from Bishop (2023). This data provides information on the proportion of workers in each region and year who are members of trade unions. This is added as a control in the second stage equation in later estimations.

5.5 Full-sample results

5.5.1 UKHLS evidence (1992-2019)

Table 5.3: Yearly Wage Curve

	[1]	[2]	[3]	[4]
Ψ_0	-0.010	-0.018	-0.002	-0.009
	(0.012)	(0.012)	(0.013)	(0.014)
φ_1	0.753***	0.444***	0.634***	0.518***
	(0.040)	(0.055)	(0.048)	(0.052)
Region fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Region time trend	No	Yes	No	Yes
First stage	Panel		Cross-section	
Observations	314	314	315	315
R^2	0.997	0.998	0.936	0.942
Degrees of Freedom	274	263	275	264
ε	-0.040	-0.032	-0.007	-0.019
	(0.047)	(0.022)	(0.035)	(0.029)

Standard errors in parentheses; delta method is employed to estimate ε standard errors
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 5.3 summarises the results of the Bell et al. (2002) wage curve estimations using the UKHLS data between 1992-2019 (ISER, 2023). [1] and [2] present estimates of the panel first-stage model whereas [3] and [4] present those for the cross-section first-stage. The key difference between [1] and [3] and [2] and [4] is in the inclusion of region-specific time trends in [2] and [4]. In the central simulations, the contemporaneous regional unemployment rate and the lag of the composition corrected wage are included as the independent variables of interest following (Bell et al., 2002).[15]

[15] As the data set does not provide balanced data at a monthly level, a yearly wage curve is estimated allowing for one lag of the composition corrected wage. Further lags are included in the monthly APS data estimates.

In columns [1] to [4] of Table 5.3, there is a high degree of autocorrelation in composition corrected wages. The autocorrelation of composition corrected wages (φ_1) is highest in the models excluding region time trends. φ_1 are both statistically significant and accurately estimated, as demonstrated by the relatively narrow confidence intervals. The estimates are also statistically different to one implying that the wage curve does not collapse to a wage Phillips curve.

Point estimates of the long-run unemployment elasticity of wages are negative and range from under -0.01 in [3] to -0.04 in [1]. Once region time trends are controlled, the panel and cross-section first-stage approaches present similar estimates of -0.03 in [2] and -0.02 in [4]. Although point estimates are in line with a downward-sloping wage curve, short-run (Ψ_0) and long-run unemployment elasticities of wages (ε) are not statistically significant. For this reason, H_0 cannot be rejected even at the 10% level. Thus, there is little evidence of a downward-sloping wage curve in the UK for 1992-2019 when using both the panel data and cross-section first stage of the Bell et al. (2002) wage curve. Although the estimates are not statistically significant, the long-run unemployment elasticity of wages (ε) in the panel method is in line with Johnes (2007), Longhi (2012) and Brown and Taylor (2015). The cross-section first stage estimates are however smaller than previous literature would suggest. Moreover, the low statistical significance of the coefficient estimates is not found by Longhi (2012) or Brown and Taylor (2015).

5.5.2 Annual Population Survey evidence (2005-2019)

Table 5.4: Monthly Wage Curve

	[1]	[2]	[3]	[4]
Ψ_0	0.012**	0.003	0.007	0.002
	(0.005)	(0.005)	(0.005)	(0.00528)
φ_{12}	0.192***	0.159***	0.143***	0.128***
	(0.022)	(0.023)	(0.023)	(0.023)
Region fixed effect	Yes	Yes	Yes	Yes
Year & month fixed effect	Yes	Yes	Yes	Yes
Region time trend	No	Yes	No	Yes
First stage	Cross-section			
Dependent variable	Gross		Net	
Observations	2160	2160	2160	2160
R^2	0.991	0.991	0.992	0.992
Degrees of Freedom	1956	1945	1956	1945
ε	0.030***	0.004	0.018	0.003
	(0.014)	(0.007)	(0.012)	(0.009)

Standard errors in parentheses; delta method employed to estimate ε standard errors
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

To verify whether the noisy and low estimates of ε are consistent across datasets, Table 5.4 presents the Bell et al. (2002) monthly wage curve results using a cross-section first stage and APS data from 2005-2019 (ONS, 2023). Each model includes 12 lags of monthly composition-corrected wages as this lag order minimises the Bayesian Information Criterion.[16] [1] and [2] are measured using gross hourly wages whereas [3] and [4] contain net hourly wages in the first stage. The only other difference between the models is that [2] and [4] include region time trends whereas [1] and [3] do not.

In columns [1] and [3] of Table 5.4, there is a high degree of autocorrelation in composition corrected wages. This is clear from comparing ε and Ψ_0 as the prior

[16]Models containing up to 24 lags of composition-corrected wages and unemployment rates are compared. The 12 lags of composition corrected wages and no lags of the unemployment rate had the minimised criteria as demonstrated in Appendix D.1.

is over twice larger in both cases. This implies that the cumulative effect of the 12 lags of composition corrected wages is comparable to the coefficient estimates of Table 5.3. The strongest and most statistically significant autocorrelation is observed in the twelfth lag which in this case is a year. This suggests that the previous year's wages have the largest impact on current wages. This strong correlation is not observed for models [2] and [4] although the twelfth lag is still highly statistically significant and has similar point estimates.

Estimates of Ψ_0 and ε in [1] are positive and statistically significant at the 5% level.[17] This provides evidence against the models that support a downward-sloping wage curve and in favour of an upward-sloping wage curve as postulated in the compensating differentials hypothesis. For net wage curves [3], [4] and once region time trends are included in the gross wage curve [2], the short- and long-run unemployment elasticity of wages collapses to values very close to 0. This suggests that the positive slope observed is driven by different regional wage trends in the case of the gross wage curve. Once other costs such as income taxes are accounted for, this positive significant effect also disappears.

Combining the evidence from Table 5.4 columns [1] to [4], there is no evidence of a downward-sloping wage curve in the UK for 2004-2019 when using a cross-section first stage of the Bell et al. (2002) wage curve. The estimates are positive using the APS data suggesting that regions with higher unemployment rates may be compensating workers with higher wages. Once region time trends are included and net wages are used, there is very little evidence of any relationship between composition-corrected wages and unemployment rates.

[17] The delta method is used to estimate the standard errors of ε. This method employs a first-order Taylor approximation to estimate moments of the data such as the standard errors of the implied long-run variable. Van der Vaart (1998) provides technical discussion.

5.5.3 Combining the evidence

Results from Tables 5.3 and 5.4 provide little evidence of a downward-sloping wage curve in the UK. Evidence using the UKHLS dataset suggests that the slope of the UK wage curve is close to 0. This is consistent regardless of the granularity of the second-stage wage curve estimation, the first-stage of the Bell et al. (2002) method employed, the use of net wages and the inclusion of region time-trends. As the UKHLS dataset includes data from 1992 and provides point estimates of ε closer to those recorded by Johnes (2007), Longhi (2012) and Brown and Taylor (2015), one potential explanation for the flatter wage curve observed using the APS data is a structural change in the late 2000s/ early 2010s. This would align with recent evidence by Blanchflower et al. (2024) of a flattening of the wage curve in the US.

5.6 Has the wage curve changed over time?

The unemployment elasticity estimates found in Tables 5.3 and 5.4 are noisier and smaller than those found previously for the UK.[18] As Blanchflower et al. (2024) find evidence of a flattening of the wage curve following the great financial crisis, Figure 5.1 is presented to summarise long-run unemployment elasticity of wages estimates over time using the APS data.[19] Unemployment elasticities are estimated on a rolling window of six years when data is available. When data is not available for six years, the longest possible dataset is employed.

In Figure 5.1, there is some evidence of a flattening of the UK wage curve in the 2010s, as has been documented by Blanchflower et al. (2024) in the US. Indeed, the 2010-2018 period records ε estimates around 0.03. More the unemployment elas-

[18] For instance by Blanchflower and Oswald (1994), Bell et al. (2002), Johnes (2007), Longhi (2012) and Brown and Taylor (2015).

[19] This dataset is chosen as it has a superior granularity.

Figure 5.1: Unemployment elasticity of wages over 2005-2020

ticity of wages has broad 95% confidence intervals suggesting that the coefficient estimates are not statistically significantly different from 0 in most periods. In the few periods where the unemployment elasticity of wages is statistically significant, its value exceeds zero providing no evidence of a downward sloping wage curve.

The evidence of Figure 5.1 suggests that the flattening of the wage curve is not driven by the Global Financial Crisis (GFC) data and persists beyond it. From 2018, ε estimates collapse back to around zero but never fall back to values below -0.005. Based on this evidence, wage curves before and after the GFC will be estimated on both the UKHLS and APS datasets.

5.6.1 Is there strong evidence of a structural break?

To determine whether the wage curve flattened in the UK following the GFC, Table 5.3 is replicated allowing for a structural break following 2008 as demonstrated in eq. (5.5).

$$\hat{\alpha}_{r,t} = \omega_t + \omega_r + \Psi_0 \cdot \ln(U_{r,t}) + \Delta\Psi_{t>2008} \cdot \ln(U_{r,t}) + \sum_{y=1}^{Y} \varphi_y \cdot \hat{\alpha}_{r,t-y} + \sum_{j=2}^{J} (\gamma_j' \cdot D_j) \cdot t + v_{r,t}. \tag{5.5}$$

Eq. (5.5) follows directly from eq. (5.3) with the addition of $\Delta\Psi_{t>2008}$ which is the change in the short-run unemployment elasticity of wages following 2008.

Table 5.5: Yearly Wage Curve - 2008 Structural Break

	[1]	[2]	[3]	[4]
Ψ_0	-0.016	-0.026**	-0.001	-0.008
	(0.012)	(0.012)	(0.013)	(0.014)
$\Delta\Psi_{t>2008}$	0.033***	0.035**	-0.008	-0.003
	(0.011)	(0.016)	(0.012)	(0.019)
φ_1	0.706***	0.427***	0.630***	0.518***
	(0.043)	(0.055)	(0.048)	(0.052)
Region fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Region time trend	No	Yes	No	Yes
First stage	Panel		Cross-section	
Observations	314	314	315	315
R^2	0.997	0.998	0.936	0.942
Degrees of Freedom	273	262	274	263
$\varepsilon_{t<2009}$	-0.053	-0.045**	-0.002	-0.018
	(0.040)	(0.022)	(0.035)	(0.030)
$\varepsilon_{t>2008}$	0.060	0.016	-0.025	-0.023
	(0.041)	(0.022)	(0.035)	(0.030)

Standard errors in parentheses; delta method employed to estimate ε standard errors
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The structure of Table 5.5 follows directly from Table 5.3 except for the addition of $\Delta\Psi_{t>2008}$ and the exposition of ε in pre-2009 and post-2008 subperiods. The results for the UKHLS dataset are presented in Table 5.5.

Table 5.5 provides mixed evidence as to whether the wage curve flattened over time. The models which include individual-level fixed effects in the first stage, namely [1] and [2], provide strong evidence that the wage curve has flattened. In model [1] the Bell et al. (2002) wage curve is estimated assuming there is no region time trend. Under this specification, the long-run unemployment elasticity of wages changes from -0.053 to 0.060. This suggests that the slope of the wage curve became positive after 2008. The evidence of model [2] also points in this direction, after region time trends are included. The unemployment elasticity surges from -0.0453 to 0.0161. Importantly, the changes in the wage curve are both statistically significant at the 5% level providing strong evidence of a flattening of the wage curve.

The results of models [3] and [4] are inconclusive. Although the unemployment elasticity of wages increases (in absolute value) in both models, the accuracy of the estimates is very poor as the standard errors are larger than the point estimates. This result could be due to omitted variable bias as individual-level fixed effects are not included in these models. Thus, unobservable time-invariant factors cannot be controlled in the first-stage cross-section approach. More, insignificant estimates of the change in the wage curve slope are also found using the APS data models in Appendix D.2.1, although these suggest that the wage curve slope became more positive. As the key advantage of the cross-section approach is that it can capture changing relationships between the covariates and the dependent variable over time, a sub-sample analysis is conducted on the models to allow for structural change in the panel model.

Sub-period analysis

Table 5.6: Yearly Wage Curve - Sub-periods

	1992-2008	2009-2019	1992-2008	2009-2019
Ψ_0	-0.019	-0.018	-0.028	0.006
	(0.017)	(0.014)	(0.019)	(0.018)
φ_1	0.199**	-0.0572	0.165*	0.1000
	(0.083)	(0.078)	(0.084)	(0.088)
Region fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Region time trend	Yes	Yes	Yes	Yes
First stage	Panel		Cross-section	
Observations	182	132	183	132
R^2	0.997	0.999	0.956	0.964
Degrees of Freedom	142	97	143	97
ε	-0.024	-0.017	-0.034	0.007
	(0.021)	(0.013)	(0.023)	(0.021)

Standard errors in parentheses; delta method employed to estimate ε standard errors
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 5.6 presents estimates of ε in two sub-periods. These are 1992-2008 and 2009-2019. From the point estimates of ε, there is evidence of a flattening of the wage curve as both the panel and cross-section first-stage approaches return lower unemployment elasticities of wages following 2008. This suggests that changes in covariate effects over time are not driving the flattening of the wage curve observed in Table 5.5. In the panel approach, the flattening of the wage curve is driven by both reductions in the short-run unemployment elasticity of wages and reductions in the autocorrelation of composition-corrected wages. In the cross-section approach, the flattening is mainly driven by a reduction in the short-run unemployment elasticity of wages.[20]

Although the coefficient estimates in Table 5.6 suggest that the slope of the

[20]The APS dataset provides qualitatively similar evidence although ε can only be estimated between 2005 and 2008 for the pre-crisis sample. Appendix D.2.2 provides further details.

wage curve may have flattened after 2008, all unemployment elasticities of wages, whether short-run or long-run, are not statistically significantly different from each other at the 5% level. Consequently, although Figure 5.1, Tables 5.5-5.6 and Appendices D.2.1-D.2.2 provide some evidence supporting the idea that the unemployment elasticity of wages flattened/ became more positive following the GFC, the results are not conclusive from a statistical perspective. Considering the small sample size of the yearly wage curve models and the short pre-crisis period in the APS models, it is likely that the power of the tests is constrained. Regardless of this limitation, the point estimates of ε are consistently quantitatively smaller in the post-2008 period a result which is very similar to what is observed in the US by Blanchflower et al. (2024). Hence, it is important to consider what may be driving the smaller unemployment elasticity estimates.

5.7 What could explain the flattening wage curve?

Three putative explanations for the flattening of the wage curve are presented in this section. First, the postulated real wage non-employment rate/ underemployment rate relationship proposed by Blanchflower et al. (2024) is tested. This is done to determine whether alternative measures of labour market slack may explain the flattening curve. Second, as the bargaining model proposed by Blanchflower and Oswald (1995a) suggests that changes in bargaining power could affect the wage curve, yearly regional trade union membership rates are added as a covariate in the testing models. Third and last, the use of the Bell et al. (2002) method may be driving some of the results. Hence, robustness checks are conducted using region means wage curves.

Table 5.7: Yearly Wage Curve - Non-employment rate

	1992-2008	2009-2019	1992-2008	2009-2019
Ψ_0	-0.111***	-0.008	-0.111**	0.001
	(0.042)	(0.036)	(0.048)	(0.046)
φ_1	0.186**	-0.061	0.157*	0.100
	(0.082)	(0.080)	(0.083)	(0.090)
Region fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Region time trend	Yes	Yes	Yes	Yes
First stage	Panel		Cross-section	
Observations	182	132	183	132
R^2	0.998	0.999	0.957	0.964
Degrees of Freedom	142	97	143	97
ε	-0.137***	-0.007	-0.132**	0.001
	(0.055)	(0.034)	(0.059)	(0.051)

Standard errors in parentheses; delta method employed to estimate ε standard errors
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

5.7.1 Non-employment / Underemployment rates

In the US, Blanchflower et al. (2024) explain that the unemployment wage curve flattening is due to changes in the form of labour market slack. That is, before the GFC, unemployment was a good measure of labour market slack whereas in the 2010s, non-employment rates and underemployment rates are better measures for the US. To test these hypotheses for the UK, the non-employment rate and underemployment rate wage curves are estimated. The non-employment rate refers to the proportion of the working-age labour force that is not employed (OECD, 2024). The underemployment rate is defined following Bell and Blanchflower (2013). Table 5.7 replicates the results of Table 5.6 replacing the regional log of the unemployment rate with the regional log of the non-employment rate (Office for National Statistics, 2023). Table 5.8 estimates a monthly underemployment rate wage curve for 2005-2008 and 2009-2019 using APS data.[21]

[21]The APS data is presented for this sensitivity check as the 2004-2008 period consists of only 60 underemployment observations in the UKHLS dataset.

The results of Tables 5.7 and 5.8 support the general conclusion drawn from the unemployment rate wage curves. In Table 5.7, a strong and stable relationship is found for the non-employment elasticity of wages before the GFC. The long-run non-employment elasticity of wages is statistically significant at the 5% level with values of -0.137 for the panel first stage and -0.132 for the cross-section first stage respectively for 1992-2008. For the post-crisis sub-period, ε is close to 0 and statistically insignificant regardless of the first stage employed.

Table 5.8: Monthly Wage Curve - Underemployment rate (2004-2019)

	2005-2008	2009-2019	2005-2008	2009-2019
Ψ_0	-0.007	-0.002	-0.006	-0.002
	(0.005)	(0.003)	(0.005)	(0.003)
φ_{12}	0.192***	0.164***	0.189***	0.155***
	(0.043)	(0.027)	(0.046)	(0.028)
Region fixed effect	Yes	Yes	Yes	Yes
Year & month fixed effect	Yes	Yes	Yes	Yes
Region time trend	Yes	Yes	Yes	Yes
First stage	Cross-section			
Dependent variable	Gross		Net	
Observations	576	1584	576	1584
R^2	0.993	0.990	0.993	0.990
Degrees of Freedom	504	1428	504	1428
ε	-0.007	-0.003	-0.007	-0.003
	(0.006)	(0.006)	(0.006)	(0.006)

Standard errors in parentheses; delta method employed to estimate ε standard errors
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 5.8 provides some evidence of a flattening of the underemployment wage curve as ε halves for both the gross wage and net wage curves. Although ε halves, there is very little evidence of a strong relationship between underemployment rates and wages as point estimates are lower than 0.01 in magnitude. More, standard errors are larger than the absolute values of the coefficient estimates.

Overall, the non-employment and underemployment wage curves provide further evidence that the wage curve has flattened over time. Although the accuracy of the results presented for the underemployment wage curve is lower than under the non-employment rate specification, the qualitative conclusions remain consistent. Regardless of the measure of labour market slack, there appears to be evidence of a flattening of the wage curve following the GFC.

5.7.2 What about trade union power?

Table 5.9 summarises results of the Bell et al. (2002) wage curve estimation when regional trade union coverage is added as a covariate. As data on regional trade union coverage is only available from 1995, periods before 1995 are removed. Both first stage approaches are tested and all models include region time trends.

Table 5.9: Yearly Wage Curve - Sub-Periods (Trade Union Control)

	1995-2008	2009-2019	1995-2008	2009-2019
Ψ_0	-0.015	-0.015	-0.014	0.009
	(0.018)	(0.014)	(0.021)	(0.019)
φ_1	0.169**	-0.054	0.106	0.108
	(0.084)	(0.077)	(0.093)	(0.089)
Region fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Region time trend	Yes	Yes	Yes	Yes
First stage	Panel		Cross-section	
Observations	161	132	161	132
R^2	0.998	0.999	0.959	0.965
Degrees of Freedom	122	96	122	96
ε	-0.018	-0.014	-0.016	0.010
	(0.022)	(0.014)	(0.024)	(0.021)

Standard errors in parentheses; delta method employed to estimate ε standard errors
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Comparing the results of Table 5.9 with those of Table 5.6, one notices that the qualitative conclusions are similar. The slope of the wage curve flattens entirely when using the cross-section approach and decreases when using the panel approach. The addition of region-specific trade union covariates and the smaller sample size decrease the accuracy of the estimates and none of the unemployment elasticity of wages estimates are statistically different from zero. The panel data results suggest that the change in the unemployment elasticity of wages is smaller than in Table 5.6 although this is partially driven by the absence of 1992-1994 in Table 5.9. Overall, these results do not suggest that regional trade union membership can explain the flattening of the wage curve.

5.7.3 Is the method driving the results?

The final potential explanation for the flattening of the wage curve tested in this chapter is an unexpected shortcoming of the Bell et al. (2002) method. To test this, a region means wage curve is estimated in Table 5.10. The dependent variable is the mean real wage in each region. This wage curve is estimated in pre- and post-crisis subperiods.

Table 5.10: Region Wage Curve

	1993-2008	2009-2019
Ψ_0	-0.024	-0.020
	(0.02)	(0.014)
φ_1	0.082	0.029
	(0.083)	(0.056)
Region fixed effect	Yes	Yes
Year fixed effect	Yes	Yes
Region time trend	Yes	Yes
Observations	183	132
R^2	0.985	0.999
Degrees of Freedom	143	97
ε	-0.026	-0.020
	(0.024)	(0.015)

Standard errors in parentheses; delta method employed to estimate ε standard errors
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 5.10 records unemployment elasticities of wages which are negative and statistically insignificant even at the 10% level. The unemployment elasticity of wages is -0.026 and -0.020 in the pre-crisis period and post-crisis period respectively. This provides strong evidence of a flattening of the wage curve since 1992 as point estimates are much lower than -0.1, however, the evidence of a flattening following the GFC is less clear. The point estimates suggest that the wage curve may have flattened however, the confidence intervals are wide. Hence, although evidence that the wage curve has flattened over time is consistent across methods, the time at which the wage curve flattened is not as certain.

5.8 Implications for General Equilibrium modellers

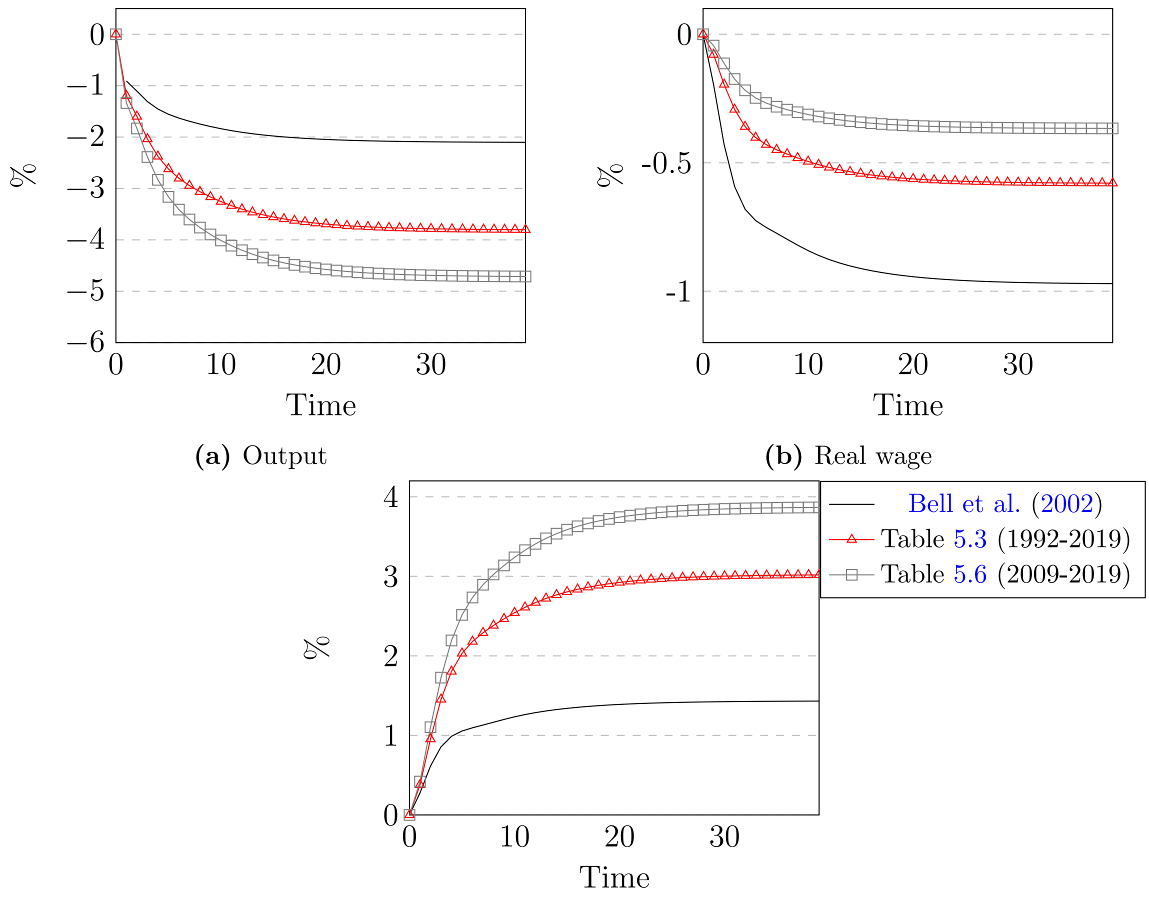
Changes in the long-run unemployment elasticity of wages (ε) have strong implications on quantitative predictions made using general equilibrium (GE) models. To demonstrate this, a Brexit-inspired trade shock is introduced to the recursive dynamic GE model described in Appendix C.1. In the model, the UK and the EU are endogenous regions whilst the Rest of the World is an exogenous region. Following OBR (2018), non-tariff barriers (NTBs) are assumed to increase by 6.5%[22] in price equivalent between the EU and the UK. This is the closest scenario to the current trade deal between the EU and the UK described by OBR (2018). The model is calibrated on the 2020 UK social accounting matrix (SAM) developed using Eurostat (2023) Input-Output tables.

[22]This is the average expected NTB between the UK and the EU in a free trade agreement scenario.

Table 5.11: Summary of figure 5.2 parameters

Source	Period	First-stage	ε
Bell et al. (2002)	1976-1997	Panel	-0.107
Table 5.3	1993-2019	Panel	-0.032
Table 5.6	2009-2019	Panel	-0.017

To understand the sensitivity of the modelling results to the unemployment elasticity of wages measured in this chapter, the wage curve estimates of Tables 5.3 and 5.6 are compared to those of Bell et al. (2002). Table 5.11 summarises the unemployment elasticities compared and their sources. Figure 5.2 then presents the results implied by the respective ε estimates.



(a) Output

(b) Real wage

(c) Unemployment

Figure 5.2: Brexit-style trade shock results. Wage curve results under different unemployment elasticity of wage assumptions.

In Figure 5.2, the impulse response curves of UK output, real wages and unemployment rates are demonstrated. Following the increase in bilateral trade costs between the UK and the EU, UK firms and households decrease their demand for EU goods and services. This is because EU goods are now relatively more expensive than domestically produced or imported goods from the Rest of the World excluding the EU. As a consequence of the increase in trade costs, UK firms' intermediate input costs increase. Hence, domestic firms' prices increase, whilst prices of imported goods from the EU increase, increasing the overall price level in the UK. With higher prices and costs, firms decrease production and demand from domestic and foreign households and firms decreases. Consequently demand for other inputs of production, namely capital and labour, falls. This leads to a reduction in real wages and rental rates of capital.

As demonstrated in Figure 5.2, the unemployment elasticity of wages affects the magnitude of the trade shock rather than the qualitative conclusions. When the unemployment elasticity of wages is lower, output impacts of trade shocks are larger. The reasoning for this is that when the unemployment elasticity of wages is low, workers are less likely to accept lower real wages. Yet following the trade shock, demand for labour decreases putting downward pressure on real wages. When ε is lower, wages become more rigid and consequently, unemployment rates must increase. As higher unemployment rates reduce the size of the labour force in the general equilibrium model, production in the UK falls by a larger amount when ε is smaller.

Crucially, the magnitude of adverse output impacts is almost doubled when comparing the Bell et al. (2002) wage curve estimates with those measured between 1992 and 2019. These adverse output impacts more than double with the post-crisis sub-period unemployment elasticity of wages estimates. Hence, if the UK wage curve has indeed flattened, then this may have strong implications for output volatility in the UK.[23]

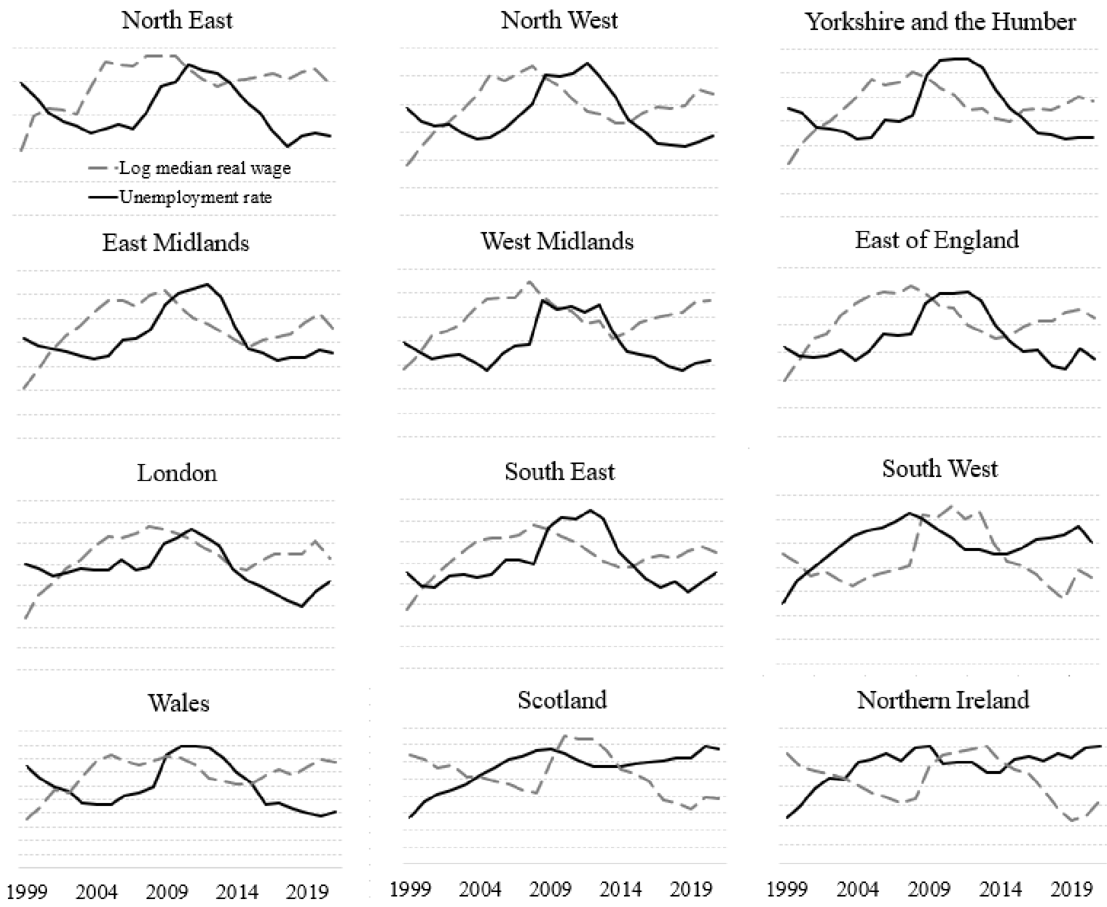


Figure 5.3: Panel of regional real wages (logarithmic scale) and unemployment rates

A lower unemployment elasticity of wages implies that real wage volatility in the UK should have decreased over time whilst unemployment volatility increased. The model's prediction of lower wage volatility is consistent with the observed volatility in the mid to late 2010s in most UK regions as demonstrated in Figure 5.3.[24] Unemployment volatility also increased in the 2010s in most regions although most of this increase was driven by a visible increase following the GFC

[23] As output volatility is associated to lower growth (Ramey and Ramey, 1991), this may lead to lower long-run growth in the UK, although this is not explicitly modelled.

[24] Scotland and Northern Ireland are the only regions where wage volatility is higher following 2008 than before 2009.

and a subsequent recovery. Based on Figure 5.3, there is some evidence that the models with lower unemployment elasticities of wages are capturing real wage and unemployment volatility better. It remains to be seen whether the lower unemployment elasticities of wages persist beyond the 2010s.

5.9 Conclusion

This paper contributes to the literature on the wage curve by estimating the unemployment elasticity of wages in the UK using data from 1992 to 2019 and sub-periods of this dataset. Yearly and monthly wage curves are estimated using both the UKHLS and APS datasets. Bell et al. (2002) panel and cross-section wage curves are estimated.

Using this approach, it is determined that the unemployment elasticity of wages is not statistically significantly different from 0 in the UK between 1992 and 2019. Point estimates of the yearly wage curve range from -0.01 to -0.04. Monthly wage curve estimates between 2005 and 2019 are close to 0 or even positive. There is some evidence suggesting that the wage curve flattened in the UK following the Great Recession. Sub-period analysis suggests that the unemployment elasticity of wages either flattened or became positive following the Global Financial Crisis. This evidence is consistent across datasets. As opposed to recent evidence from the US, there is no evidence that the observed flattening is driven by increases in discouraged workers or underemployed workers. General Equilibrium simulations conducted using the new point estimates suggest that the flattening may increase output and unemployment volatility whilst decreasing wage volatility. Under the lower unemployment elasticities of wages, adverse output impacts of Brexit-like trade shocks double.

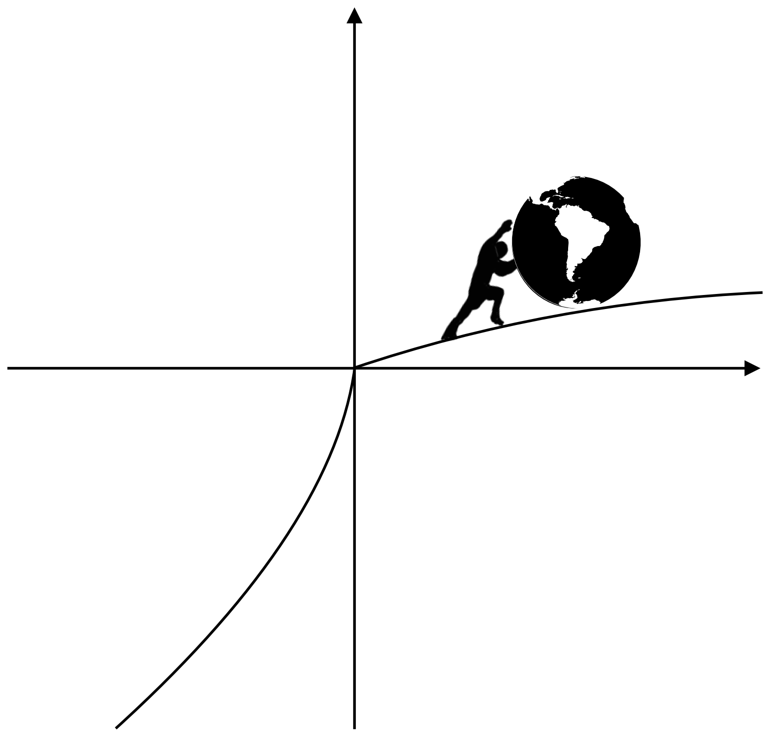
Future empirical research should evaluate the stability of wage curves using other measures of labour market slack such as labour market tightness. This work depends critically on the existence and the quality of regional measures of vacancy rates in the UK which are not available for the full sample period at the time of writing. Future extensions could however uncover how changes in vacancy posting costs may have reduced the unemployment elasticity of wages. Moreover, decreases in monopsony power could have contributed to the flattening of the UK wage curve.[25]

Wage curves should also be estimated for other countries to determine whether the flattening is unique to the US and the UK or consistent across countries. Future theoretical work should aim to extend the theory of the wage curve to determine whether downward wage rigidity or migration effects could explain the instability of coefficient estimates in the post-GFC period. Finally, future research should evaluate the implications of a flattening wage curve for optimal monetary policy.

[25] Thank you to Victor Saldarriaga for insightful discussion on search and matching models.

Chapter 6

Concluding the thesis



Just like Sisyphus, economists continue to push a boulder up an infinite hill. In contrast to Sisyphus, our journey is fruitful and helps us understand the world around us. On the journey, we enhance and extend our tools and knowledge, enabling us to improve our policy recommendations and, therefore, household wellbeing. With this philosophy in mind, this PhD has aimed to contribute to economic knowledge through four chapters on household decisions and behaviour.

Chapter 2 aimed to extend the consumption modelling toolbox by incorporating habit formation and reference dependence models into a simple CGE model. These models were adopted within a CGE framework as many research questions require a nuanced understanding of intertemporal consumption decisions.

Through a set of stylised simulations, three important qualitative conclusions were drawn. First, long-run CGE results are not affected by the choice of the intertemporal consumption modelling framework. Second, ignoring short- to medium-run asymmetries in consumption responses to positive and negative shocks and habit persistence in aggregate consumption may lead to inconsistencies between empirical evidence and model predictions made using neoclassical consumption models. Third, CGE modellers should consider the importance of anticipation effects in modelling short to medium-run impacts when shocks are expected.

Chapter 3 extended neoclassical growth theory by considering how heterogeneity in household behaviours affect the consumption and income distribution during growth. This chapter contributes to our theoretical understanding of growth and its impacts and provides simple testable predictions.

Chapter 3 has four key conclusions. First, if the elasticity of intertemporal substitution (EIS) is not equal to one, heterogeneities in habit strength will unambiguously affect the consumption and income distribution during growth. Second, distributional effects on consumption in the short-run will reverse in the long run. Third, if households are reference dependent *and* forward-looking, economic growth will be associated to consumption and income convergence in the long run. Fourth, if households are reference dependent *but* not forward-looking, economic growth may result in consumption and income divergence in the long run depending on how households form expectations.

Chapter 4 contributes to our understanding of energy policies by investigating the impacts of demand- and supply-side policies following energy price crises. This study employs a multi-region CGE model to demonstrate the combined effects of energy price shocks and fiscal policies on aggregate and distributional outcomes.

Four stylised conclusions are drawn. First, targeted demand-side policies are more effective at reducing overall energy-driven inflation and improving household welfare. Second, supply-side policies and mixed demand- and supply-side policies support firms and aggregate output better than demand-side policies. Third, windfall tax financing improves long run welfare as long as household care about the provision of public good sufficiently. Fourth, the optimal policy mix is likely a mix of demand- and supply-side policies.

Chapter 5 contributes to our understanding of UK labour markets by estimating the UK wage curve between 1992 and 2020. Using an exhaustive set of methods and datasets a set of stylised conclusions are drawn.

First, the UK wage curve has flattened in the UK. Second, since the Global Financial Crisis, the unemployment elasticity of wages is arbitrarily close to 0. Third, other measures of labour market slack such as non-employment rates or underemployment rates do not explain the flattening of the wage curve. Fourth, this flattening of the wage curve has large impacts on CGE simulations demonstrating the importance of choosing appropriate labour market assumptions for post Global

Financial Crisis UK labour markets.

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Appendix A

Chapter 2

A.1 Technical considerations for habit formation models

$$U_h = \sum_{t=0}^{\infty} \beta^t u\left(C_{h,t} - \gamma \cdot H_t\right). \tag{A.1}$$

The notation in eq. (A.1) is the same as that in eq. (2.1) with the addition of two new terms: $H_t \in \mathbb{R}_+ :=$ contemporaneous habit level by individual i at time t and $\gamma \in \mathbb{R}_+ :=$ level of habit formation. When $\gamma = 0$ in eq. (2.2), the equations reduce to the classical time-separable utility function. Habits are additive in the Pollak (1970) utility function.

The functional form usually employed for the Pollak (1970) habit formation model is presented in eq. (A.2).

$$u(C_{h,t}) = \begin{cases} \frac{\epsilon}{\epsilon-1} \cdot \left(C_{h,t} - \gamma \cdot H_t\right)^{\frac{\epsilon-1}{\epsilon}} & \epsilon \neq 1 \\ \ln\left(C_{h,t} - \gamma \cdot H_t\right) & \epsilon = 1 \end{cases}. \tag{A.2}$$

The notation follows directly from Section 2.4. The marginal utility function is then defined in eq. (A.3) for KUJ habits.

$$u'(C_{h,t}|H_t) = (C_{h,t} - \gamma \cdot H_t)^{-\frac{1}{\epsilon}}. \tag{A.3}$$

A.2 Internal vs. External habit formation

When representative households form internal habits (e.g. Fuhrer, 2000), the household chooses both the consumption today and the future habit stock. In this case, the marginal utility of consumption is defined in eq. (A.4) for the Pollak (1970) utility function and eq. (A.5) for the Abel (1990) utility function:

$$\begin{aligned} u'(C_{h,t}|H_t) &= (C_{h,t} - \gamma \cdot H_t)^{-\frac{1}{\epsilon}} \\ &\quad - \gamma \cdot (1-\Theta) \cdot \mathbb{E}_t \left(\sum_{\tau=1}^{\infty} \beta^{\tau} \cdot \Theta^{\tau-1} \cdot (C_{h,t+\tau} - \gamma \cdot H_{t+\tau})^{-\frac{1}{\epsilon}} \right). \end{aligned} \tag{A.4}$$

$$\begin{aligned} u'(C_{h,t}|H_t) &= \left(\frac{C_{h,t}}{H_t^{\gamma}} \right)^{-\frac{1}{\epsilon}} \cdot H_t^{-\gamma} \\ &\quad - \gamma \cdot (1-\Theta) \cdot \mathbb{E}_t \left(\sum_{\tau=1}^{\infty} \beta^{\tau} \cdot \Theta^{\tau-1} \cdot u(C_{h,t+\tau}|H_{t+\tau}) \cdot H_{t+\tau}^{-1} \right). \end{aligned} \tag{A.5}$$

Figure A.1 presents the IRFs of a neoclassical consumption model (the full black line), a Pollak (1970) internal habit formation model (the black line with circle marks) and a Pollak (1970) external habit formation model (the red line with triangle marks). The consumption responses occur following an unanticipated permanent 2% increase in TFP.

As is clear from Figure A.1, the difference between the IRFs of the internal and external habit formation models is negligible. This result is in line with Alvarez-Cuadrado et al. (2004).

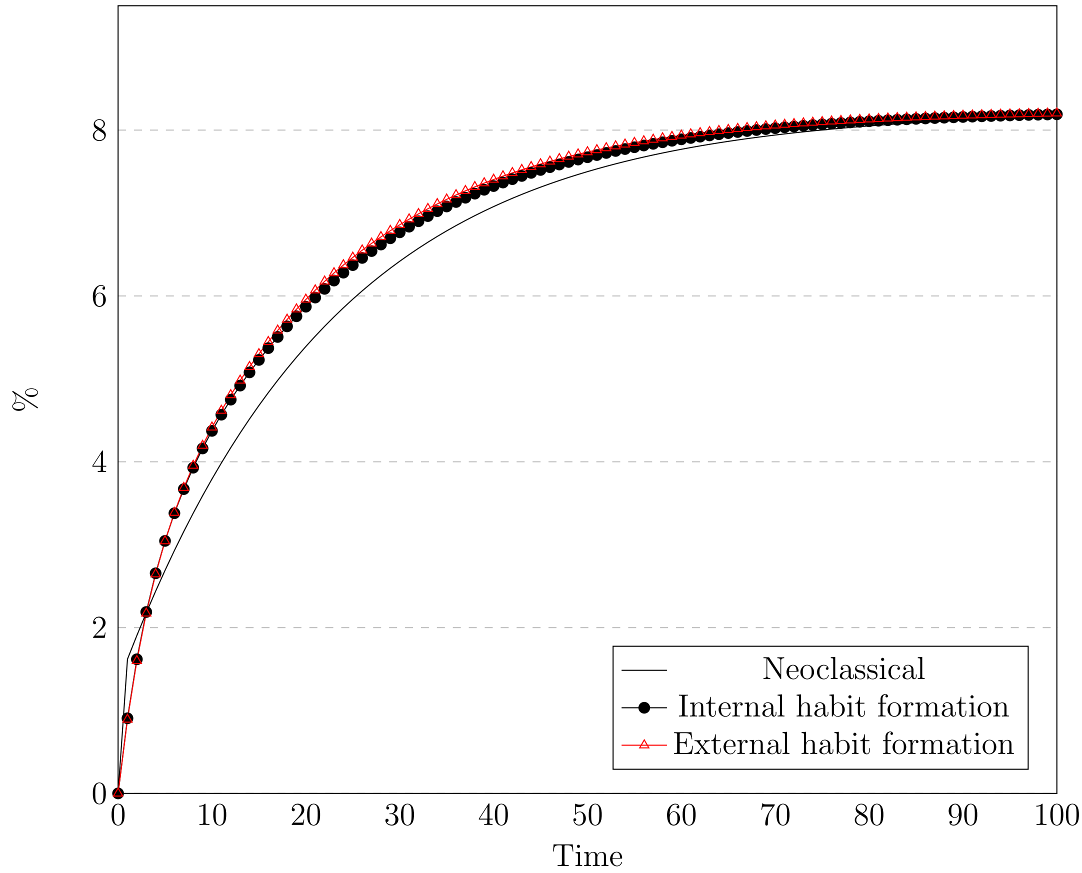
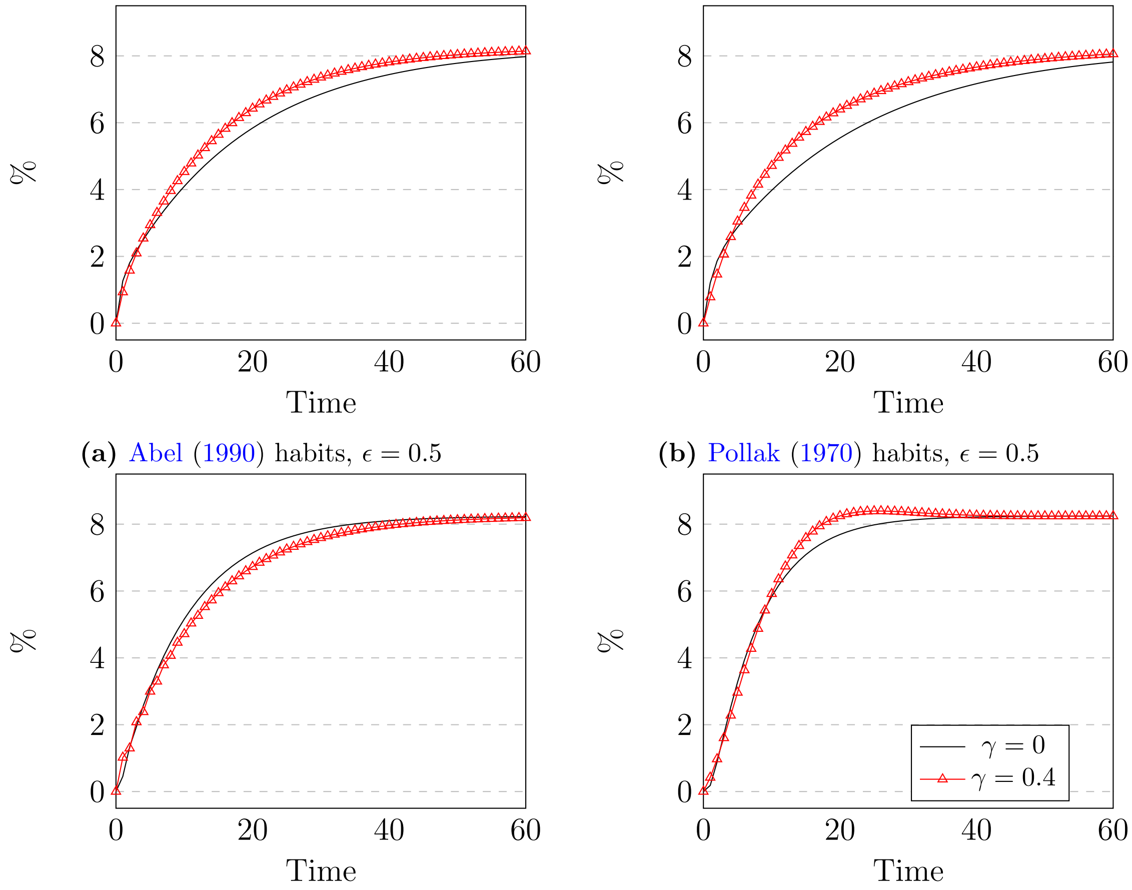


Figure A.1: Aggregate consumption IRF: permanent 2% increase in TFP, Pollak (1970) habit formation model internal and external $\Theta = 1$, $\sigma = 0.5$, $\gamma = 0.7$

A.3 Abel (1990) vs. Pollak (1970) habits

Figure A.2 presents impulse response functions (IRFs) of the external habit formation models. Panels A.2a and A.2b compare Abel (1990) and Pollak (1970) habit formation models to neoclassical consumption models when the EIS is equal to 0.5 whereas panels A.2c and A.2d compare these models when the EIS is equal to 2. In all panels, the full black line represents the neoclassical consumption model whereas the red line with triangular marks represents the given habit formation model.

Following the TFP shock, the economy's production capacity increases. In the short-run, capital stocks are fixed and labour is exogenously fixed in all periods. For simplicity, the simulations are conducted in a closed-economy setting. Con-



(a) Abel (1990) habits, $\epsilon = 0.5$

(b) Pollak (1970) habits, $\epsilon = 0.5$

(c) Abel (1990) habits, $\epsilon = 2$

(d) Pollak (1970) habits, $\epsilon = 2$

Figure A.2: TFP shock aggregate consumption IRFs under different habit forms

sequently, production unambiguously increases with wages and the rental rate of capital increasing relative to the output price. This increases households' real incomes. The increase in TFP leads to an income effect increasing the intertemporal consumption possibilities. Meanwhile, there is a substitution effect as the next period's rental rate of capital increases when TFP increases. Thus, households must choose how much to save and consume from the additional income. These decisions will determine the speed of adjustment to the new steady-state consumption level.

Comparing the black lines of panels A.2a and A.2c, it is clear that increasing the EIS leads to a faster convergence to equilibrium in the neoclassical consumption model. This is because higher EISs imply that households have fewer incentives to smooth consumption over time. Consequently, higher EISs are associated with quicker convergence to equilibrium.

When households form Abel (1990) habits, consumption smoothing motives increase as demonstrated in the red lines with triangular marks of panels A.2a and A.2c. This is because households now optimise both absolute and relative utility. The key difference between the Abel (1990) habit formation IRFs in panels A.2a and A.2c is the immediate response to the shock. When the EIS is less (greater) than one, the Abel (1990) habit formation model's short-run consumption response is smaller (larger) than that of the neoclassical model. Consequently, as capital stocks accumulate at a slower (faster) rate, the convergence speed to equilibrium is slower (faster).

When households form Pollak (1970) habits, the intuition is similar. Comparing panels A.2a and A.2b, the IRFs are almost identical although the Pollak (1970) form presents smaller initial consumption responses. Therefore, the convergence to the consumption steady state is relatively faster. When the EIS exceeds 1, the Pollak (1970) IRF is different to the Abel (1990) IRF. Indeed, there is a hump-shaped consumption response with the consumption level briefly exceeding its equilibrium in the medium run. Therefore, although Abel (1990) and Pollak (1970) both capture habit formation, their habit persistence parameter is not directly comparable and may lead to qualitatively different results.

Figure 3.1 demonstrates that employing habit formation models will affect the consumption IRFs of CGE simulations. This contrast is particularly pertinent for short-run results. When the EIS is smaller (larger) than 1, using neoclassical consumption models will overestimate (underestimate) short-run consumption responses if the model is better proxied by Abel (1990) habit persistence models.

These issues are more pronounced in closed economy models as investment is entirely driven by domestic savings. In an open economy setting, these issues will persist, although they will be less pronounced. This is because, in an open economy setting, domestic reductions (increases) in savings will be partially substituted by increases (decreases) in foreign direct investment. Consequently, capital stocks will not depreciate as much. In an open economy setting, the composition of savings and investment will change with foreign direct investment either increasing or decreasing relative to domestic savings.

External habit formation when $\Theta > 0$

Figure A.3 demonstrates consumption IRFs for the Pollak (1970) habit formation model under different assumptions about the level of habit memory Θ. Larger values of Θ are associated with larger habit memory. The full black line represents the Pollak (1970) habit formation model when $\Theta = 0$. The black line with circular marks and the red line with triangular marks represent the Pollak (1970) habit formation model when $\Theta = 0.5$ and $\Theta = 0.9$ respectively.

Introducing a longer habit memory affects the curvature of the IRF. As Θ increases, changes in the curvature of the slope decrease. This decreases the speed of adjustment to the new consumption steady state. In the extreme case where $\Theta = 0.9$, the consumption IRF has a hump shape, as has been observed by Fuhrer (2000). Consumption overshoots the steady state level and slowly converges towards it in oscillations (An observation in line with Ryder and Heal, 1973).

The slower adjustment mechanism when Θ is larger than zero occurs as changes in consumption only have lagged effects on the habit level. This means that initially, utility is increasing as consumption increases and the habit level remains relatively low when $\Theta > 0$. This decreases the marginal utility of consumption and thus,

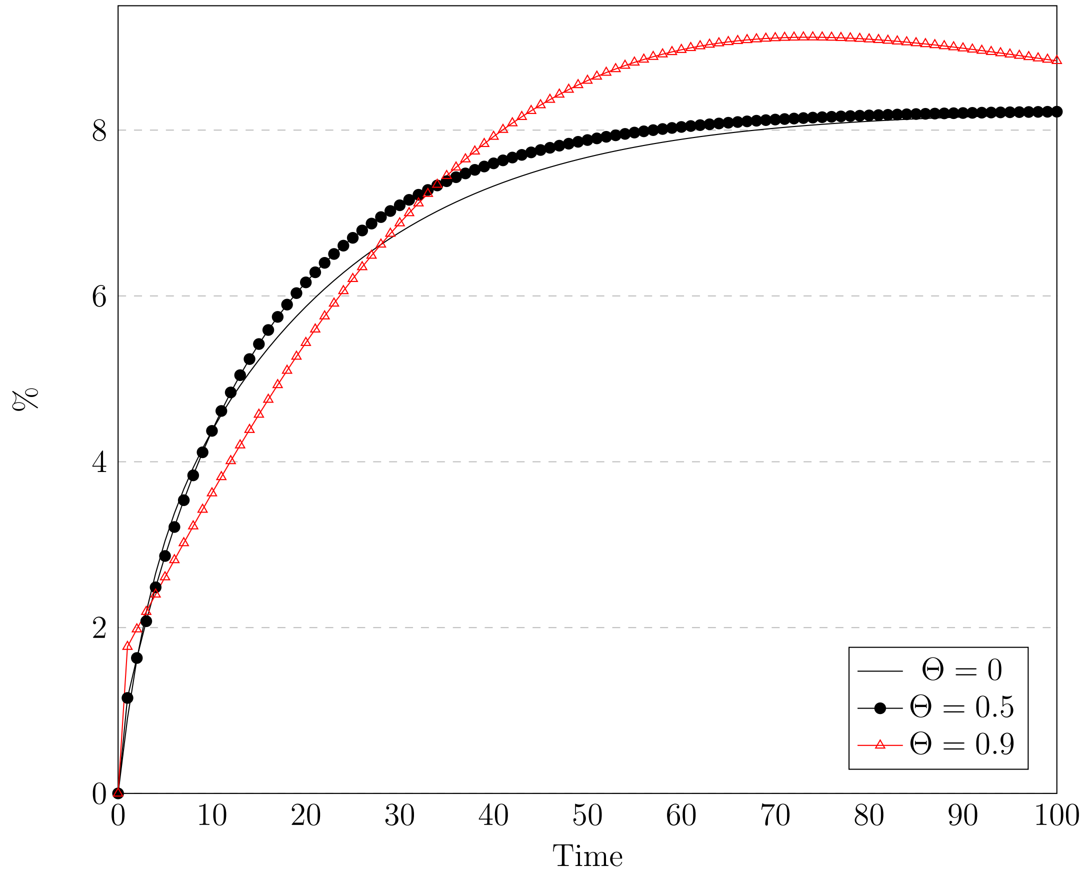


Figure A.3: Aggregate consumption IRF: Pollak (1970) habit formation model under different levels of habit memory Θ, $\sigma = 0.5$, $\gamma = 0.7$

households increase consumption by less than they would when $\Theta = 0$. What is not consumed is saved resulting in an accumulation of future capital stocks.

The larger is Θ, the higher is the capital accumulation. Past consumption levels only begin affecting the habit level cumulatively. Once the habit level adjusts sufficiently, the marginal utility of consumption begins increasing once more. At this point, households increase consumption in proportion to savings to increase their utility. This effect drags the household back towards the steady state consumption level. In the case where $\Theta \to 1$, this adjustment occurs in oscillations of decreasing magnitudes. When Θ is closer to 0, the magnitude of these oscillations is smaller.

A.4 Open economy sensitivities

Table A.1: ORCK Open Economy Social Accounting Matrix

	F	K	L	H	S	ROW
F	0	0	0	20	2	13
K	20	0	0	0	0	0
L	10	0	0	0	0	0
H	0	16	10	0	0	0
S	0	0	0	1.6	0	0.4
ROW	5	4	0	4.4	0	0

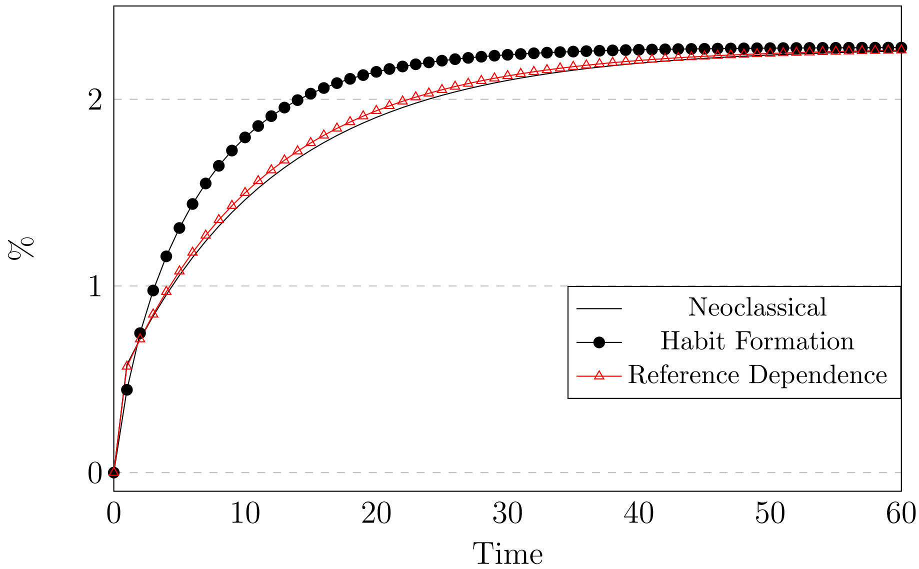
F= Firms, K= Capital, L= Labour, Hi= Household i,
S= Capital formation, ROW= Rest of the World

Table A.1 presents the SAM used in the open economy simulations. The key difference between Table A.1 and 2.5 is that in the prior, the economy is open. The structure of the economy is chosen arbitrarily.

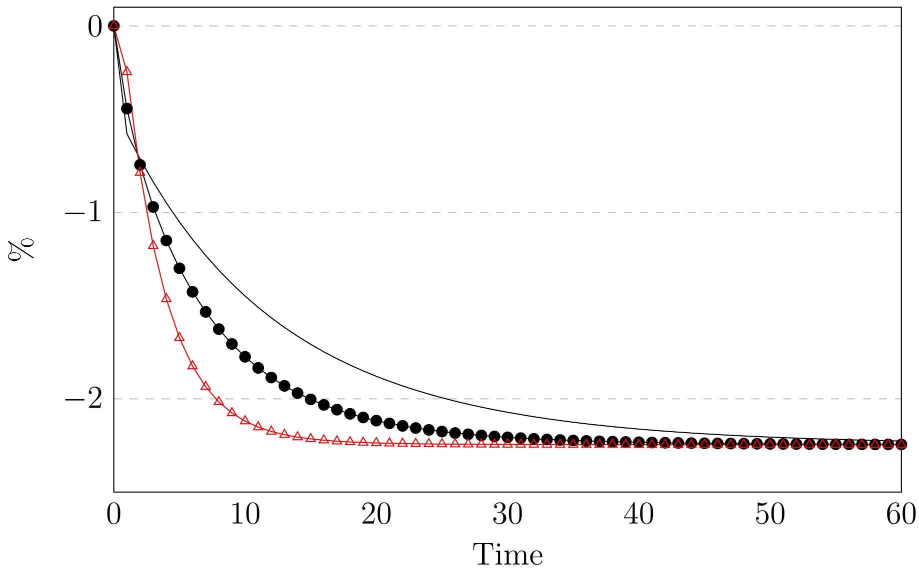
Additionally, the empirical reference dependence model is altered to be directly comparable to the neoclassical and habit formation Euler equations as presented in eq. (A.6).

$$\Delta C_t = a + \lambda_G(POS_t)\Delta\hat{Q}_t + \lambda_L(NEG_t)\Delta\hat{Q}_t + b \cdot \hat{r}_t \cdot \frac{cpi_{h,t}}{cpi_{h,t+1} \cdot p_t}. \tag{A.6}$$

The key difference between eq. (A.6) and (2.37) is in the real interest rate adjustment. As the Shea (1995a,b) model is built on a linear approximation of an Euler equation, the same price adjustment procedure is applied as in the case of eq. (2.29).

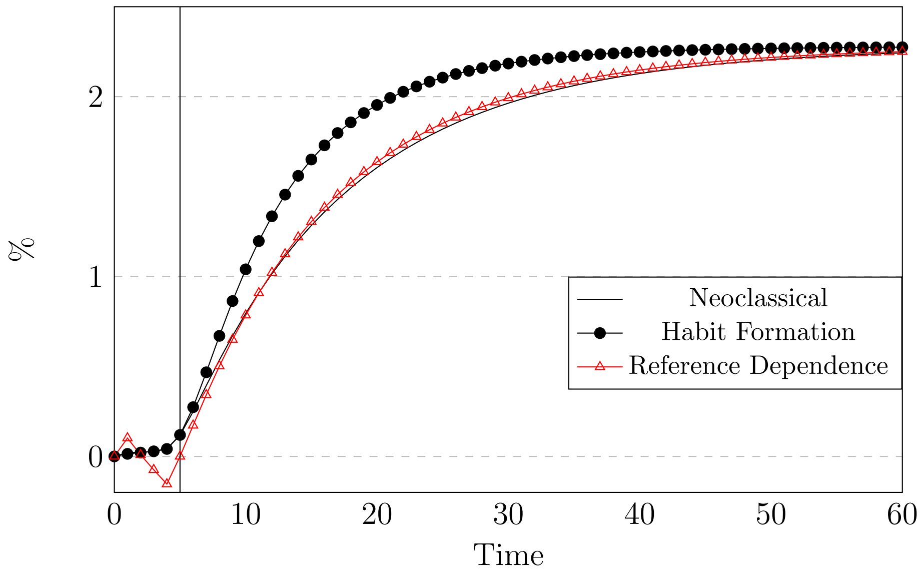


(a) Positive TFP shock (+2%)

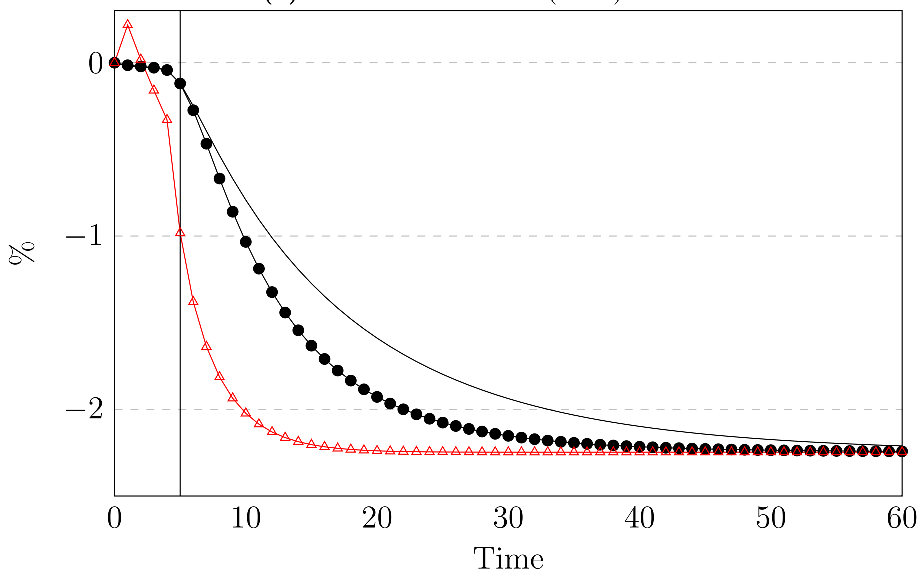


(b) Negative TFP shock (-2%)

Figure A.4: Consumption IRF for unanticipated permanent TFP shock ±2% in an open economy: Classical model $\epsilon = 0.3$; Abel (1990) habit formation model $\gamma = 0.6$; Reference dependence model $\lambda_G = 1.1$, $\lambda_L = 0.2$

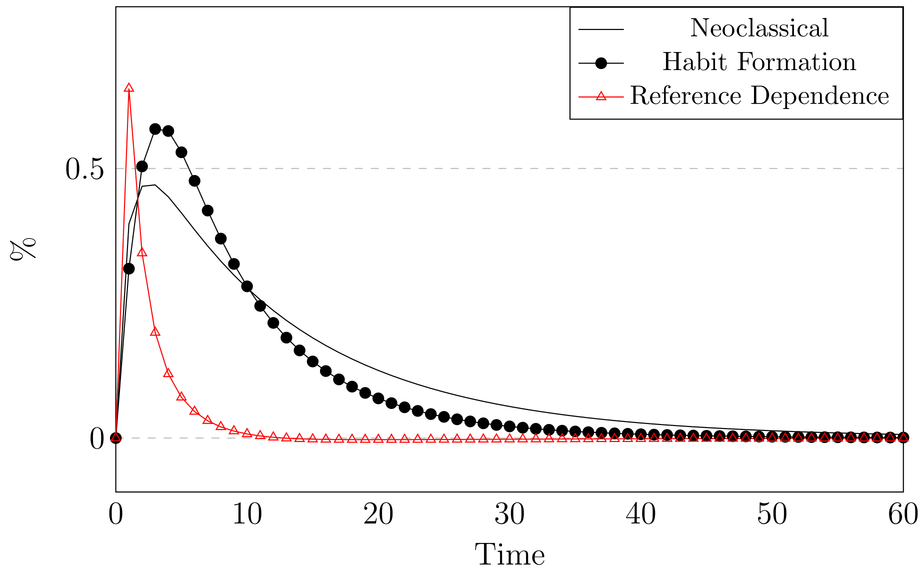


(a) Positive TFP shock (+2%)

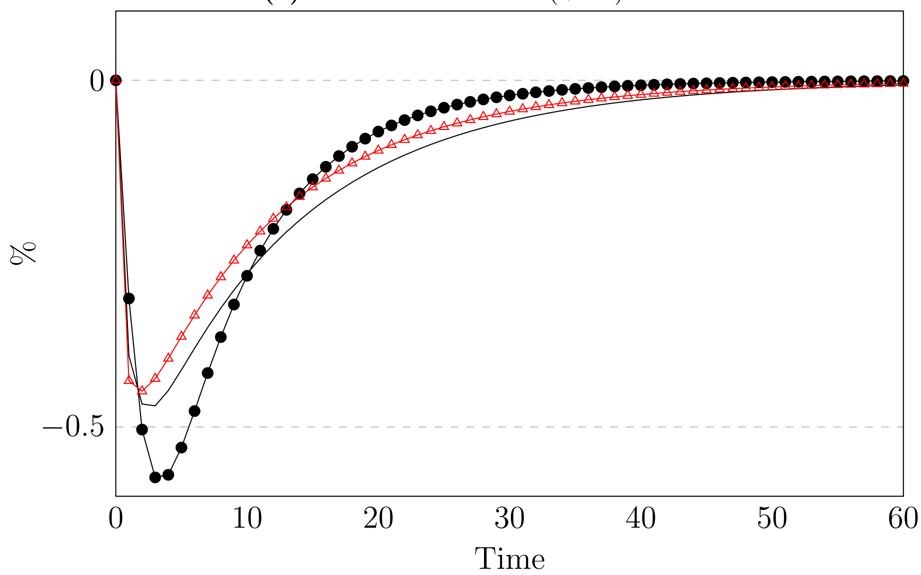


(b) Negative TFP shock (-2%)

Figure A.5: Consumption IRF for anticipated permanent TFP shock ±2% open economy: Classical model $\epsilon = 0.3$; Abel (1990) habit formation model $\gamma = 0.6$; Reference dependence model $\lambda_G = 1.1$, $\lambda_L = 0.2$



(a) Positive TFP shock (+2%)



(b) Negative TFP shock (-2%)

Figure A.6: Consumption IRF for unanticipated temporary TFP shock ±2% open economy: Classical model $\epsilon = 0.3$; Abel (1990) habit formation model $\gamma = 0.6$; Reference dependence model $\lambda_G = 1.1$, $\lambda_L = 0.2$

Appendix B

Chapter 3

B.1 Loss aversion corner solution

Following the proof of proposition 5, we know that:

$$\left(\frac{\Delta_{1,t}}{\Delta_{2,t}}\right)^{\frac{1}{\epsilon}} = 1 + \lambda \cdot (1 - \Delta_{1,t}^{\frac{1}{\epsilon}}) \cdot (C_{2,t})^{\frac{1}{\epsilon}}.$$

As consumption can't be negative in the model, the LHS is strictly positive. The above inequality would not hold however if:

$$\begin{aligned}
0 &> 1 + \lambda \cdot (1 - \Delta_{1,t}^{\frac{1}{\epsilon}}) \cdot C_{2,t}^{\frac{1}{\epsilon}}, \\
\implies -\frac{1}{\lambda \cdot C_{2,t}^{\frac{1}{\epsilon}}} &> (1 - \Delta_{1,t}^{\frac{1}{\epsilon}}), \\
\implies \Delta_{1,t}^{\frac{1}{\epsilon}} &> 1 + \frac{1}{\lambda \cdot C_{2,t}^{\frac{1}{\epsilon}}}, \\
\implies \Delta_{1,t} &> \left(1 + \frac{1}{\lambda \cdot C_{2,t}^{\frac{1}{\epsilon}}}\right)^{\epsilon}.
\end{aligned}$$

Hence, there exists a loss aversion threshold for the household in the domain of gains such that the Euler equations can't hold. Future research should define an explicit expression for this threshold.

Appendix C

Chapter 4

C.1 The mathematical presentation of the CGE model

Prices:

$$cpi_{r,t} = \frac{\sum_h C^H_{h,r,t} \cdot cpi^H_{h,r,t}}{C_{r,t}} \tag{C.1}$$

$$cpi^H_{h,r,t} = \frac{\sum_i pc^T_{h,r,i,t} \cdot \mu^{HC}_{h,r,i}}{\sum_i pc^T_{h,r,i,t=0} \cdot \mu^{HC}_{h,r,i}} \tag{C.2}$$

$$pc^T_{h,r,i,t} = \frac{\sum_{r'} pd_{r',i,t} \cdot CD^H_{h,r',r,i,t=0}}{\sum_{r'} pd_{r',i,t=0} \cdot CD^H_{h,r',r,i,t=0}} \tag{C.3}$$

$$w_{r,t} = \begin{cases} w_{r,t=0} \\ \exp\left(\log cpi_{r,t} + \alpha^{WC}_r - \beta^{WC}_r \cdot \log UN_{r,t}\right) \forall t \in T,\, t \neq 1 \end{cases} \tag{C.4}$$

$$rk_{r,i,t} = py_{r,i,t} \cdot \alpha^K_{r,i} \cdot \Psi^{K\,\rho^H_i}_{r,i} \cdot \left(\frac{Y_{r,i,t}}{K_{r,i,t}}\right)^{1-\rho^H_i} \tag{C.5}$$

$$uck_{r,t} = ipi_{r,t} \cdot (ir_r + \delta_r) \tag{C.6}$$

$$pv_{r,i,t} = \frac{\sum_{r',j} pd_{r',i,t} \cdot VR_{r',i,r,j,t}}{\sum_j V_{r,i,j,t}} \tag{C.7}$$

$$pd_{r,j,t} \cdot (1 - \tau^p_{r,j,t}) = \sum_i \left(pv_{r,i,t} \cdot \mu^V_{r,i,j}\right) + py_{r,j,t} \cdot \mu^Y_{r,j} \tag{C.8}$$

$$gpi_{r,t} = \frac{\sum_{i,r'} G^C_{r',i,r,t=0} \cdot pd_{r',i,t}}{\sum_{i,r'} G^C_{r',i,r,t=0} \cdot pd_{r',i,t=0}} \tag{C.9}$$

$$ipi_{r,t} = \frac{\sum_{i,r'} pd_{r',i,t} \cdot \mu^I_{r',i,r}}{\sum_{i,r',} pd_{r',i,t=0} \cdot \mu^I_{r',i,r}} \tag{C.10}$$

$$pd_{r,i,t} = \begin{cases} ps_{r,i,t} \text{ Perfect competition} \\ \frac{\epsilon^M_{r,i}}{\epsilon^M_{r,i}-1} \cdot ps_{r,i,t} \text{ Monopoly/ oligopoly model} \end{cases} \tag{C.11}$$

Households

Intratemporal behaviour

$$C^H_{h,r,t} \cdot cpi^H_{h,r,t} = II^H_{h,r,t} - S^H_{h,r,t} - T^H_{h,r,t} \tag{C.12}$$

$$T^H_{h,r,t} = \tau^H_{h,r} \cdot II^H_{h,r,t} \tag{C.13}$$

$$CT^H_{h,r,i,t} = \begin{cases} \mu^{HC}_{h,r,i} \cdot C^H_{h,r,t}, \text{ Leontief} \\ \gamma^{SG}_{h,r,i} + \frac{\beta^{SG}_{h,r,i}}{pc^T_{h,r,i,t}} \cdot (C^H_{h,r,t} \cdot cpi^H_{h,r,t} - \sum_j \gamma^{SG}_{h,r,j} \cdot pc^T_{h,r,j,t}), \text{ Stone-Geary} \end{cases} \tag{C.14}$$

$$CD^H_{h,r',r,i,t} = \left({\Psi^C_{h,r,i}}^{\rho^V_{r,i}} \cdot \alpha^C_{h,r',r,i} \cdot \frac{pc^T_{h,r,i,t}}{pd_{r',i,t}} \right)^{\frac{1}{1-\rho^V_{r,i}}} \cdot CT^H_{h,r,i,t} \tag{C.15}$$

$$II^H_{h,r,t} = uck_{r,t} \cdot KS^H_{h,r,t} + w_{r,t} \cdot LS^H_{h,r,t} + \theta^\Pi_{h,r} \cdot \sum_i \Pi_{r,i,t} + cpi_{r,t} \cdot TR_{h,r,t} \tag{C.16}$$

$$KS^H_{h,r,t} = \theta^K_{h,r} \cdot \sum_i K_{r,i,t} \tag{C.17}$$

$$LS^H_{h,r,t} = \theta^L_{h,r} \cdot \sum_i L_{r,i,t} \tag{C.18}$$

$$II_{r,t} = \sum_h II^H_{h,r,t} \tag{C.19}$$

$$C_{r,t} = \sum_h C^H_{h,r,t} \tag{C.20}$$

$$CD_{r,i,t} = \sum_h CD^H_{h,r,r,i,t} \tag{C.21}$$

$$CI_{r,i,t} = \sum_{h,r' \neq r} CD^H_{h,r',r,i,t} \tag{C.22}$$

$$S_{r,t} = \sum_h S^H_{h,r,t} \tag{C.23}$$

$$T_{r,t} = \sum_h T^H_{h,r,t} \tag{C.24}$$

Forward-Looking behaviour:

$$\frac{C^H_{h,r,t}}{C^H_{h,r,t+1}} = \left[\beta_{h,r} \cdot \left(\frac{1 + \Delta ipi_{r,t+1}}{1 + \Delta cpi^H_{h,r,t+1}} \cdot \left((1 - \delta_r) + (ir_r + \delta_r) \cdot \left(1 - \tau^H_{h,r}\right)\right)\right)\right]^{-\frac{1}{\epsilon_{h,r}}} \tag{C.25}$$

Production:

Production structure:

$$Y_{r,i,t} = \left(\alpha^K_{r,i} \cdot (\Psi^K_{r,i} \cdot K_{r,i,t})^{\rho^H_i} + \alpha^L_{r,i} \cdot (\Psi^L_{r,i} \cdot L_{r,i,t})^{\rho^H_i}\right)^{\frac{1}{\rho^H_i}} \tag{C.26}$$

$$KS^T_{r,i,t} = \left({\Psi^K_{r,i}}^{\rho^H_i} \cdot \alpha^K_{r,i} \cdot \frac{py_{r,i,t}}{uck_{r,t}}\right)^{\frac{1}{1-\rho^H_i}} \cdot Y_{r,i,t} \tag{C.27}$$

$$L_{r,i,t} = \left({\Psi^L_{r,i}}^{\rho^H_i} \cdot \alpha^L_{r,i} \cdot \frac{py_{r,i,t}}{w_{r,t}}\right)^{\frac{1}{1-\rho^H_i}} \cdot Y_{r,i,t} \tag{C.28}$$

$$VR_{r',i,r,j,t} = \left({\Psi^V_{r,i,j}}^{\rho^V_{r,i}} \cdot \alpha^{ARM}_{r',i,r,j} \cdot \frac{pv_{r,i,t}}{pd_{r',i,t}}\right)^{\frac{1}{1-\rho^V_{r,i}}} \cdot V_{r,i,j,t} \tag{C.29}$$

$$pv_{r,i,t} \cdot V_{r,i,j,t} = \mu^V_{r,i,j} \cdot O_{r,j,t} \cdot ps_{r,j,t} \tag{C.30}$$

$$py_{r,i,t} \cdot Y_{r,i,t} = \mu^Y_{r,i} \cdot O_{r,i,t} \cdot ps_{r,i,t} \tag{C.31}$$

Perfect competition:

$$NZ_{r,i,t} = NZ_{r,i,t=0} \tag{C.32}$$

“Monopoly/ Oligopoly” production structure:

$$\Pi_{r,i,t} = \frac{1}{\epsilon^M_{r,i}} \cdot O_{r,i,t} \cdot pd_{r,i,t} \cdot (1 - \tau^p_{r,i,t}) \tag{C.33}$$

$$NZ_{r,i,t} = NZ_{r,i,t=0} \tag{C.34}$$

Factor accumulation:

$$KS_{r,i,t} = \begin{cases} KS_{r,i,t=0} \text{ if t=1} \\ KS_{r,i,t-1} \cdot (1-\delta_r) + I^D_{r,i,t-1} \text{ if } t \in (1,\infty) \\ \frac{I^D_{r,i,t}}{\delta_r} \text{ if t} \to \infty \end{cases} \tag{C.35}$$

$$\sum_i L_{r,i,t} = LS_{r,t=0} \cdot (1 - UN_{r,t}) \tag{C.36}$$

Market clearing conditions:

$$K_{r,i,t} = KS_{r,i,t} \tag{C.37}$$

$$X_{r,i,t} = \sum_{r'} X^R_{r',i,r,t} - X^R_{r,i,r,t} \tag{C.38}$$

$$X^R_{r,i,r',t} = M^R_{r',i,r,t} \tag{C.39}$$

$$M^R_{r',i,r,t} = \sum_j VR_{r',i,r,j,t} + \sum_h CD^H_{h,r',r,i,t} + G^C_{r',i,r,t} + I^O_{r',i,r,t} + STK_{r',i,r} \tag{C.40}$$

$$M_{r,i,t} = \sum_{r'} M^R_{r',i,r,t} - M^R_{r,i,r,t} \tag{C.41}$$

$$O_{r,i,t} = \sum_{r'} X^R_{r',i,r,t} \tag{C.42}$$

$$D_{r,i,t} = M^R_{r,i,r,t} \tag{C.43}$$

$$I^T_{r,t} \cdot ipi_{r,t} = S^G_{r,t} + S_{r,t} + S^F_{r,t} \tag{C.44}$$

$$\sum_i I^D_{r,i,t} = \sum_{i,r'} I^O_{r',i,r,t} + \sum_i STK_{r,i,r} + STK^F_r \tag{C.45}$$

Export demand:

$$X^R_{row,i,r,t} = X^R_{row,i,r,t=0} \cdot \frac{pd_{row,i,t}}{pd_{r,i,t}} \tag{C.46}$$

Government expenditure and income:

$$G^{C}_{r',i,r,t} = G_{r,t} \cdot \mu^{GC}_{r',i,r} \tag{C.47}$$

$$G_{r,t} \cdot gpi_{r,t} = G^{Y}_{r,t} - S^{G}_{r,t} - TR^{T}_{r,t} \tag{C.48}$$

$$G^{Y}_{r,t} = T_{r,t} + \sum_{i} T^{F}_{r,i,t} \tag{C.49}$$

$$S^{G}_{r,t} = \mu^{GS}_{r} \cdot G^{Y}_{r,t} \tag{C.50}$$

$$T^{F}_{r,i,t} = \tau^{p}_{r,i,t} \cdot O_{r,i,t} \cdot pd_{r,i,t} \tag{C.51}$$

Investment:

$$I^{D}_{r,i,t} = (KS_{r,i,t} \cdot \delta_r) + (KS^{T}_{r,i,t} - KS_{r,i,t}) \cdot \phi_r \tag{C.52}$$

$$I^{O}_{r',i,r,t} = I^{T}_{r,t} \cdot \mu^{I}_{r',i,r} \tag{C.53}$$

$$I^{O}_{row,i,r,t} = I^{O}_{row,i,r,t=0} \tag{C.54}$$

Sets:

r/r' := region subscript

h := household subscript

t := time subscript

i/j := industry subscript

Parameters:

$\alpha^{ARM}_{r',i,r,j}$:= Armington share parameter

α^{WC}_{r} := wage curve intercept

$\alpha^{C}_{h,r',r,i}$:= Armington share parameter

$\alpha^{K}_{r,i}$:= CES share parameter

$\alpha^{L}_{r,i}$:= CES share parameter

$\beta^{SG}_{h,r,i}$:= Stone-Geary weight parameter

β_r^{WC} := wage curve slope

$\beta_{h,r} \in (0,1)$:= Samuelson discount factor

$\delta_r \in (0,1)$:= depreciation rate

$\epsilon_{r,i}^{M}$:= monopoly/ oligopoly elasticity of demand

$\epsilon_{h,r}$:= CRRA parameter

$\gamma_{h,r,i}^{SG}$:= Stone-Geary sustenance parameter

$\mu_{r',i,r}^{GC}$:= Leontief share parameter

$\mu_r^{GS} \in [0,1]$:= government marginal propensity to save

$\mu_{h,r,i}^{HC} \in [0,1]$:= Leontief consumption share parameter

$\mu_{h,r}^{HS} \in (0,1)$:= marginal propensity to save (myopic model)

$\mu_{r',i,r}^{I}$:= share of investment by sector

$\mu_{r,i,j}^{V}$:= Leontief share parameter

$\mu_{r,i}^{Y}$:= Leontief share parameter

$\phi_r \in (0,1)$:= capital adjustment speed

ρ_i^H := CES substitution parameter

$\rho_{r,i}^V$:= Armington substitution parameter

$\tau_{r,j,t}^{p}$:= business tax rate

$\tau_{h,r}^{H}$:= tax rate for h

$\theta_{h,r}^{\Pi}$:= share of firm ownership

$\theta_{h,r}^{K}$:= share of capital endowment

$\theta_{h,r}^{L}$:= share of labour endowment

$\Psi_{h,r,i}^{C}$:= Armington push parameter

$\Psi_{r,i}^{K}$:= CES push parameter

$\Psi_{r,i}^{L}$:= CES push parameter

$\Psi_{r,i,j}^{V}$:= Armington push parameter

Variables:

Prices:

$cpi^H_{h,r,t} \in \mathbb{R}^*_+ :=$ consumer price index for h

$cpi_{r,t} \in \mathbb{R}^*_+ :=$ consumer price index

$gpi_{r.t} \in \mathbb{R}^*_+ :=$ government price index

$ipi_{r,t} \in \mathbb{R}^*_+ :=$ investment price index

$ir_r \in \mathbb{R}_+ :=$ interest rate

$pc^T_{h,r,i,t} \in \mathbb{R}^*_+ :=$ price of Armington good for h

$pd_{r,i,t} \in \mathbb{R}^*_+ :=$ market price

$ps_{r,j,t} \in \mathbb{R}_+ :=$ supply price

$pv_{r,i,t} \in \mathbb{R}_+ :=$ price of Armington intermediate good

$py_{r,i,t} \in \mathbb{R}_+ :=$ price of value added

$rk_{r,i,t} \in \mathbb{R}^*_+ :=$ rental rate of capital

$uck_{r,t} \in \mathbb{R}^*_+ :=$ user cost of capital

$w_{r,t} \in \mathbb{R}^*_+ :=$ wage

Quantities:

$\Pi_{r,i,t} \in \mathbb{R}_+ :=$ profits

$C^H_{h,r,t} \in \mathbb{R}_+ :=$ aggregate household consumption for representative household h

$C_{r,t} \in \mathbb{R}_+ :=$ aggregate household consumption

$CD^H_{h,r',r,t} \in \mathbb{R}_+ :=$ region r household consumption of goods from region r'

$CD_{r,t} \in \mathbb{R}_+ :=$ domestic household consumption

$CI_{r,t} \in \mathbb{R}_+ :=$ foreign household consumption

$CT^H_{h,r,i,t} \in \mathbb{R}_+ :=$ Armington good for h

$D_{r,i,t} \in \mathbb{R}_+ :=$ domestic demand

$f^Z_{r,i} \in \mathbb{R}_+ :=$ fixed cost of entry

$G_{r,t} \in \mathbb{R}_+ :=$ aggregate government expenditure

$G^C_{r',i,r,t} \in \mathbb{R}_+ :=$ government expenditure of i from r'

$G^Y_{r,t} \in \mathbb{R}_+ :=$ government income

$I^D_{r,i,t} \in \mathbb{R}_+ :=$ investment by destination

$I^O_{r',i,r,t} \in \mathbb{R}_+ :=$ investment by origin in i from r'

$I^T_{r,t} \in \mathbb{R}_+ :=$ total investment

$II^H_{h,r,t} \in \mathbb{R}_+ :=$ gross household income for representative household h

$II_{r,t} \in \mathbb{R}_+ :=$ gross household income

$K_{r,i,t} \in \mathbb{R}_+ :=$ capital demand

$KS^H_{h,r,t} \in \mathbb{R}_+ :=$ capital by household group

$KS^T_{r,i,t} \in \mathbb{R}_+ :=$ desired capital

$KS_{r,i,t} \in \mathbb{R}_+ :=$ capital supply

$L_{r,i,t} \in \mathbb{R}_+ :=$ labour demand

$LS_{r,t} \in \mathbb{R}_+ :=$ aggregate labour supply

$LS^H_{h,r,t} \in \mathbb{R}_+ :=$ labour supply by household group

$M^R_{r',i,r,t} \in \mathbb{R}_+ :=$ purchases of i from r' to r

$M_{r,i,t} \in \mathbb{R}_+ :=$ imports from ROW

$NZ_{r,i,t} \in \mathbb{R}_+ :=$ number of firm index

$O_{r,j,t} \in \mathbb{R}_+ :=$ output

$S^F_{r,t} \in \mathbb{R}_+ :=$ FDI

$S^G_{r,t} \in \mathbb{R}_+ :=$ government savings

$S^H_{h,r,t} \in \mathbb{R}_+ :=$ household saving for h

$S_{r,t} \in \mathbb{R}_+ :=$ aggregate household saving

$STK^F_r \in \mathbb{R}_+ :=$ foreign change in inventories (balancing item)

$STK_{r',i,r} \in \mathbb{R}_+ :=$ change in inventories

$T^F_{r,i,t} \in \mathbb{R}_+ :=$ indirect business tax

$T^H_{h,r,t} \in \mathbb{R} :=$ household tax for h

$T_{r,t} \in \mathbb{R} :=$ aggregate household tax

$TR^T_{r,t} \in \mathbb{R}_+ :=$ total government transfers

$TR_{h,r,t} \in \mathbb{R}_+ :=$ government transfers

$UN_{r,t} \in (0,1) :=$ unemployment rate

$V_{r,i,j,t} \in \mathbb{R}_+ :=$ Armington intermediate good

$VR_{r',i,r,j,t} \in \mathbb{R}_+ :=$ intermediate good

$X^R_{r',i,r,t} \in \mathbb{R}_+ :=$ sales of i from r' to r

$X_{r,i,t} \in \mathbb{R}_+ :=$ exports to ROW

$Y_{r,i,t} \in \mathbb{R}_+ :=$ value added

C.2 Expenditure by income group

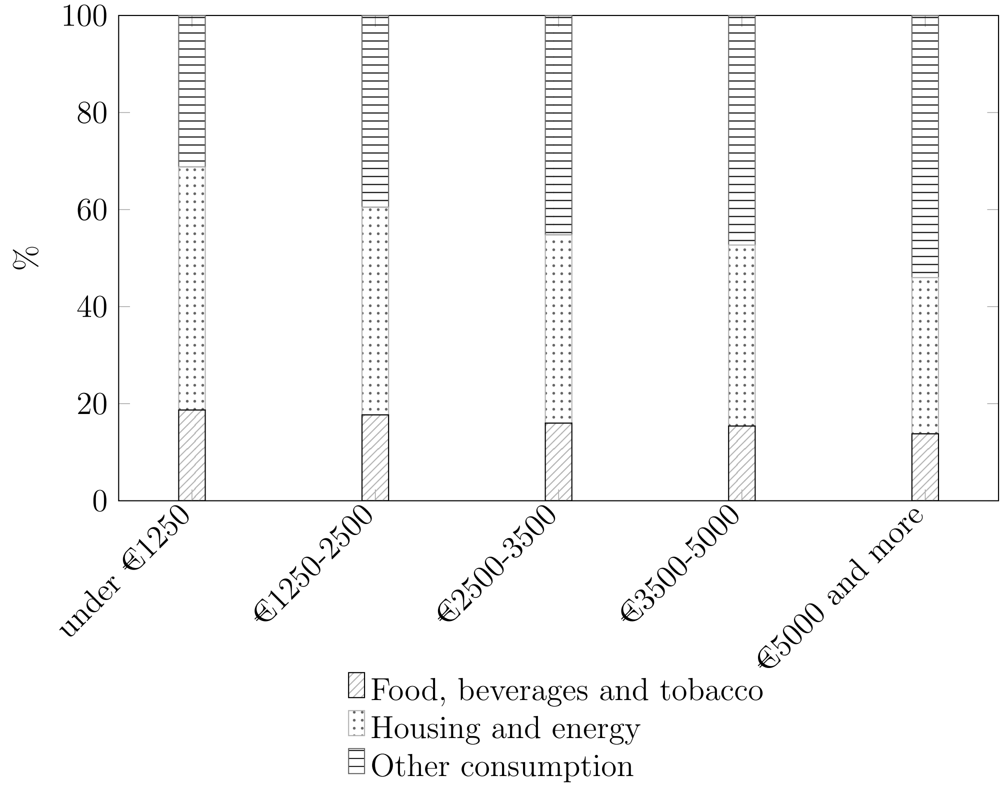


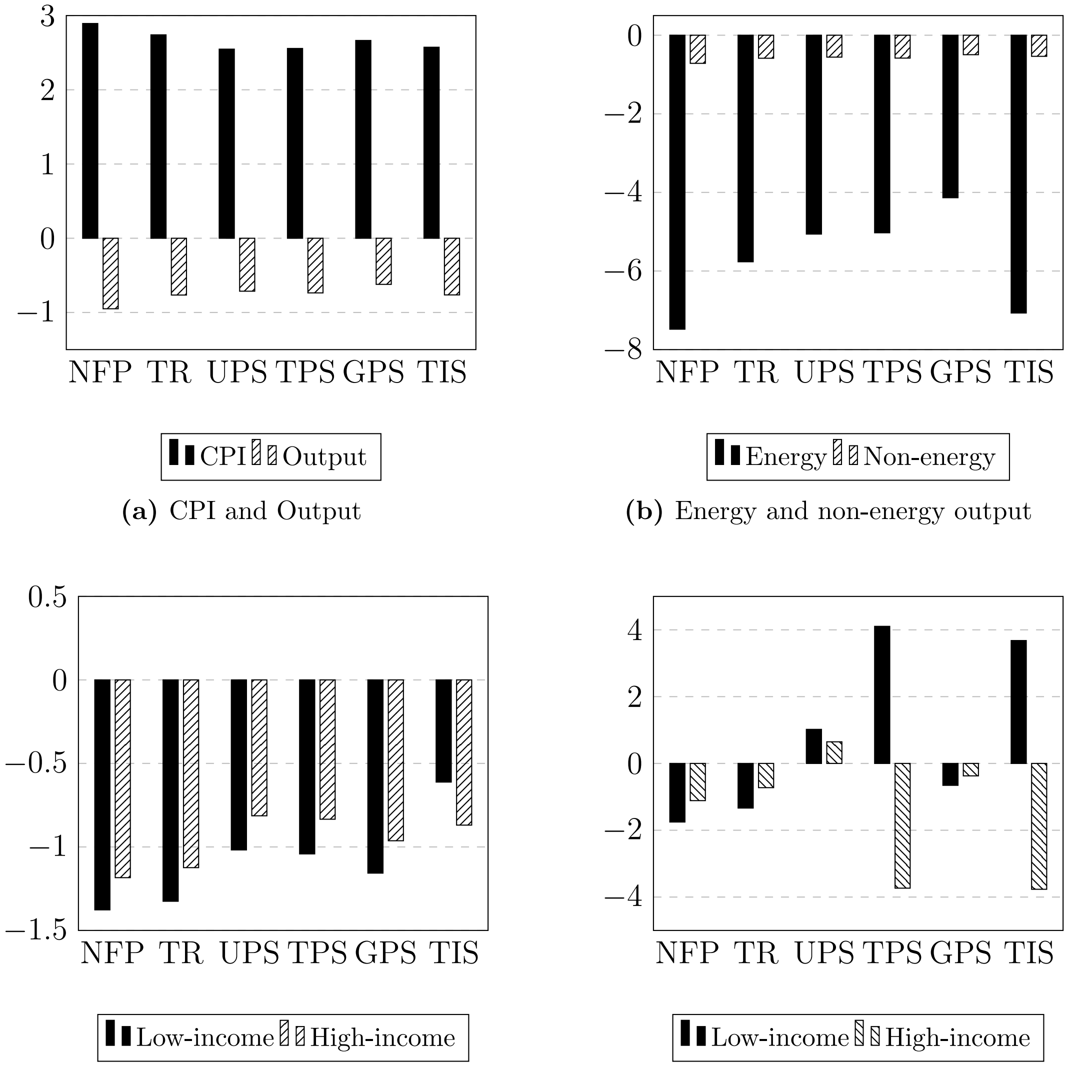
Figure C.1: Author's calculations of total expenditure proportions by income group (FSO, 2023a).

C.3 Data appendix

Table C.3.1: Author's matching of ISIC and FSO sectors

Figaro code	FSO Match
A, C	Food, beverages and tobacco, Clothing and footwear, Furnishings, equipment and household maintenance
B, C19, D	Housing, energy, maintenance of the dwelling
H	Transport
I	Restaurants and hotels
J	Postal and telecommunication services
P	Education
Q	Health
R	Recreation, entertainment and culture
N, O, S, T, U	Miscellaneous goods and services
E, F, G, K, L, M	*Aggregate minus matched weight*

C.4 Sensitivities



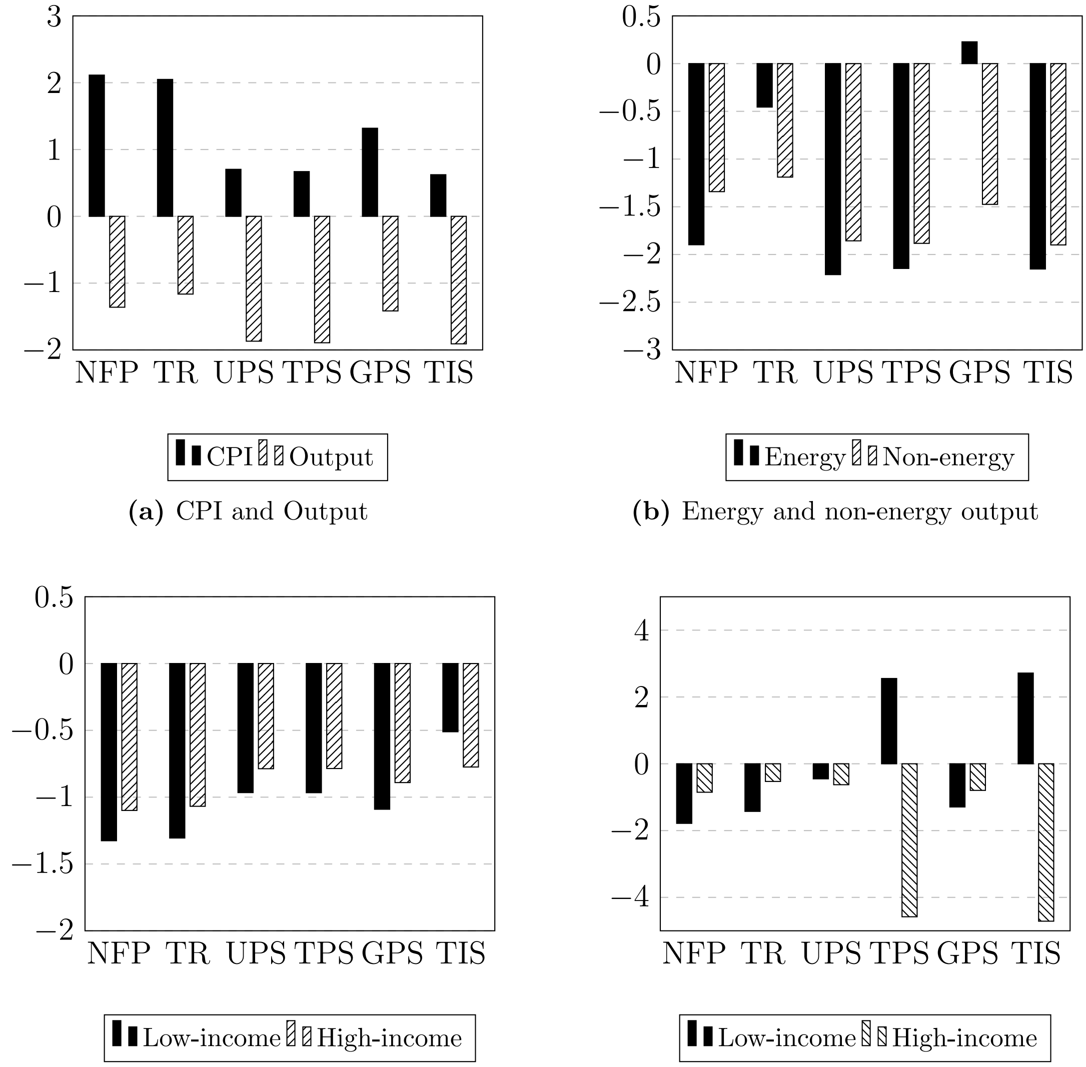
(a) CPI and Output

(b) Energy and non-energy output

(c) Real household income

(d) Consumption

Figure C.2: Short-run % deviations from a no-shock baseline for debt-financed policies (Cobb-Douglas consumption shares); NFP = no fiscal policy, TR = firm tax reduction, UPS = untargeted price subsidy, TPS = targeted price subsidy, GPS = general price subsidy, TIS = targeted income subsidy.



(a) CPI and Output

(b) Energy and non-energy output

(c) Real household income

(d) Consumption

Figure C.3: Short-run % deviations from a no-shock baseline for debt-financed policies (Leontief shares of consumption); NFP = no fiscal policy, TR = firm tax reduction, UPS = untargeted price subsidy, TPS = targeted price subsidy, GPS = general price subsidy, TIS = targeted income subsidy.

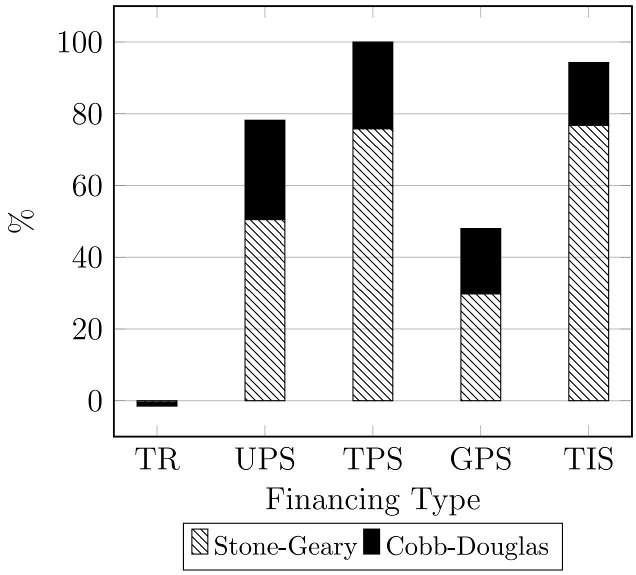
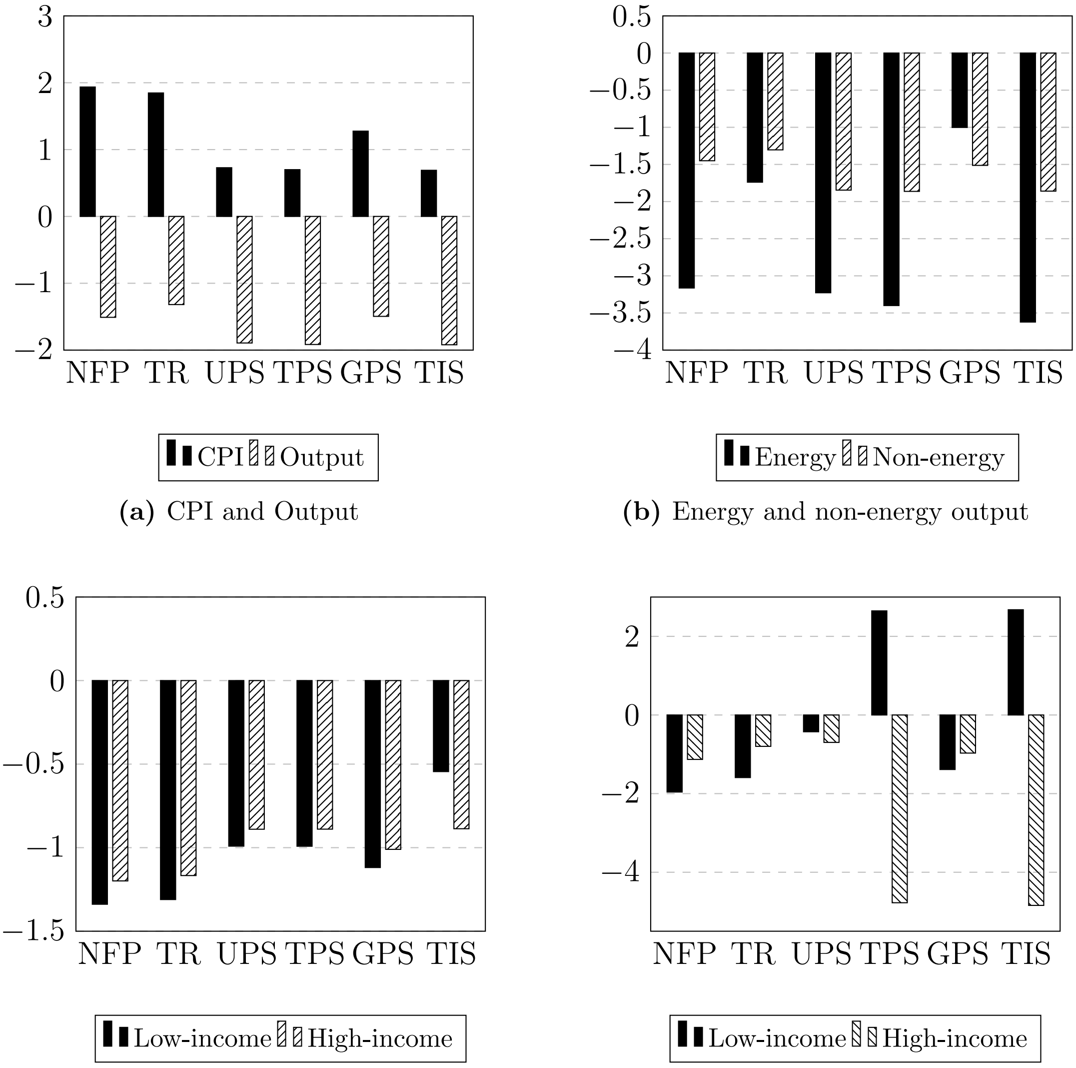


Figure C.4: Welfare in debt policies under Stone-Geary and Cobb-Douglas intersectoral household demand models when $\gamma_g = 0.42$



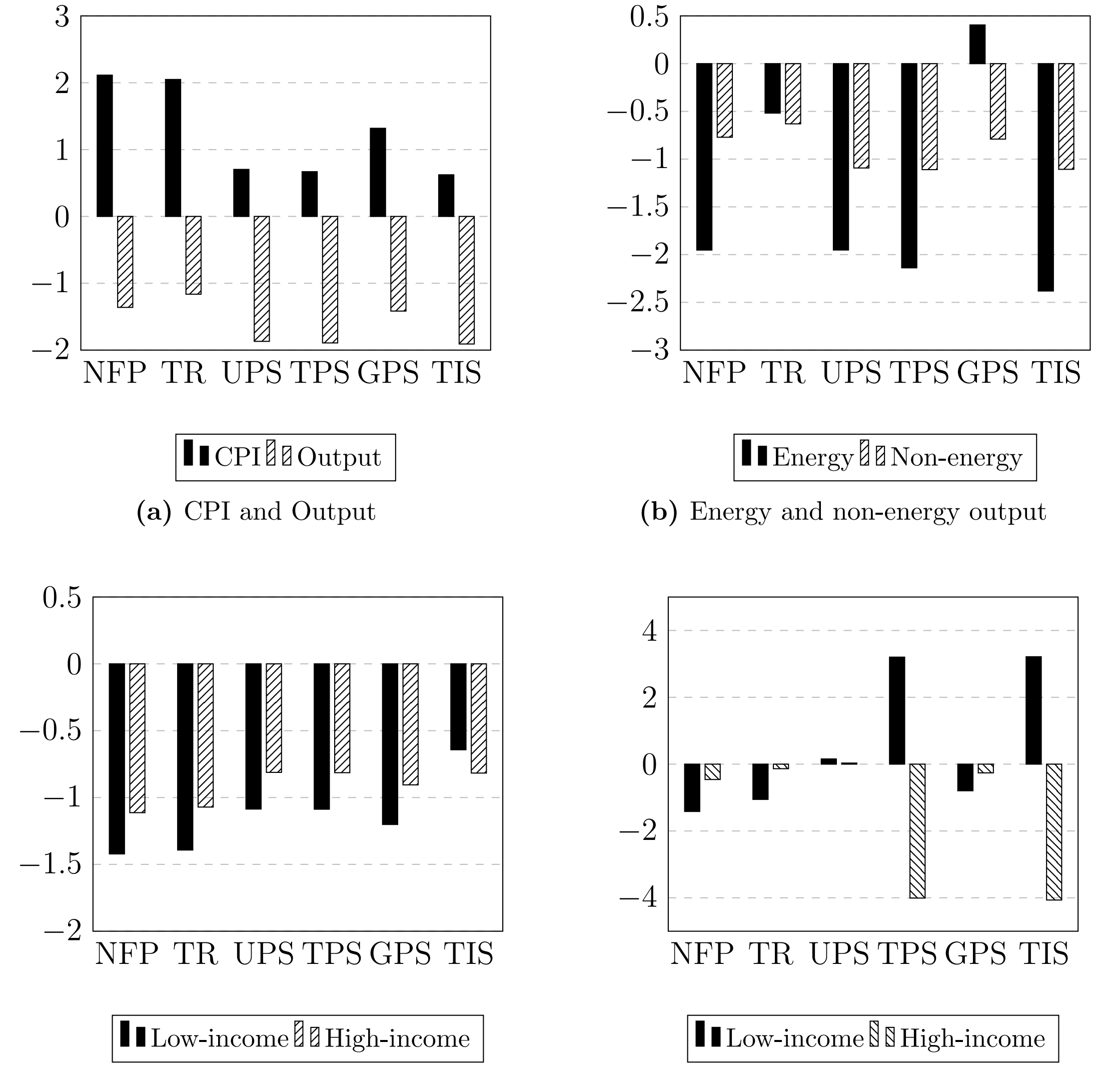
(a) CPI and Output

(b) Energy and non-energy output

(c) Real household income

(d) Consumption

Figure C.5: Short-run % deviations from a no-shock baseline for debt-financed policies (1% of capital allocated to profits); NFP = no fiscal policy, TR = firm tax reduction, UPS = untargeted price subsidy, TPS = targeted price subsidy, GPS = general price subsidy, TIS = targeted income subsidy.



(a) CPI and Output

(b) Energy and non-energy output

(c) Real household income

(d) Consumption

Figure C.6: Short-run % deviations from a no-shock baseline for debt-financed policies (50% of capital allocated to profits); NFP = no fiscal policy, TR = firm tax reduction, UPS = untargeted price subsidy, TPS = targeted price subsidy, GPS = general price subsidy, TIS = targeted income subsidy.

Appendix D

Chapter 5

D.1 BIC Heat Map

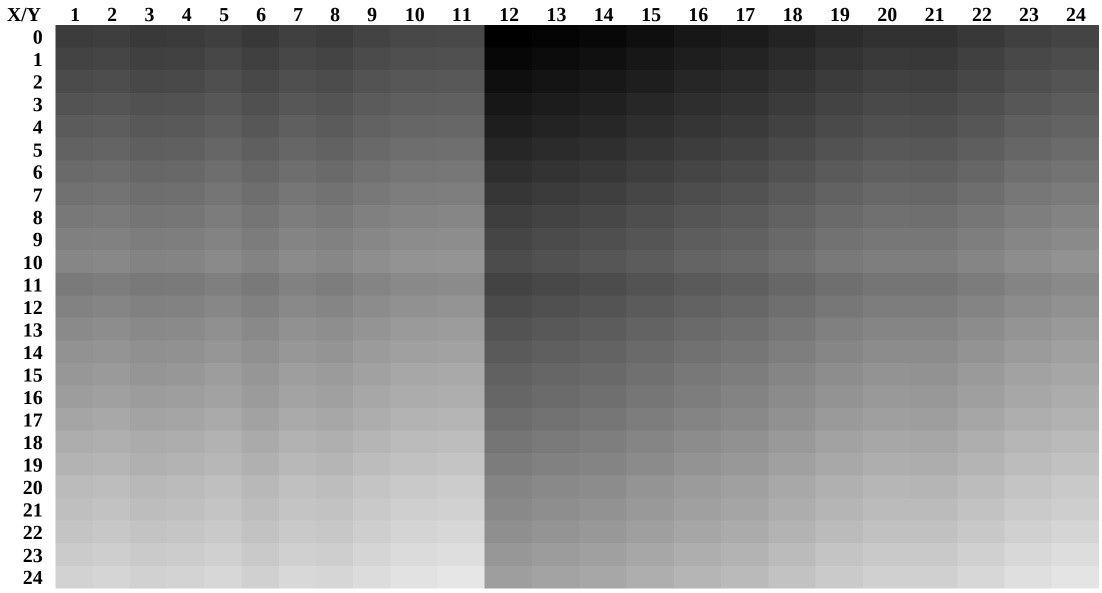


Figure D.1: Bayesian Information Criterion heat map developed by estimating equation (5.3) on APS data between 2006 and 2019 (ONS, 2023). X = number of unemployment lags, Y = number of composition corrected wage lags. No region trend.

Figure D.1 demonstrates that the optimal balance between parsimony and fit occurs for the model with no lags of unemployment and 12 lags of composition-corrected wages. An interesting observation is that the twelfth lag adds visually more to the model's fit than any other lag order. This implies that the previous year's wage is very important in determining contemporaneous wages.

D.2 APS sensitivities

Table D.2.1: Monthly Wage Curve - 2008 Structural Break

	[1]	[2]	[3]	[4]
Ψ_0	0.012*	0.001	0.005	0.001
	(0.006)	(0.007)	(0.006)	(0.007)
$\Delta\Psi_{t>2008}$	0.001	0.004	0.004	0.001
	(0.005)	(0.008)	(0.005)	(0.007)
φ_{12}	0.192***	0.159***	0.143***	0.128***
	(0.022)	(0.023)	(0.023)	(0.023)
Region fixed effect	Yes	Yes	Yes	Yes
Year & month fixed effect	Yes	Yes	Yes	Yes
Region time trend	No	Yes	No	Yes
First stage	Cross-section			
Dependent variable	Gross		Net	
Observations	2160	2160	2160	2160
R^2	0.991	0.991	0.992	0.992
Degrees of Freedom	1955	1944	1955	1944
$\varepsilon_{t<2009}$	0.029**	0.001	0.012	0.002
	(0.017)	(0.010)	(0.015)	(0.012)
$\varepsilon_{t>2008}$	0.032**	0.006	0.021	0.004
	(0.015)	(0.008)	(0.013)	(0.010)

Standard errors in parentheses; delta method employed to estimate ε standard errors
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table D.2.1 presents the results of the APS wage curve estimates when a structural break is allowed in December 2008. $\Delta\Psi_{t>2008}$ is positive across the models suggesting that the wage curve flattened/ became more positive following 2008. Although the coefficients are positive, these are inaccurately estimated. Indeed, the standard errors are larger than the coefficients in all cases. Hence, there is little evidence that the wage curve flattened in 2008 according to Table D.2.1.

As is found in Table D.2.2, there is some evidence of a flattening of the wage curve in Table D.2.2. The point estimates of the short- and long-run unemployment elasticity of wages are more positive in the 2009-2019 period. The difference in the coefficients across periods is not statistically significant at the 5% level.

Table D.2.2: Monthly Wage Curve - Sub-Periods

	2005-2008	2009-2019	2005-2008	2009-2019
Ψ_0	0.005	0.008	-0.011	0.007
	(0.015)	(0.007)	(0.015)	(0.007)
φ_{12}	0.130***	0.136***	0.0985**	0.114***
	(0.044)	(0.027)	(0.045)	(0.027)
Region fixed effect	Yes	Yes	Yes	Yes
Year & month fixed effect	Yes	Yes	Yes	Yes
Region time trend	Yes	Yes	Yes	Yes
First stage	Cross-section			
Dependent variable	Gross		Net	
Observations	576	1584	576	1584
R^2	0.993	0.991	0.995	0.990
df_r	493	1417	493	1417
ε	0.002	0.009	-0.007	0.010
	(0.008)	(0.008)	(0.009)	(0.009)

Standard errors in parentheses; delta method employed to estimate ε standard errors
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Consequently, although there is some evidence of a flattening based on the point estimates of D.2.1 and D.2.2, this is inconclusive due to the broad confidence intervals.