Optimal Monetary Policy during a Cost-of-Living Crisis*

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Abstract

How should monetary policy react to aggregate and sectoral disruptions in a world in which consumption baskets and hence inflation rates vary across households? We present a multi-sector New Keynesian with generalized, non-homothetic preferences and realistic heterogeneity in wealth, income, and consumption of different goods. Despite its richness, the model is computationally tractable. We highlight two novel wedges emerging in the New Keynesian Phillips Curve, which fluctuate with the distribution of consumption expenditures. We find that these wedges can have profound implications for the joint dynamics of inflation and the output gap, and hence policy trade-offs, in particular following sectoral shocks. Moreover, shocks and policy changes are found to have vastly heterogeneous effects on different households. Finally, we find that the optimal policy reaction to negative productivity shock is relatively loose, as compared to standard policy prescriptions, due to distributional concerns. The model is applied to the United Kingdom, and disciplined by micro data from the Living Costs and Food survey.

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1 Introduction

Since 2020, economies across the world have been subject to unprecedented supply disruptions, following the COVID-19 pandemic and the war in Ukraine. These developments resulted in a large increase in inflation in specific sectors, such as food and energy, which had unequal effects on households, depending on the composition of their consumption baskets. Low-income households have been hit disproportionately hard, as they tend to devote a relatively large fraction of their spending to necessity goods, which were subject to the largest price increases.[1] Indeed, the strong squeeze in real incomes, in particular among the poorest households, has led many commentators to declare the situation a "cost-of-living crisis".

To central banks, these events raised important yet unanswered questions: how to conduct monetary policy in a world in which inflation rates (and thus real interest rates) may differ sharply across households? What are the aggregate output versus inflation trade-offs following an uneven disruption of sectors? To what extent should the central bank aim to address distortions at the sector level, as well as the distributional implications of relative price movements? Is the Consumer Price Index (CPI) still an appropriate target for monetary policy?

To answer these questions in a comprehensive way, the standard New Keynesian model –a standard tool for monetary analysis– is arguably not well suited, even when extended with sectoral heterogeneity and inequality in household income and wealth. A key limitation is that preferences are typically assumed to be of a homothetic CES (Constant Elasticity of Substitution) form, which directly implies that the composition of consumption baskets is equal across households. As a result, all household share the same relevant price index and are equally affected by sector-specific price increases, unlike in reality.

[1] According to the Office for National Statistics, in October 2022, UK households in the lowest income decile faced on average a nearly 3 percentage points higher rate of inflation than those in the highest income decile, see ONS (2022).

In this paper, we develop a New Keynesian model which combines (i) multiple sectors, (ii) generalized, non-homothetic preferences, and (iii) realistic heterogeneity in income, wealth and consumption baskets. We use the model to study the positive as well as normative implications of aggregate and sector-level shocks.

A key feature of the model, which matters directly for policy trade-offs, is the emergence of two novel wedges in the New Keynesian Phillip Curves (NKPC), which move along with the distribution of of income and wealth across households.[2] The first wedge is a *non-homotheticity wedge*, which derives from the fact that households' marginal budget shares differ from their average budget shares. Specifically, they tend to devote a larger share of marginal spending to luxury goods than they do on average. Accordingly, households' marginal labor supply decisions are based on a real wage which deflates prices in different sectors according to marginal rather than average budget shares. This creates a disconnect with the real wage relevant to the average firm's marginal cost. Hence, sector-level price distortions affect workers and firms differently, which leads to a labor market distortion similar to a time-varying labor income tax.

The second wedge is in the NKPC is an *endogenous markup wedge*, which is due to the fact within-sector demand elasticities generally vary with the level of consumption once preferences are non-homothetic and non-CES. Realistically, poorer households are likely to be more price sensitive and demand elasticities may increase during recessions, as consumption falls. For firms, demand elasticities are a key consideration when setting markups. Fluctuations in the level and distribution of expenditures thus create fluctuations in markups, in addition to changes in markup distortions induced by nominal rigidities. However, while nominal distortions may be eliminated via a monetary policy which eliminates price stability, the central bank cannot fully neutralize the endogenous markup wedge, as it derives from real sources.

A practical advantage of the model's structure is that its steady state can be directly

[2]In the literature, exogenous markup shocks are often introduced to the NKPC, in order to generate meaningful policy trade-offs. In our setting, this role is fulfilled by the NKPC wedges.

disciplined by micro data on income, wealth and consumption across different consumption goods categories. The model can then be used to study how macroeconomic shocks and policy changes propagate through the income and wealth distribution and how this feeds into macroeconomic outcomes. Despite this richness, the model turns out to be computationally tractable, up to a first-order approximation. In particular, we can characterise the model as a system of sector-level NKPCs and Euler equations, complemented by a sector-level equation tracking the relevant aspects of the consumption distribution across households. For quantitative purposes, we extend the model with input-output linkages in production as well as hand-to-mouth households. We apply the model to the United Kingdom, feeding distributional data from the Living Costs and Food (LCF) survey directly into the model.

Quantitatively, we find that the two new wedges have important implications for the dynamics of inflation and the aggregate output gap, and that these implications can be very different for sector-level versus aggregate shocks. Specifically, we find that negative productivity shocks to necessity sectors, such as Food, push CPI inflation and the output gap in *opposite* directions, implying that a marginal tightening of monetary policy, in order to reduce inflation, would come at the expense of a more negative output gap. On the other hand, for aggregate productivity shocks and shocks to luxury sectors, such as Restaurants and Hotels, the output gap and the CPI in the same direction.

The model also implies that different shocks have highly heterogeneous effects on households, due to differences in income, wealth and consumption baskets. Some of these heterogeneous effects correlate with income, wealth, and demographic characteristics. For instance, a shock to the Food sector affects consumption of those in the lowest income decile more than twice as much as those in the highest decile. But even conditional on observed household characteristics, there is substantial heterogeneity in consumption responses.[3]

[3] In addition to non-homothetic preferences, the model includes idiosyncratic preference shifters for goods from different sectors. This allows us to discipline the steady state of the model directly with the

Finally, we turn to optimal monetary policy. We derive equation characterising the Ramsey Optimal Policy under commitment. In order to understand the policy trade-offs, we first consider optimal policy in simplified versions of the model. Next, we implement the optimal policy in the quantitative model. We find that optimal policy is generally more accommodating relative to negative productivity shocks compared to standard models, and keeps far from fully stabilizing fluctuations in inflation and the output gap. Distributional concerns play a key role in this regard.

Relation to the literature. A main contribution of this paper is to embed a generalized, non-homothetic preference structure into a multi-sector New Keynesian model with heterogeneous agents. Empirical evidence supporting the relevance of such preferences has a long history in the literature. A particularly famous and robust finding is that expenditure shares on food are negatively related to income (Engel, 1857; Houthakker, 1957). It is also understood that these patterns have important implications for the aggregate price indices and the measurement of inequality, see e.g. Hamilton (2001); Almås (2012); Argente and Lee (2021).

While in this paper we focus on monetary policy and business cycles, others have studied the implications for non-homothetic preferences for growth an structural transformation Herrendorf et al. (2014); Boppart (2014); Comin et al. (2021). Non-homothetic preferences are also recognized to have important policy implications. For instance, Jaravel and Olivi (2021) explore the implications for optimal income taxation, whereas Xhani (2021) studies the optimal taxation of firms.

The New-Keynesian literature typically sticks to the simplifying assumption of (homothetic) CES preferences.[4] Thereby, it rules out heterogeneity in consumption baskets

distribution of consumption baskets as observed in the LCF, in which we also observe demographic characteristics.

[4]Some authors in this literature have deviated from CES utility by assuming a Kimball demand function, see e.g. Smets and Wouters (2007). However, such preference preserve homotheticity and do not create endogenous markup fluctuations.

even when it features household heterogeneity.[5] Indeed, the mechanisms that we highlight complement (but interact with) the channels highlighted in the literature on monetary policy transmission in Heterogeneous Agents New-Keynesian (HANK) models, see e.g. McKay et al. (2016); Kaplan et al. (2017); Auclert (2019) and many others. This literature often emphasizes the role of heterogeneity in Marginal Propensities to Consume MPCs), a micro-level non-linearity which makes the distribution matter. In our setting, a key micro-level heterogeneity comes directly from preferences, as we move beyond the standard homothetic CES assumption.[6] Moreover, a key difference vis-à-vis most of the HANK literature is that in our model household heterogeneity matters not only for the demand block of the model (characterised by Euler equations and household constraints) but also for the supply block of the model, as characterised by the NKPC. Indeed, we show that household heterogeneity affects both the slope of the NKPC and the time-varying wedges that emerge under generalized preferences.

The normative analysis in this paper connects to the literature on how inequality and redistribution affect optimal monetary policy trade-offs in HANK models, which includes redistributive effects, see Challe (2020); Bhandari et al. (2021); Nuno and Thomas (2022). As explained above, non-homothetic preferences creates policy trade-offs which are not present in their models. Finally, the multi-sector structure of our model connects our contribution to several recent papers on intersectoral transmission of shocks in NK models, including Pasten et al. (2020); Rubbo (2019); LaO and Tahbaz-Salehi (2019); Baqaee et al. (2021); Guerrieri et al. (2022).

The remainder of this paper is organized as follows. Section 2 lays out the primitive model environment. In section 3, we linearize the model around a deterministic steady state and show that it can be solved using standard methods, despite the time-varying

[5]One exception is Blanco and Diz (2021) who study a representative-agent household NK model with two consumption good, on of which is subject to a subsistence point. Another one is Melcangi and Sterk (2019), who develop a heterogeneous-agents New Keynesian model with an infrequently consumed luxury good.

[6]For quantitative purposes, we also include MPC heterogeneity.

wealth distribution. We also discuss the parametrisation of the model. In Section 4 we inspect the mechanisms in a relatively simple version of the model, focusing on the role of the two new wedges in the NKPC. Results for the full quantitative model (including input-output linkages) are then presented in Section 5. Optimal policy is discussed in Section 6. Finally, Section 7 concludes.

2 Model Environment

2.1 Households

There is a continuum of heterogeneous households, of unit mass. In every period t, a household dies with a probability $\delta \in (0,1)$. The expected utility of a household j is given by:

$$\mathbb{E}_t \sum_{s=0}^{\infty} (\beta(1-\delta))^{t+s} \left(U(\mathbf{c}_{t+s}) - \chi(n_{t+s}) \right), \tag{1}$$

where $\mathbf{c}_t(j)$ is an overall consumption bundle, $n_t(j)$ is labor supply, $\beta \in (0,1)$ is the subjective discount factor, and $\mathbb{E}_t$ is the conditional expectations operator over aggregate risk. The overall consumption bundle consists of bundles of goods produced in different sectors, indexed by $k = 1, 2.., K$. The flow utility from consumption of these sectoral bundles is given by:

$$U(\mathbf{c}_t(j)) = U(\mathcal{U}(\mathbf{c}_{1,t}(j)), ..., \mathcal{U}(\mathbf{c}_{K,t}(j))),$$

where we assume that $U(\cdot)$ is weakly separable and symmetric across sectors. Each sectoral consumption bundle $\mathbf{c}_{k,t}(j)$ in turn consists of a unit-mass continuum of varieties, indexed by i. The sub-utility function $\mathcal{U}$ is symmetric across varieties, concave and twice Frechet differentiable. Moreover, $\chi(\cdot)$ is an increasing function.

Households differ in terms of their labor productivity, denoted by $\vartheta(j)$, which is constant over time. They are also heterogeneous in their ownership of firms. Households can further save in one-period nominal bonds, denoted by $b_t(j)$. The budget constraint of household j is given by:

$$e_t(j) + b_t(j) = R_{t-1} b_{t-1}(j) + \vartheta(j) n_t(j) W_t + \sum_k \varsigma_k(j) Div_{k,t}. \tag{2}$$

Here, $e_t(j) = \sum_k e_{k,t}(j) = \sum_k \int_0^1 p_{k,t}(i) c_{k,t}(i,j) di$ are the household's total consumption expenditures, R_t is the gross nominal interest rate on bonds, which is set by a monetary authority, W_t is the nominal wage per effective unit of labor, $Div_{k,t}$ are total dividends from sector k and $\varsigma_k(j)$ is the share of households of type j in firms in sector k.

In any period t, household j chooses consumption of each goods variety ($c_{k,t}(i,j)$), bond holdings ($b_t(j)$) and labor supply ($n_t(j)$) to maximize utility objective (1), subject to the budget constraint (2) and the laws of motion of equilibrium objects exogenous to households. Deceased households are replaced by newborn households and we assume that the distribution of wealth of newborn households coincides with the steady-state distribution of wealth across all households.[7]

Some notation. In the absence of a parametric form for household preferences, let us introduce some notation regarding household behavior. As shown in the appendix, we can express the demand of household j for a certain goods variety as a function of its price, $p_{k,t}(i)$), the set of all other prices in the sector, denoted $\mathbf{p}_k$, and the total expenditures of the household on sector k goods, $e_{k,t}(j)$. We denote this demand function by $c_{k,t}(i,j) = d_k\left(p_{k,t}(i), \mathbf{p}_{k,t}, e_{k,t}(j)\right)$.

We can now define a number of partial equilibrium objects, evaluated at the steady state of the model with zero inflation and therefore equal prices within sectors ($P_k = p_k(i)$ for any variety i in sector k). These statistics, which may all vary across households, are presented in Table 1.

The price elasticity of demand is denoted by $\epsilon_k(j)$, and note that it varies not only

[7]This overlapping generations structure rules out long-term effects of transitory shocks. The model is consistent with any arbitrary steady-state distribution of wealth. Below we elaborate further on this point.

Table 1. Steady-state statistics

Demand elasticity:	$\epsilon_k(j) = \frac{\partial c_k(i,j)}{\partial p_k(i)} \frac{p_k(i)}{c_k(i,j)}$
Super-elasticity:	$\epsilon^s_k(j) = \frac{\partial \epsilon_k(j)}{\partial p_k(i)} \frac{p_k(i)}{\epsilon_k(j)}$
Cross-price elasticity:	$\rho_{k,l}(j) = \frac{P_l}{c_k(j)} \frac{\partial c_k(j)}{\partial P_l}$
Budget share:	$s_k(j) = \frac{e_k(j)}{e(j)}$
Marginal budget share:	$\xi_k(j) = \frac{\partial e_k(j)}{\partial e(j)}$
Elasticity of Intertemporal Substitution:	$\sigma(j) = \frac{\partial \ln(e_{t+1}(j)/e_t(j))}{\partial R}$
Frisch elasticity of labor supply:	$\psi(j) = \frac{\partial_n \chi(j)}{\partial_n \partial_n \chi(j) n(j)}$

across households, but also across sectors. While $\epsilon_k(j)$ denotes the demand elasticity at the steady state, the distribution of demand elasticities moves around over time, as households change their levels of expenditures in response to shocks. The extent of this time-variation is governed by the super-elasticity of demand, i.e. the elasticity of with respect to the price, is denoted by $\epsilon^s_k(j)$.[8]

Next, the cross-price elasticity, i.e. the change in consumption in sector k bundle in response to a change in the price the sector l bundle (P_l), is denoted by $\rho_{k,l}(j)$. The budget share, i.e. the share of sector-k goods in the total expenditures of a household, is denoted by $s_k(j)$. Moreover, we denote the *marginal* budget share by $\xi_k(j)$. This is the fraction of any marginal unit of total expenditures that a households spends on goods in sector k.

Finally, we denote the Elasticity of Intertemporal Substitution (EIS) by $\sigma(j)$. Similarly, we define the Frisch elasticity of labour supply by $\psi(j)$ (see the Appendix for a derivation). For now, we will assume this elasticity is homogeneous across households, denoting it by ψ. In the Appendix we present the case with heterogeneous Frisch elasticities.

[8]The super-elasticity pins down how the demand elasticity changes with the level of expenditures. To see this, note that $\frac{\partial \epsilon_k(j)}{\partial e_k(j)} \frac{e_k(j)}{\epsilon_k(j)} = \frac{\epsilon^s_k(j)}{\epsilon_k(j)}$.

2.2 Firms

Firms are monopolistically competitive, each producing a single goods variety in a certain sector. Within a sector, there is a unit measure of firms which are ex-ante identical. Firms are subject to a Calvo-style pricing rigidity, which means that they are able to adjust their price with a probability $1-\theta_k$ in every period. This probability may vary across sectors. The firms produce with a linear technology given by

$$y_{k,t}(i) = A_{k,t} l_{k,t}(i). \tag{3}$$

Here $A_{k,t}$ is an exogenous productivity variable, which may vary over time and across sectors, but is homogeneous among firms within a certain sector. Moreover, $l_{k,t}(i)$ are effective units of labor hired by the firm. Firms take as given the aggregate of household demand functions, given by

$$y_{k,t}(i) = D\left(p_{k,t}(i), \mathbf{p}_{k,t}, e_{k,t}(j)\right) \equiv \int_0^1 d_k\left(p_{k,t}(i), \mathbf{p}_{k,t}, e_{k,t}(j)\right) dj. \tag{4}$$

Firms which are allowed to adjust their price do so to maximize the expected present value of profits. The decision problem of firms which can adjust the price is given by:

$$\max_{p_{k,t}(i), l_{k,t}(i), y_{k,t}(i)} \mathbb{E}_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \theta_k^s (p_{k,t+s}(i)((1+\tilde{\tau}_k) y_{k,t+s}(i) - W_{t+s} l_{k,t+s}(i)) - T_{k,t}), \tag{5}$$

subject to Equations (19) and (4), where $\Lambda_{t,t+s}$ is the firm's stochastic discount factor.[9] In the above equation, $\tilde{\tau}_k$ is a time-invariant, sector-specific subsidy which may be used by the government to correct markup distortions in the steady state, and $T_{k,t}$ a lump-sum tax to finance the subsidy.

[9] We do not specify the details of the discount factor since we will linearize the model around a steady state with zero inflation, which implies that $\Lambda_{t,t+s}$ drops out of the equations.

2.3 Government Policy

We assume that the fiscal authority runs a balanced budget, which implies

$$\sum_k \tilde{\tau}_k \int_0^1 y_{k,t}(i)di - \sum_k T_{k,t} = 0. \tag{6}$$

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The nominal interest rate R_t is set by the monetary authority. We will study how the interest rate is set optimally (taking fiscal policy as given). We will also consider a simple interest rate rules and study how closely such rules can approximate monetary policy.[10]

2.4 Demographics and Equilibrium

In any period, a fraction δ of all household dies. We assume that each deceased household is replaced by a new household of the same type, with the steady-state level of assets of that type. Bond market clearing implies that the average wealth of households is zero, and hence the same is true for deceased and newborn households, due to the large of large numbers. Therefore, the wealth given to new households can always be financed and the net inheritance from all deceased households is zero.

Clearing in the labor market and the goods market requires, respectively:

$$\begin{aligned} \int_0^1 \vartheta(j) n_t(j) dj &= \sum_k \int_0^1 l_{k,t}(i) di, \\ \int_0^1 b_t(j) dj &= 0. \end{aligned} \tag{7}$$

Goods market clearing requires, for any goods variety:

$$\int_0^1 c_{k,t}(i,j)dj = y_{k,t}(i). \tag{8}$$

[10] Alternatively, one could include sector-level output gaps or price levels in the rule, without compromising the model's tractability.

An equilibrium is a law of motion for prices and allocations such that households, firms and the government behave as specified above, and markets clear. As is common in the New Keynesian literature, we linearize the model around a steady state, in order to study dynamics.

3 Dynamic Equations and Quantitative Implementation

We solve for the dyanmic equilibrium of the model by linearizing it around a deterministic steady state. The dynamic linearized equations, presented in Section 3.1, provide several preliminary but important insights into the workings of the model and policy trade-offs. In particular, we will demonstrate the emergence of novel wedges in the New Keynesian Phillips Curve. In Section 3.2 we discuss the parametrization of the model. Finally, in Section 3.3 we discuss extensions of the model with input-output linkages and hand-to-mouth households.

3.1 The linearized model

We linearize the model around a deterministic steady state in which prices are identical within sectors. We assume the central bank targets price stability in the steady state. We further assume that the government eliminates steady-state markups are equalized using time-invariant subsidies, financed using lump-sum taxes on firms. In the appendix, we provide derivations for the results presented below.

New Keynesian Phillips Curve. Let $\hat{P}_{k,t} = \int_i \hat{p}_{k,t}(i)di$ be the price of the sector- k consumption bundle, where hatted variables denote log deviations from the steady state.[11] The net rate of inflation in sector $k = 1, 2, ..., K$ is given by:

$$\pi_{k,t} = \hat{P}_{k,t} - \hat{P}_{k,t-1}, \tag{9}$$

[11] Here we use that in the steady state prices are identical.

Let $\bar{\sigma} = \int \frac{e(j)}{E} \sigma(j) dj$ be the expenditure-weighted average EIS, where E denotes aggregate consumption expenditures. The New Keynesian Phillips Curve (NKPC) for any sector $k = 1, .., K$ can be expressed as:

$$\pi_{k,t} = \lambda_k \left(\tilde{\mathcal{Y}}_t - \mathcal{P}_{k,t} + \mathcal{NH}_t + \mathcal{M}_{k,t} \right) + \beta \mathbb{E}_t \pi_{k,t+1}, \tag{10}$$

where

$$\lambda_k = \frac{(1-\theta_k)(1-\beta\theta_k)}{\theta_k} \frac{\bar{\epsilon}_k - 1}{\bar{\epsilon}_k - 1 + \bar{\eta}_k}, \qquad \text{(slope NKPC)}$$

$$\tilde{\mathcal{Y}}_t = (\frac{1}{\bar{\sigma}} + \frac{1}{\psi})(\hat{\mathcal{Y}}_t - \hat{\mathcal{Y}}_t^*), \qquad \text{(Output gap)}$$

$$\mathcal{P}_{k,t} = (\hat{P}_{k,t} - \hat{P}_{cpi,t}) - (\hat{P}_{k,t}^* - \hat{P}_{cpi,t}^*), \qquad \text{(Relative price wedge)}$$

$$\mathcal{NH}_t = \sum_l (\bar{\xi}_l - \bar{s}_l)(\hat{P}_{l,t} - \hat{P}_{l,t}^*), \qquad \text{(Non-homotheticity wedge)}$$

$$\mathcal{M}_{k,t} = \int \gamma_{e,k}(j) \hat{c}_{k,t}(j) dj. \qquad \text{(Endogenous markup wedge)}$$

Before explaining the generalized NKPC in detail, let us note that has the same form as the "standard" NKPC, but with a modified slope and additional wedges. Specifically, the equation relates current sectoral rate of inflation, $\pi_{t,k}$, to the discounted expected rate of inflation, $\beta \mathbb{E}_t \pi_{k,t+1}$, and a term related to marginal costs and markup distortions, denote in between brackets. The latter consists of an aggregate "output gap", $\tilde{\mathcal{Y}}_t$, as well as a sectoral relative price wedge, $\mathcal{P}_{k,t}$, both of which are also present in multi-sector New-Keynesian model with standard homothetic CES preferences. In addition, there is a new wedge, $\mathcal{NH}_t$, which arises due to non-homothetic preferences, i.e. consumption baskets varying with the total level of expenditures. Moreover, another new wedge, $\mathcal{M}_{k,t}$, arises due to changes in markups due to fluctuations in the elasticity of demand faced by firms, which is no long constant once one deviates from CES preferences. We label this wedge the "endogenous markup wedge". The two new wedges will affect the trade-offs between output and inflation faced by the central bank.

Slope of the NKPC. Let us now discuss the equation in more detail, starting with the slope coefficient λ_k. It is modified by term $\frac{\bar{\epsilon}_k-1}{\bar{\epsilon}_k-1+\bar{\eta}_k}$, where $\bar{\epsilon}_k \equiv \int \frac{e_k(j)}{E_k}\epsilon_k(j)dj$ is the average demand elasticity weighted by expenditures, with $E_k \equiv \int e_k(j)dj$ being aggregate expenditure in sector k. Moreover, $\bar{\eta}_k \equiv P_k \partial_p ln(\bar{\epsilon}_k) = \left(-\int (\epsilon_k(j)-\bar{\epsilon}_k)^2 \frac{e_k(j)}{E_k}dj + \int \frac{\epsilon_k^s(j)}{\epsilon_k(j)}\frac{e_k(j)}{E_k}dj\right) / \bar{\epsilon}_k$ is the super-elasticity of aggregate demand, which is pinned down by the joint distribution of individual elasticities, super-elasticities and expenditures in the steady state.

The modification of λ_k captures the degree of imperfect pass-through of marginal costs to prices which is unrelated to nominal rigidities, but rather due to deviation from CES preferences.[12] Intuitively, a firm realises that when it increases its price, not only doe households' expenditure levels change, but with it also their demand elasticities, which prompts firms to change the markup. As a result a firm may, for instance, choose to pass on a marginal cost shock less than one-for-one to its customers, even if prices were to be fully flexible.

Note that λ_k now depends on the entire steady-state distribution of expenditures. Thus, long-run changes in inequality affect the slope of the NKPC in our setting. As such, our environment different from other HANK settings, in the sense that inequality affects not only the "demand block" of the model, but also the "supply block", as captured by the NKPC.

Having discussed the slope, let us now turn to the terms within brackets in equation 10.

Output gap. The first term is given by $\tilde{\mathcal{Y}}_t = (\frac{1}{\bar{\sigma}} + \frac{1}{\psi})(\hat{\mathcal{Y}}_t - \hat{\mathcal{Y}}_t^*)$, where $\hat{\mathcal{Y}}_t$ is an aggregate demand index, and $\hat{\mathcal{Y}}_t^*$ is its counterpart in the absence of any markup distortions. This term is also present in the most basic NK model, and it is commonly referred to as the

[12]In the special case of CES preferences, demand elasticities are constant over time and across households, which implies $\bar{\eta}_k = 0$. We then obtain the standard coefficient $\lambda_k = \frac{(1-\theta_k)(1-\beta\theta_k)}{\theta_k}$.

"output gap". A positive output gap exerts upward pressure on wages, which induces firms to increase prices. The demand index evolves according to the following Euler equation:

$$\hat{\mathcal{Y}}_t = \mathbb{E}_t \hat{\mathcal{Y}}_{t+1} - \bar{\sigma}\left(\hat{R}_t - \mathbb{E}_t \pi_{cpi,t+1} - \mathbb{E}_t \tilde{\pi}_{\mathcal{NH},t+1}\right), \tag{11}$$

where $\pi_{cpi,t} = \sum_k \bar{s}_k \pi_{k,t}$ is growth rate of the consumer price index, i.e. cpi inflation, which weighs sectors according to their average budget shares. The above equation is the standard consumption Euler equation, except for a wedge which adjusts expected inflation for the non-homothetic preferences, which is given by: $\tilde{\pi}_{\mathcal{NH},t} = \sum_{k=1}^{K}\left(\frac{\bar{\sigma}_k + \psi\bar{\bar{\xi}}_k}{\bar{\sigma}+\psi} - \bar{s}_k\right)\pi_{k,t}$, where $\bar{\sigma}_k = \int \frac{e(j)}{E}\xi(j)\sigma(j)dj$ is the good-specific average EIS and $\bar{\bar{\xi}}_k = \int_j \frac{\vartheta(j)Wn(j)}{\int_j \vartheta(j)Wn(j)}\xi_k(j)dj$ is the marginal budget share on good l, weighted by labor income and averaged across households. The wedge $\tilde{\pi}_{\mathcal{NH},t}$ adjusts for the fact that, generally, marginal budget shares do not equal average budget shares. Intuitively, expected inflation in a sector with a small marginal budget share has a small impact on the real interest rate relevant to the households' consumption saving decisions, even if that sector has a high average budget share.

In the Appendix we show that under flexible prices the demand index is given by $\hat{\mathcal{Y}}_t^* = \sum_k \frac{\psi\bar{\bar{\xi}}_k + \bar{s}_k}{1+\bar{\sigma}}\hat{A}_{k,t}$, where $\bar{s}_k = \frac{E_k}{E}$ is the share of sector k in aggregate expenditures.

Relative price wedge. The second marginal cost component in Equation 10, $\mathcal{P}_{k,t} = (\hat{P}_{k,t} - \hat{P}_{cpi,t}) - (\hat{P}^*_{k,t} - \hat{P}^*_{cpi,t})$ arises due to distortions in relative sectoral prices, which can arise for instance due to sectoral heterogeneity in the degree of price stickiness. Specifically, $\hat{P}_{k,t} - \hat{P}_{cpi,t}$ is the sectoral price, relative to the CPI index $P_{cpi,t} = \sum_l \bar{s}_l P_{l,t}$, and $\hat{P}^*_{k,t} - \hat{P}^*_{cpi,t}$ is its counterpart in the absence of markup distortions, where it can be shown that $\hat{P}^*_{k,t} = -\hat{A}_{k,t}$. The wedge $\mathcal{P}_{k,t}$ is generally present in multi-sector extensions of the standard NK model.

Non-homotheticity wedge. The next term, $\mathcal{NH}_t = \sum_{l=1}^{K}(\bar{\xi}_l - \bar{s}_l)(\hat{P}_{l,t} - \hat{P}^*_{l,t})$, is a wedge which arises due to non-homothetic preferences.[13] The wedge increases when prices are distorted upwards ($\hat{P}_{l,t} > \hat{P}^*_{l,t}$) relatively more in sectors with a high marginal budget share relative to their average shares ($\bar{\xi}_l > \bar{s}_l$). Note that the wedge is the same for all sectors. The wedge emerges from the fact that the price index relevant to workers' real wages are weighted with marginal rather than average budget shares. This creates a discrepancy vis-à-vis real wages relevant to firms' marginal costs, resulting in a wedge similar to a "labour wedge" which has been studied widely in the business cycle literature. The effect of a rise in $\mathcal{NH}_t$ is then similar to an increase in labor income taxation. We will later return to this interpretation in more detail, and discuss the role of this wedge in shaping aggregate dynamics.

Endogenous markup wedge. Finally, $\mathcal{M}_{k,t} = \int \gamma_{e,k}(j)\hat{c}_{k,t}(j)dj$ is wedge which captures the evolution of the distribution of demand elasticities, which affects inflation via the price setting behavior of the firms. Here, $\gamma_{e,k}(j) = \left(1 - \frac{\epsilon_k(j)}{\bar{\epsilon}_k}\left(1 + \epsilon^s_k(j)\right)\right)\frac{1}{\bar{\epsilon}_k - 1}$ captures how the individual demand elasticity varies with the level of expenditures, and where $s_l(j) = \frac{e_l(j)}{e(j)}$ is household j's budget share on good l.

The wedge thus arises due to deviation from CES utility.[14] Indeed, $\gamma_{e,k}(j) = 0$ under homothetic preferences, since $\epsilon^s_k(j) = 0$ and $\epsilon_k(j) = \bar{\epsilon}_k$, since demand elasticities are constant. It then follows that $\mathcal{M}_{k,t} = 0$ at all times under CES preferences.

The wedge takes the same for as exogenous markup shocks often considered in New Keynesian models. However, in our setting it is a rich endogenous object, which is shaped by the distribution of expenditures across households, and therefore moves along with the distribution of income and wealth.

Nonetheless, it turns out that the evolution of the endogenous markup wedge can be

[13]Indeed, note that under homothetic preferences $\mathcal{NH}_t = 0$, since in that case marginal budget shares equal average budget shares ($\bar{\xi}_l = \bar{s}_l$).

[14]Note that preferences may be homothetic but non-CES and vice versa.

represented in a tractable way. Specifically, it can be decomposed as:

$$\mathcal{M}_{k,t} = \mathcal{M}_{k,t}^{P} + \mathcal{M}_{k,t}^{E}. \tag{12}$$

The first component captures how substitutions in response to changes in prices in other sectors affect demand elasticities:

$$\mathcal{M}_{k,t}^{P} = \sum_{l} \mathcal{S}_{k,l} \cdot \left(\hat{P}_{l,t} - \hat{P}_{k,t}\right), \tag{13}$$

where $\mathcal{S}_{k,l} = \int_j \frac{e_k(j)}{E_k} \gamma_{e,k}(j) \rho_{k,l}(j) dj$ captures the effect of cross-price substitution on demand elasticities, and hence markups.

The second component, $\mathcal{M}_{k,t}^{E}$, captures changes in the distribution of household-level real expenditures. Its evolution can be characterized by the following equation:

$$\mathcal{M}_{k,t}^{E} = \mathbb{E}_t \mathcal{M}_{k,t+1}^{E} - \bar{\gamma}_{e,k} \bar{\sigma}_{k}^{\mathcal{M}} \hat{R}_t + \sum_{l} \bar{\gamma}_{e,k} \bar{\sigma}_{k,l}^{\mathcal{M}} \mathbb{E}_t \pi_{l,t+1} - \frac{\delta}{1-\delta} \mathbb{E}_t \mathcal{M}_{k,t}^{0}, \tag{14}$$

for any sector $k = 1, .., K$, where

$$\begin{aligned}
\bar{\gamma}_{e,k} &= \int \frac{e(j)}{E} \gamma_{e,k}(j) dj, \\
\bar{\sigma}_{k}^{\mathcal{M}} &= \int \frac{\gamma_{e,k}(j)}{\bar{\gamma}_{e,k}} \frac{e(j)}{E_k} \xi_k(j) \sigma(j) dj, \\
\bar{\sigma}_{k,l}^{\mathcal{M}} &= \int \frac{\gamma_{e,k}(j)}{\bar{\gamma}_{e,k}} \frac{e(j)}{E_k} \xi_k(j) \xi_l(j)\, \sigma(j) dj.
\end{aligned}$$

In Equation (14), $\mathcal{M}_{k,t+1}^{0}$ captures the contribution of the newborn agents to the endogenous markup wedge. Assuming that the share of profit is proportional to household j, this variable is pinned down by the following equation (for any $k = 1, .., K$):

$$\frac{1}{(1-\delta) R}\hat{\mathcal{M}}^0_{k,t} = \hat{\mathcal{M}}^0_{k,t-1} - \int \gamma_{b,k}(j) \frac{b(j)}{RE} dj \left(\hat{R}_t - \sum_l \bar{s}_l \pi_{l,t+1} \right) - \left(1 + \frac{\bar{\psi}}{\bar{\sigma}} \right) \int \gamma_{b,k}(j) \frac{wn(j)}{WL} dj \hat{\mathcal{Y}}_t$$
$$- \sum_l \int \gamma_{b,k}(j) \left(\frac{e(j)}{E} \left(\bar{s}_l - s_l(j) \right) + \frac{wn(j)}{WL} \left(\bar{\psi}_l - \psi_l(j) \right) \right) dj \hat{P}_{l,t} + \frac{R-1}{R} \hat{\mathcal{M}}^E_{k,t}, \tag{15}$$

with an initial value for $\mathcal{M}^0_{k,t-1}$ given and where $b_0(j)$ is the initial wealth of a newborn household, $\gamma_{b,k}(j) = \frac{R-1}{R} \frac{\gamma_{e,k}(j)\xi_k(j)}{1+\frac{W\xi(j)n(j)\psi}{e(j)\sigma(j)}}$ captures the change in markup when the wealth of agent j increases.[15]

Monetary policy. Regarding monetary policy, we will consider a simple interest rate rule of the following form:

$$\hat{R}_t = \sum_k \phi_k \pi_{k,t}, \tag{16}$$

where setting $\phi_k = \phi \bar{s}_k$ delivers a rule which responds to the CPI inflation rate. In section 6, we will analyze the optimal path of the nominal interest rate and how well the optimal policy can be approximated by a simple rule.

Equilibrium. Equations (9)-(16) constitute a system of $4K + 2$ equations in $4K + 2$ variables, given by $\{\hat{P}_t, \pi_{k,t}, \mathcal{M}^E_{k,t}, \mathcal{M}^P_{k,t}, \mathcal{M}^0_{k,t}\}_{k=1}^K, \hat{\mathcal{Y}}_t, \hat{R}_t$. We can thus characterise the model with a core block of equations, despite the fact that fluctuations in the distribution of income and wealth matter for the aggregate equilibrium outcomes. The equations for $\mathcal{M}^E_{k,t}$ and $\mathcal{M}^0_{k,t}$ keep track of the relevant distributional moments in a tractable way.

Distributional dynamics. While we do not need to keep track of full distributional dynamics in order to solve for the aggregate equilibrium, it is straightforward to solve for

[15]Indeed an increase in wealth increases total expenditure by $\frac{R-1}{R} \frac{1}{1+\frac{W\xi(j)n(j)\psi}{e(j)\sigma(j)}}$ where first term is the marginal propensity to spend out of wealth and the second captures the reduction in income due to the wealth effect on labor supply.

such dynamics. Here, we focus on the distribution of consumption, which are of primary interest from a welfare perspective. Let us define the response of real consumption expenditures of household j as $\hat{c}_t(j) = \hat{e}_t(j) - \sum_{l=1}^{K} s_l(j)\widehat{P}_{l,t}$.[16] Moreover, let $\chi(j)$ be a function defining arbitrary weights on households, with $\int \chi(j)dj = 1$. This function can be used to select particular households.

Suppose that we are interested in some moment $\hat{C}_{\chi,t} = \int \chi(j)\hat{c}_t(j)dj$. For instance, if we set $\chi(j) = e(j)/E$, then this moment corresponds to the aggregate response of real expenditures. We could also set $\chi(j) = 1$ for only one specific household (and zero for the others). In that case, $\hat{C}_{\chi,t}$ corresponds to the individual consumption response of a particular (type of) household. Alternatively, one can choose $\chi(j)$ to compute the average response among people with certain demographic characteristics, which we observe in the micro survey data that are fed into the model. We can characterise $\hat{C}_{\chi,t}$ with the following Euler equation:

$$\mathbb{E}_t\hat{C}_{\chi,t+1} - \hat{C}_{\chi,t} = \bar{\sigma}\left(\int \chi(j)dj\hat{R}_t - \sum_{l=1}^{K}\int \chi(j)\xi_l(j)dj\,\pi_{l,t+1}\right) + \frac{\delta}{1-\delta}\hat{C}^0_{\chi,t}, \tag{17}$$

where wealth dynamics are captured by:

$$\begin{aligned}\hat{C}^0_{\chi,t-1} - \frac{1}{(1-\delta)\,R}\hat{C}^0_{\chi,t} &= \int \chi^0(j)\frac{b(j)}{RE}dj\left(\hat{R}_t - \mathbb{E}_t\sum_{l=1}^{K}\bar{s}_l\pi_{l,t+1}\right) + \left(1+\frac{\bar{\psi}}{\bar{\sigma}}\right)\int \chi^0(j)\frac{\vartheta W n(j)}{WL}dj\hat{\mathcal{Y}}_t\\ &+ \sum_{l=1}^{K}\int \chi^0(j)\left(\frac{e(j)}{E}\left(\bar{s}_l - s_l(j)\right) + \frac{\vartheta(j)Wn(j)}{WL}\psi\left(\bar{\xi}_l - \xi_l(j)\right)\right)dj\hat{P}_{l,t} - \frac{R-1}{R}\hat{C}_{\chi,t},\end{aligned} \tag{18}$$

where we defined $\chi^0(j) = \frac{R-1}{R}\frac{\chi(j)}{e(j)+\vartheta(j)WN(j)\frac{\psi}{\bar{\sigma}}}$.

[16] XXX discuss that prices are not defined relative to P0

3.2 Parameterization

We calibrate the model to the United Kingdom. The model period is set to one quarter. Parameter values are displayed in Tables 2 and 3, and are discussed below in detail. We include eight COICOP sectors in the model: Food, Clothing, Electricity and Gas, Furniture, Transport, Recreation, Restaurants and Hotels, and Miscellaneous.

Income and wealth distribution. An advantage of the model is that its steady state can be disciplined by directly feeding in observed distributions for income, wealth and consumption by sector. To this end, we rely on the Living Costs and Food (LCF) survey, which collects detailed survey data for about 6000 households in the UK.[17] We weigh households using population weights from the LCF.[18]

We used 2019 data to calibrate the model. We construct nominal wealth, $b(j)$, as nominal savings minus mortgage and credit card debt.[19] Total expenditures $e(j)$ and budget shares by sector $\bar{s}_j$ are directly observed in the LCF survey. To ensure consistency with the model, we back out labor income $\vartheta(j)Wn(j)$ as a residual from the budget constraint.[20]

Preferences. We set $\beta = 0.99$ which implies an annual real interest rate of about X percent. We further set $\psi(j) = \sigma(j) = 1$, i.e. the Elasticity of Intertemporal Substitution and Frisch elasticity of labour supply are both assumed to be homogeneous across households and equal to one. In the baseline parametrization we abstract from Hand-to-Mouth households. In the Appendix we explore how dynamics change when we extend the model with such households. We set $\delta = 0.0167$, which implies that on average it takes

[17] The UK consumer price index produced by the ONS is based on expenditure baskets observed in the LCF survey.

[18] One can think of each survey households as a representative for a particular type of household. In this sense, our model has about 6000 types of households, with demographic turnover within each type, as households are replaced by steady-state versions of their type at a rate δ.

[19] In the LCF we observe interest income. We convert this into the stock of saving by assuming an interest rate of 1 percent annually.

[20] Note that in the model's steady state, household savings, $b(j)$, are constant at the household level, so total expenditure equals labor income plus interest income for each household j.

about 30 years before an individual's wealth level is "re-set" to the steady state level.

Outer utility. To parametrize the outer utility function, $U()$, we follow the approach of Comin et al. (2021), who propose a class of non-homothetic CES preferences defined implicitly by:

$$\sum_{k=1}^{K} \mathcal{V}_k \left(\frac{c_k}{g(U)^{\zeta_k}} \right)^{\frac{\mu-1}{\mu}} = 1,$$

where μ is the elasticity of substitution across sectors. As shown by Comin et al. (2021), these preference imply the following relation for household j's budget share of sector k (relative to some baseline sector):

$$\ln(\frac{s_k(j)}{s_0(j)}) = (1-\mu)\ln(\frac{p_k}{p_0}) + (1-\mu)(\zeta_k - 1)\ln(\frac{e(j)}{p_0}) + \zeta_k + \ln(\frac{\mathcal{V}_k(j)}{\mathcal{V}_0(j)^{\zeta_k}}),$$

This class of preferences thus allows the sectoral composition of the consumption basket to vary with total expenditures, and it also allows for household-level preference shifters. We estimate the above equation (jointly for all sectors) using a GMM approach, following Comin et al. (2021) but using household-level data. In the appendix, we provide details on the estimation. With the estimated equations at hand, we can compute for each household the implied marginal budget shares $\xi_k(j)$, for each sector k. Table 3 shows the marginal budget shares, averaged across households, $\bar{\xi}_k(j)$ along with the average budget share $\bar{s}_k(j)$, as well as the difference $\bar{\xi}_k(j) - \bar{s}_k(j)$, which matters directly for the $\mathcal{NH}$ wedge. In sectors such as Food and Clothing, this difference is positive. This is to be expected since these goods are often considered necessities. On the other, for Restaurants and Hotels, a luxury sector, the difference is positive.

Inner utility. Regarding the inner utility function, $\mathcal{U}()$, we assume a HARA form, which implies that the elasticity of substitution between goods in sector k, for household j, is then given by:

$$\epsilon_k(j) = a_k + \frac{b_k}{e_k(j)},$$

where $a_k > 0$ is a constant and b_k determines how the demand elasticity varies with the total amount of expenditures on goods in the sector. When $b_k < 0$, households become less price sensitive as they spend more and it then holds that $\gamma_{e,k}(j) > 0$.

We calibrate a_k and b_k to target empirical evidence on markups and pass-through. Specifically, given a_k and b_k and the empirical distribution of expenditures at the sector level, $e_k(j)$, we can compute the distributions of individual demand elasticities, $\epsilon_k(j)$, and super-elasticities, $\epsilon_k^s(j)$, which also gives us $\gamma_{e,k}(j)$. Using formulas provided in Section 3.1, we then aggregate these to obtain the sector-level coefficients $\bar{\epsilon}_k$ and $\bar{\eta}_k$, and $\bar{\gamma}_{e,k}$. From the first two we can compute the steady-state markup $\frac{\bar{\epsilon}_k}{\bar{\epsilon}_k-1}$ and pass-through $\frac{\bar{\epsilon}_k-1}{\bar{\epsilon}_k-1+\bar{\eta}_k}$ at the sector-level, which we target in the calibration. To this end we use sector-level markup estimates produced by the Office for National Statistics, following the method of De Loecker and Warzynski (2012). Moreover, we target 60 percent pass-through (in all sectors), based on empirical evidence by Amiti et al. (2019). Table 3 presents the implied sector-level coefficients.

Price rigidity. To calibrate the price rigidity parameter in each sector, θ_k, we follow empirical evidence on price adjustment frequencies in the United Kingdom, as documented by Dixon and Tian (2017). We convert these into quarterly Calvo probabilities, see Table 3 for the implied values.

Technology. We further assume an AR(1) process in logs for the shock in the model. For both sectoral and aggregate productivity shocks, we assume an autoregressive coefficient $\rho_A = 0.95$. For the monetary policy shock we assume a coefficient $\rho_R = 0.25$.

3.3 Extensions

The baseline model described above in several ways. These extensions preserve the tractability of the model. However, because we introduce them mainly for quantitative purposes, we discuss them in more detail in the Appendix, focusing on the key elements of the model in the main text.

Input-Output structure. Second, we introduce an input-output linkages in production. Concretely, we extend the firm's production function to:

$$y_{k,t}(i) = A_{k,t} F_k(l_{k,t}(i), \tilde{Y}_{1,k,t}(i), \tilde{Y}_{2,k,t}(i), ..., \tilde{Y}_{K,k,t}(i)), \tag{19}$$

where $\tilde{Y}_{l,k,t}(i)$ is the quantity of intermediate goods bundles produced in sector l used by by firm i in sector k. Here, $F_k(\cdot)$ is a function with constant returns to scale. More details are provided in the appendix. The NKPC now becomes:

$$\pi_{k,t} = \lambda_k \left(\omega_k \tilde{\mathcal{Y}}_t - \omega_k \mathcal{P}_{k,t} + \omega_k \mathcal{N}\mathcal{H}_t + s_k^{\mathcal{C}} \mathcal{M}_{k,t} + \mathcal{I}_{k,t} \right) + \beta \mathbb{E}_t \pi_{k,t+1}, \tag{20}$$

where $\omega_k = \frac{WL_k}{P_k Y_k}$ is the steady state cost share of labor input in sector k, $s_k^{\mathcal{C}} = \frac{E_k}{P_k Y_k}$ is the steady-state sales share to consumers. In the equation, a new "intermediate goods wedge" emerges:

$$\mathcal{I}_{k,t} = \sum_l \frac{P_l \tilde{Y}_{l,k}}{P_k \tilde{Y}_k} \left(\mathcal{P}_{l,t} - \mathcal{P}_{k,t} \right), \tag{21}$$

where $\frac{P_l \tilde{Y}_{l,k}}{P_k Y_k}$ are steady-state intermediate purchases of sector-l goods by sector k. The wedge arises due to price distortions in intermediate goods prices. The other equations of the model remain unchanged.

Hand-to-Mouth households. In addition to the households described above, we also allow for the presence of "Hand-to-Mouth" (HtM) households. These households cannot use bonds to smooth consumption, i.e. they set $b_t(j) = b_{t-1}(j)$. Otherwise they are identical to the households described above. Note that this means that the HtM households do optimally allocate their total expenditures over different consumption goods, reacting to changes in relative prices.

The introduction of household affects, the Euler equation for the endogenous markup wedge, Equation (14). Intuitively, the presence of HtM households changes the dynamics of fluctuations in consumption expenditures, and hence in demand elasticities. The introduction of HtM agents also affects the aggregate Euler equation for the demand index, Equation (11), but only when there is a systematic relation between the propensity of being HtM and other household characteristics, so that re-distributions between HtM and non-HtM households matter. We present the equations in the Appendix. To calibrate the version of the model with intermediate goods in production, we rely on input-output tables produced by the Office for National Statistics.

4 Inspecting the Mechanisms

Before analyzing the quantitative results from the full model, let us delve into some of the underlying mechanisms.

4.1 Breakdown of the Divine coincidence

A well-known property of the standard NK model is the "Divine Coincidence" which refers to the possibility that aggregate inflation and the output gap can be stabilized simultaneously. This property follows immediately from the standard NKPC, which depends only on the output gap and inflation. Moreover, in the standard NK model, full stabilization of the output gap and inflation is optimal from a welfare perspective, at least when there no exogenous shocks to the NKPC.

In our setting, the divine coincidence generally breaks down, due to the several wedges appear in the generalized sectoral NKPCs, Equation 10. The central bank therefore faces a meaningful trade-off between stabilizing CPI inflation and the output gap.

We will explore the normative equations in Section 6.1. For now, let us note that in the absence of the endogenous markup wedge, i.e. $\mathcal{M}_{k,t} = 0$ in any sector k, there does exist a "Divine Coincidence" inflation index which can be stabilized simultaneously with the output gap. This index is given by $\pi_{dc,t} = \sum_k \frac{\bar{\xi}_k/\lambda_k}{\sum_l \bar{\xi}_l/\lambda_l}\pi_{k,t}$, and is similar to the one proposed by Rubbo (2019), except that it depends on marginal budget shares ($\bar{\xi}_k$) rather than average budget shares ($\bar{s}_k$).[21] Note however that in our setting it is not necessarily welfare optimal to stabilize this inflation index. Even without fluctuations in the output gap, there are still distortions of relative prices within and across sectors, as well as distributional fluctuations, which all matter for welfare.

4.2 Propagation channels

The model features two kinds of endogenous persistence channels. The first type of channel is due to relative sectoral prices, which become state variables in the presence of heterogeneity in nominal rigidities across sectors. This kind of channel has long be recognized in the literature. In our setting, the channel is shaped by non-homothetic preferences, which directly alter fluctuations in the relative demand for goods from different sectors.

A second, novel propagation mechanism is due to the endogenous markup wedge. Specifically, $\hat{M}^0_{k,t}$ for $k = 1, .., K$ are endogenous state variables tracking the relevant aspects of the distribution of the joint distribution of income and wealth, which moves persistently over time and shapes the distribution of expenditures, and therefore the distribution of demand elasticities. Firms react to changes in demand elasticities by altering markups. Therefore, distributional dynamics feed back into output and inflation dynam-

[21] It can be shown that the aggregate NKPC for the divine coincidence index is given by $\pi_{d,t} = \lambda_{dc}\tilde{\mathcal{Y}}_t + \mathcal{M}_t + \beta\mathbb{E}_t\pi_{dc,t+1}$, where $\lambda_{dc} = \sum_k \frac{\bar{\xi}_k/\lambda_k}{\sum_l \bar{\xi}_l/\lambda_l}$ and $\mathcal{M}_t = \sum_k \lambda_k \mathcal{M}_{k,t}$. When $\mathcal{M}_t = 0$, then $\pi_{dc,t} = 0$ at all times implies that $\tilde{\mathcal{Y}}_t = 0$, i.e. the divine coincidence holds.

ics.

4.3 Shock transmission in a simplified model

In order to analyze the transmission mechanisms of aggregate and sectoral shocks, let us for the moment consider a simplified version in which the degree of price stickiness is equal across sectors and there is no input-output structure. In this case, the sectors can be aggregated to give the following NKPC for the CPI inflation rate:

$$\pi_{cpi,t} = \lambda \left(\tilde{\mathcal{Y}}_t + \mathcal{NH}_t + \mathcal{M}_t \right) + \beta \mathbb{E}_t \pi_{cpi,t+1}, \tag{22}$$

where $\mathcal{M}_t = \sum_k \bar{s}_k \mathcal{M}_{k,t}$. Due to the absence of heterogeneity in nominal rigidity, the NKPC slope λ is equal across sectors and the relative price wedge collapses to zero.[22] The two wedges at the centre of our analysis, $\mathcal{M}_t$ and $\mathcal{NH}_t$, are preserved.

Aggregate productivity shock. Figure 4 plots the responses of various variables to four different shocks, which illustrate several of the key mechanisms. Let us start with an aggregate productivity shock, shown in the first column. Following the shock, productivity falls across all firms by the same percentage (the figure zooms in on the sectors Food and Restaurants & Hotels, but productivity falls in all other sectors as well). As shown in the second row, inflation and the output gap both increase following the negative productivity shock, which is a typical finding in New Keynesian models: prices increase but less so than without nominal rigidities, which dampens the decline in goods demand, pushing up aggregated demand above its efficient level.

There is however a second force pushing up the output gap in our model, which is a decline in the endogenous markup wedge $\mathcal{M}_t$. Intuitively, consumption falls after the negative shock, which makes households more price sensitive, i.e. their demand elastic-

[22] We set the Calvo parameter to the simple average across sectors, which equals $\theta = 0.5075$.

ity increases. Firms react to this increased price sensitivity by adjusting markups downwards, which pushes up inflation and/or pushes down the output gap.

By contrast, the $\mathcal{NH}_t$ wedge does not move much following the shock, as all sectors are subject to the same decline in productivity and the degree of price rigidity is the same as well. Nonetheless, the third row of Figure 4 shows that the response of prices is somewhat different across sectors, with food prices responding more than restaurant and hotel prices, which is due to the fact that households but back more on luxuries than on necessities, pushing down markups relatively strongly luxury sectors. The sectoral heterogeneity in price responses in turn has distributional effects. Indeed, the bottom left panel of Figure 4 shows that real expenditure falls somewhat more strongly for poor households than for the rich.

Sectoral productivity shocks. A central question in this paper is whether central bank trade-offs are very different following a specific shocks to necessity sector, than following an aggregate shock. To investigate this question, we consider a negative productivity shock which affects only firms in the sector Food, an important necessity. The second column of Figure 4 reports the result. The second row shows that following the negative Food productivity shock, the CPI inflation rate and the output gap initially move in *opposite* directions. This is important given that it implies an immediate trade-off for the central bank that is not present under the aggregate shock: by tightening monetary policy, the central bank could curb the increase inflation, but this would be at the expense of a more negative output gap. That is, at the margin it does not seem feasible for policy to stabilise both the output gap and inflation. About a year after the shock, however, the output gap turns positive. From that moment onward, joint stabilisation of the output gap and inflation may become possible. Possibly, this result could provide a rationale for the observation that during the 2021/2022 cost of living crisis, many central banks appeared reluctant to immediately tighten policy.

What drives the initial fall in the output gap following a Food shock? The panel on the third row, second column of Figure 4 shows that this is driven by an increase in the non-homotheticity wedge. Following the shock, prices rise in the Food sector, but not by as much as under flexible prices. In other words, there is a *downward* distortion in Food prices, i.e. $P_{Food,t} - P^*_{Food,t} < 0$, which pushes up the real wage. However, given that workers spend at the margin less on Food than they do on average $\xi_{Food} - \bar{s}_{Food} < 0$, their relevant real wage increases less than for the average (CPI-weighted) firm. This discrepancy can be interpreted as an increased labour wedge, akin to a rise in labor taxes, which pushes down hours worked and hence the output gap declines. This strength of this effect, however, diminishes relatively quickly, as more firms update their prices. Indeed, a year after the shock the $\mathcal{NH}_t$ wedge has reverted nearly to zero. At that point, the fall in the $\mathcal{M}_t$ wedge dominates, pushing up the aggregate output gap as explained above. The different balance of the two wedges at different time horizon creates a relatively difficult challenge for the central bank, compared to e.g. an aggregate productivity shock. Considering distributional effects, the Food shock turns out to have a much stronger effect on poor households than on rich households, see the bottom panel. This is to be expected, given that food prices increase and poor households tend to have a higher expenditure share on food as compared to rich households.

To better understand movements of the non-homotheticity wedge, let us re-express it as $\mathcal{NH}_t = \left(\hat{w}_{f,t} - \hat{w}^*_{f,t}\right) - \left(\hat{w}_{h,t} - \hat{w}^*_{h,t}\right)$.Here, we exploit the simplifying assumption that the Calvo friction is homogeneous across sectors. Here, $\hat{w}_{f,t} = \hat{W}_t - \hat{P}_{cpi,t}$ is the real wage according to the CPI, which is relevant to the marginal cost of the average firm (weighted by sales), and $\hat{w}^*_{f,t} = \sum_{l=1}^{K} \bar{s}_l \hat{A}_{l,t}$ is its counterpart under flexible prices. Moreover, $\hat{w}_{h,t} = \hat{W}_t - \sum_{l=1}^{K} \bar{\xi}_l \hat{P}_{l,t}$ is the real wage according to worker's averaged marginal budget shares, which is relevant to labor supply decisions, and $\hat{w}^*_{h,t} = \sum_{l=1}^{K} \bar{\xi}_l \hat{A}_{l,t}$ is its efficient counterpart. We now observe that $\mathcal{NH}_t$ can be interpreted as a term capturing the extent to which real wage distortions differ between workers and firms. As such,

$\mathcal{NH}_t$ can be interpreted as a labor wedge, akin to a labor income tax distortion, as drives a wedge between the real wage paid by firms and the one received by the worker.

The third column of Figure 4 shows the responses to a negative productivity shock among Restaurants & Hotels, a luxury sector. In line with the logic explained above, the $\mathcal{NH}_t$ wedge now declines, since $\zeta_{R\&H} - \bar{s}_{R\&H} > 0$. Along with the decline in $\mathcal{M}_t$, the output gap is pushed upward strongly, moving in the same direction as the CPI inflation rate, and providing possibly an additional rationale to tighten policy. Note further that, as anticipated, the shock disproportionately affects rich households.

Monetary policy shock. Finally, the fourth row of Figure 4 shows the responses to a monetary tightening. The results are similar to findings in standard New Keynesian model. Specifically, the two wedges move relatively little, as sectoral prices move in tandem and the $\mathcal{NH}_t$ and $\mathcal{M}_t$ wedges move little.[23] Thus, monetary policy appears to have relatively little direct control of the two wedges. Regarding the distributional implications, we observe that poor households are affected slightly more by a monetary tightening than rich households, which may provide another rational for the reluctance of central banks to strongly tighten policy at the onset of the cost-of-living crisis.

5 Quantitative Results

5.1 The baseline model: results

Let us now consider the baseline model, which includes heterogeneity in Calvo rigidities across sectors as well as an input-output structure. Figure 5 plots results responses to an aggregate productivity shock, a monetary policy shock, as well as productivity shocks to each of the eight sectors.

[23]The modest change in $\mathcal{M}_t$ is largely due to the fact that the shock is relatively transitory, with a persistence coefficient of 0.25, vis-à-vis a coefficient of 0.95 for the productivity shocks.

Let us first consider the responses of the output gap and the CPI inflation rate. As in the simplified model, both variables move into the same direction following aggregate shocks, and a number of sectoral shocks. But importantly, we again observe that for a shock to the Food sector, the output gap initially declines, followed by an upswing after about one year. The same is true for shocks to the Clothing, Furniture, and Transport sectors. Thus, shocks to these sectors may pose a particular challenges to central banks seeking to stabilize both the output gap and CPI inflation.

Figure 5 also plots the responses of the wedges in the NKPC, where aggregate using as weights the CPI weights times the coefficients Equation 20, so that all variables are expressed in units of CPI inflation. We observe that, as in the simple model, the $\mathcal{NH}_t$ wedge increases following a negative Food shock, contributing to a decline in the output gap. This is strengthened by the fact that the aggregate relative price wedge $\mathcal{P}_t$ and the intermediate goods wedge $\mathcal{I}_t$ also increase following the Food shock. For the Food shock, another necessity sector, we observe similar outcomes. By contrast, the decline in the output gap following a Transport shock is driven by the $\mathcal{P}_t$ wedge and the $\mathcal{I}_t$ wedge. Indeed, Transport is a luxury sector and the $\mathcal{NH}_t$ declines following the shock. More generally, the combined dynamics of the four wedges gives rise to rich dynamics in aggregate inflation and the output gap. For instance, following a shock to the Recreation sector, we observed a hump-shaped response of CPI inflation, whereas the output gap initially increases, then falls, and subsequently increases again.

Let us now consider distributional responses, see Figure 6. Each dot represents a household in the LCF survey. The horizontal axis denotes the total steady-state income (expenditure) of the household, wheres the vertical axes denotes the real consumption response of the household to various shocks, averaged over the first four quarters following the shock. The red line represents a 10th order polynomial fitted on these data. Following a monetary contraction, consumption falls, but somewhat more so for low-income households. However, for any given income level there is a substantial degree of heterogeneity in the consumption response. For instance, some lower-income households experience consumption gains. This heterogeneity is due to heterogeneity in the composition of labour versus asset income, as well as heterogeneity in steady-state consumption basket, due to taste heterogeneity (we feed the observed consumption shares into the model). Following an aggregate productivity shock, we observe a similar pattern, with low-income households hit slightly more, but again with substantial heterogeneity.

Following a negative productivity shock to the food sector, we observe that poor households tend to be affected much more strongly than richer households. Again there is a very large degree of heterogeneity, with some low-income households being affected 8-9 times as much as others. For a shock to electricity we observe a similar pattern. On the other hand, for a shock to Restaurants and Hotels, a typical luxury sector, we observe that the richest households are affected more than the poorest households, but we observe a non-monotonic pattern at intermediate income levels. Moreover, the largest degree of heterogeneity we again observe at the bottom of the income distribution, as restaurant meals and hotel nights may be a necessity for some low-income households, e.g. for work or personal reasons.

Clearly, income is not the only relevant dimension of heterogeneity in accounting for the unequal effects of shocks on the consumption of different households. To explore more thoroughly the important of different dimensions of heterogeneity, we regress the consumption response on dummies for different household characteristics: region, housing status, couple/parental status, income, age, and race. The results are reported in Tables 4 and 5 . Consider first the monetary policy shock. Comparing different regions, we observe that households in London, the North east and Scotland are affected relatively strongly. Also the Table shows that home owners with a mortgage are affected relatively strongly. This happens at least in part because they are more affected by an increase in interest rate, and an increase in the real value of their mortgage debt. However, renters, in particular in the social sector, also suffer a decline in consumption. Comparing age groups, youngest households are most negatively affected.

Considering aggregate and sectoral productivity we also observe several interesting differences between various groups in society. For instance, renters in the private sector are much more strongly affected by an aggregate productivity shock than renters in the private sector, controlling for other characteristics, and the same is true for couples, as compared to singles. Considering a negative shock to the Food sector, the Table reports the strongest negative effects among older, low-income households living in London, Scotland and Northern Ireland, who rent in the social sector. Moreover, couples with children are more strongly affected. Patterns are somewhat similar for a shock to the Clothing sector.

Households hit strongly by a negative shock to Electricity and Gas tend to live, unsurprisingly, in the north of the UK. Moreover, young mortgagors in a couple with child tend to be affected relatively strongly. Overall, these results indicate that distributional effects of shocks and policy changes go much beyond the dimensions income and wealth, which are typically the focus of the HANK literature.

6 Optimal Monetary Policy

Having explored the dynamics of the model under an interest rate rule, let us now analyze the normative implications for monetary policy. Specifically we study the optimal interest rate policy under commitment.

We consider social planner who maximizes, at some initial date, a welfare function of the form:

$$\mathcal{W} = \mathbb{E}\,(1-\delta)\int G(V^0(j),j)dj + \delta\sum_{t_0=0}^{\infty}\beta^{t_0}\int G(V^{t_0}(j),j)dj, \tag{23}$$

where the first term on the right-hand side stems from pre-existing households, and the second term from current and future newborns, where the superscript t_0 denotes the period of birth. Moreover, G is a function which captures the social planner's aggregation of welfare levels of different households. The lifetime welfare of household j is given by:

$$V^{t_0}(j) = \sum_{s=0}^{\infty} \left((1-\delta)\beta\right)^s \left(v\left(e^{t_0}_{t_0+s}(j), P_{1,t_0+s}, ..., P_{K,t_0+s}\right) - \chi\left(n^{t_0}_{t_0+s}(j)\right)\right),$$

where setting $t_0 = 0$ gives the value of the pre-existing households. In the steady state we have $V^{t_0}(j) = \frac{R}{R-1}\left(v\left(e(i), P_1, ..., P_K\right) - \chi\left(n(j)\right)\right)$. To solve the optimal policy problem, the planner sets in the nominal interest rate R_t to maximize the Welfare criterion (23), subject to Equations (9)-(15) holding currently and at any future date. In the Appendix, we present the first-order conditions associated with the planner problem. These conditions contain Pareto weights:

$$g(j) = \left(-\frac{R}{R-1}\frac{G''\left(V^{t_0}_{ss}(j), j\right)}{G'\left(V^{t_0}_{ss}(j), j\right)}\partial_e v\left(e(j), P_1, ..., P_K\right) + \frac{1}{\left(\psi\vartheta(j)Wn(j) + \sigma(j)e(j)\right)}\right)E \quad (24)$$

Our setup allows the planner to have an arbitrary social preference function G. For quantitative experiments, we need to make further assumptions on this function. We proceed as follows. First, we rule out any motive for the central bank to redistribute wealth in the absence of aggregate shocks. That is, the steady-state distribution is treated as efficient. The underlying idea is that long-run wealth redistribution is considered the domain of fiscal rather than monetary policy. We operationalize this assumption by imposing that:

$$G'\left(V^{t_0}(j), j\right)\partial_e v\left(e(j), P_1, ..., P_K\right) = 1.$$

Second, we set $G''\left(V^{t_0}_{ss}(j), j\right) = 0$, which implies that households' fluctuations in utility are weighed equally by the planner.[24]

[24]Still, fluctuations in consumption of poor agents are typically assigned higher weight by the planner, as those agents are at a point in the utility function with higher curvature. This enters via the second term in Equation 24.

6.1 Quantitative results under optimal policy.

Figures **??**-**??** present responses to shocks under optimal policy (red solid lines), as well as under the a counterfactuals with optimal policy and a representative agent (yellow dashed lines), as well as under the baseline interest rate rule (Taylor rule) with coefficient $\phi = 1.5$ (black solid lines).

As shown in the top left panel of Figure 7, under the optimal policy the nominal interest rate sharply drops initially, followed by a relatively mild tightening. Alongside this response there are initial sharp increases in CPI inflation and the output gap, which subsequently remain elevated. These responses sharply deviate from both the responses under the Taylor rule. Also note that the optimal policy does not get close to achieving the "divine coincidence" traditional to the NK model, as both the output gap and CPI inflation fluctuate. Considering the representative agent version, we no longer observe the sharp initial drop in the interest rate. Indeed, this drop is motivated by a desire to distribute towards poorer agents following the shock.

Figure 7 also shows responses to productivity shocks in the sectors Food shock and Recreation, respectively. Qualitatively, the responses are both similar to those observed for the aggregate productivity shock. Quantitatively, there are differences. For instance, the monetary policy reaction is relatively tight in the luxury sector (Recreation), as compared to the necessity sector (Food). We also observe a relatively mild increase in the CPI inflation and the output gap in response to the Food shock. The previous analysis suggests that this is due to the dampening effects of the Non-homotheticity wedge.

7 Conclusion

We have developed a multi-sector New Keynesian model with household heterogeneity and generalized non-homothetic preferences. We use the model to study both positive and normative implications.

We find that sector-level shocks can have very different implications than aggregate shocks, depending on the nature of the sector (necessity vs luxury, sticky-price vs flexible price, etc.). Moreover the optimal monetary policy responses differ sharply from those prescribed by interest rate rules and optimal policy in simpler NK models, since here distributional concerns play an important role in the policy response. More generally, we find that the effects of shocks and policy changes have vastly heterogeneous effects on households, even among those with similar levels of income.

We hope our framework will help central banks navigate policy in a world in which sectoral shocks becoming more frequent and households have highly heterogeneous consumption baskets, and thus inflation rates, real wages and real interest rates. The framework we presented is rich but computationally tractable, and we are planning to extend the model in various directions, and use it to study other policies, such as fiscal interventions. We also plan to study the extent simple rules, based on a specific inflation index that may not be the CPI, can approximate the optimal policy.

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Appendix

A. Equations for Optimal Policy

Let us define

$$
\begin{aligned}
\Gamma_{e,l} &= \int \gamma_{e,l} \frac{e}{E_l} \xi_l \\
\mathrm{Cov}\left(\xi_k, \gamma_{e,l} \frac{E \xi_l}{E_l}\right) &= \int \gamma_{e,l} \frac{e}{E_l} \xi_l \xi_k di - \int \frac{e}{E} \xi_k \int \gamma_{e,l} \frac{e}{E_l} \xi_l \\
\mathrm{Cov}\left(\xi_k, \xi_l\right) &= \int \frac{e}{E} \xi_k \xi_l - \int \frac{e}{E} \xi_k di \int \frac{e}{E} \xi_l \\
\vartheta_k &= \bar{\epsilon}_k \frac{\theta_k}{\left(1-\theta_k\right)\left(1-\beta\theta_k\right)}
\end{aligned}
$$

Here, integrals are over individuals, where we omitted the household index (j) from the notation for parsimony. The system of equations for optimal policy (replacing the interest rate rule) is given by:

$$
Q_{y,t} + \frac{\bar{\psi}\bar{\sigma}}{\bar{\psi}+\bar{\sigma}} \sum_l \left(\frac{\bar{\sigma}_l}{\bar{\sigma}} - \bar{\xi}_l\right)\left(\hat{A}_{l,t} + \hat{P}_{l,t}\right) + \frac{\bar{\psi}}{\bar{\psi}+\bar{\sigma}} \frac{1}{R}\left(X_{r,t} - R\left(1-\delta\right) X_{r,t-1}\right) = \left(\mathcal{Y}_t - \mathcal{Y}_t^*\right) + \sum \lambda_l \left(1 + \frac{\bar{\psi}\bar{\sigma}}{\bar{\psi}+\bar{\sigma}} \Gamma_{e,l}\right) \mu_{l,t}
$$

$$
X_{r,t+1} - X_{r,t} = \frac{\delta}{1-\delta} X_{r,t}^0
$$

$$
\begin{aligned}
X_{r,t-1}^0 - \frac{1}{R\left(1-\delta\right)} X_{r,t}^0 = &\left(1-\frac{1}{R}\right) \int \frac{b}{E} g(i) \frac{b}{ER} di \left(\hat{R}_t - \sum_l \bar{s}_l \pi_{l,t+1}\right) \\
&- \sum_l \left(1-\frac{1}{R}\right) \int \frac{b}{E} g(i) \frac{e}{E}\left(s_l - \bar{s}_l\right) di \left(\hat{P}_{l,t} + \hat{A}_{l,t}\right) \\
&+ \left(1-\frac{1}{R}\right) \sum_l \int \frac{b}{E} \left\{ g(i) \left(\frac{e}{E}\left(s_l - \bar{s}_l\right) + \frac{wn}{WN} \bar{s}_l\right) - \frac{\sigma e \xi_l}{\left(\psi wn + \sigma e\right)} \right\} di \, \hat{A}_{l,t} \\
&- \left(1-\frac{1}{R}\right) \sum_l \int \frac{b}{E} \frac{\sigma e}{\left(\psi wn + \sigma e\right)} \gamma_{e,l} \frac{E \xi_l}{E_l} di \lambda_l \mu_{l,t} - \left(1-\frac{1}{R}\right) X_{r,t}
\end{aligned}
$$

$$
Q_{y,t+1} - Q_{y,t} = \frac{\delta}{1-\delta} Q_{y,t}^0
$$

$$
\begin{aligned}
Q^0_{y,t-1} - \frac{1}{R(1-\delta)} Q^0_{y,t} =& \frac{R-1}{R}\int \frac{e}{E}\frac{R-1}{R}\frac{\sigma b}{\psi wn+\sigma e} di\left(\mathcal{Y}_t - \mathcal{Y}^*_t\right) \\
&+ \frac{\bar{\psi}\bar{\sigma}}{\bar{\psi}+\bar{\sigma}}\frac{R-1}{R}\sum_l \int \frac{e}{E}\frac{R-1}{R}\frac{\sigma b}{\psi wn+\sigma e}\left(\frac{\bar{\psi}_l}{\bar{\psi}} - \bar{\xi}_l\right) di\left(\hat{P}_{l,t} + \hat{A}_{l,t}\right) + \\
&\frac{\bar{\psi}\bar{\sigma}}{\bar{\psi}+\bar{\sigma}}\frac{R-1}{R}\sum_l \int \frac{e}{E_l}\frac{R-1}{R}\frac{\sigma b}{\psi wn+\sigma e}\gamma_{e,l}\xi_l di\, \lambda_l \mu_{l,t} - \frac{R-1}{R} Q_{y,t}
\end{aligned}
$$

$$
Q_{\pi,t} = \mu_{k,t} - (1-\delta)\,\mu_{k,t-1}
$$

$$
\begin{aligned}
&\beta Q_{\pi,t+1} - Q_{\pi,t} + \sum_l \mathbb{E}_t \gamma_{e,l}\frac{\left(p_k \partial_k c^h_l\right)}{C_l}\lambda_l \mu_{l,t} - \lambda_k \mu_{k,t} - \sum_l \left(\bar{\sigma}\mathrm{Cov}\left(\xi_k, \gamma_{e,l}\frac{E\xi_l}{E_l}\right) + \frac{\bar{\sigma}_k \bar{\psi}}{\bar{\sigma}+\bar{\psi}}\Gamma_l\right)\lambda_l \mu_{l,t} = \\
&- Q^p_t + \frac{\bar{\sigma}_k}{\bar{\sigma}}\left(\mathcal{Y}_t - \mathcal{Y}^*_t\right) + \sum_l \left\{\frac{\bar{\sigma}_k \bar{\psi}}{\bar{\sigma}+\bar{\psi}}\left(\xi_l - \frac{\bar{\sigma}_l}{\bar{\sigma}}\right) - \bar{\sigma}\mathrm{Cov}\left(\xi_k, \xi_l\right)\right\}\left(\hat{P}_{l,t} + \hat{A}_{l,t}\right) \\
&+ \frac{\bar{\sigma}_k}{\bar{\sigma}+\bar{\psi}}\frac{1}{R}\left(X_{r,t} - R(1-\delta) X_{r,t-1}\right) + Q_{p,t} + \left(1 - \frac{1}{R}\right)\bar{s}_k X_{r,t} - \delta \bar{s}_k \left(X^0_{r,t} + X_{r,t}\right) \\
&+ \sum_l \bar{s}_l \mathcal{S}_{l,k}\left(\hat{P}_{l,t} + \hat{A}_{l,t}\right) + \bar{s}_k \vartheta_k \left(\beta \pi_{k,t+1} - \pi_{k,t}\right)
\end{aligned}
$$

for any sector k:

$$
X^p_{k,t+1} - X^p_{k,t} = \frac{\delta}{1-\delta} X^{p0}_{k,t}
$$

$$
\begin{aligned}
X^{p0}_{k,t-1} - \frac{1}{R(1-\delta)} X^{p0}_{k,t} =& \left(1 - \frac{1}{R}\right)\int \frac{e}{E}\left(s_k(i) - \bar{s}_k\right) g(i)\frac{b}{ER} di\left(\hat{R}_t - \sum_l \bar{s}_l \pi_{l,t+1}\right) - \\
&\sum_l \left(1 - \frac{1}{R}\right)\int \frac{e}{E}\left(s_k(i) - \bar{s}_k\right) g(i)\frac{e}{E}\left(s_l - \bar{s}_l\right) di\left(\hat{P}_{l,t} + \hat{A}_{l,t}\right) \\
&+ \left(1 - \frac{1}{R}\right)\sum_l \int \frac{e}{E}\left(s_k(i) - \bar{s}_k\right)\left\{g(i)\left(\frac{e}{E}\left(s_l - \bar{s}_l\right) + \frac{wn}{WN}\bar{s}_l\right) - \frac{\sigma e \xi_l}{(\psi wn + \sigma e)}\right\} di\, \hat{A}_{l,t} \\
&- \left(1 - \frac{1}{R}\right)\sum_l \int \frac{e}{E}\left(s_k(i) - \bar{s}_k\right)\frac{\sigma e}{(\psi wn + \sigma e)}\gamma_{e,l}\frac{E\xi_l}{E_l} di \lambda_l \mu_{l,t} - \left(1 - \frac{1}{R}\right) X^p_{k,t}
\end{aligned}
$$

for any sector k:

$$
Q^p_{k,t+1} - Q^p_{k,t} = \frac{\delta}{1-\delta} Q^{p0}_{k,t}
$$

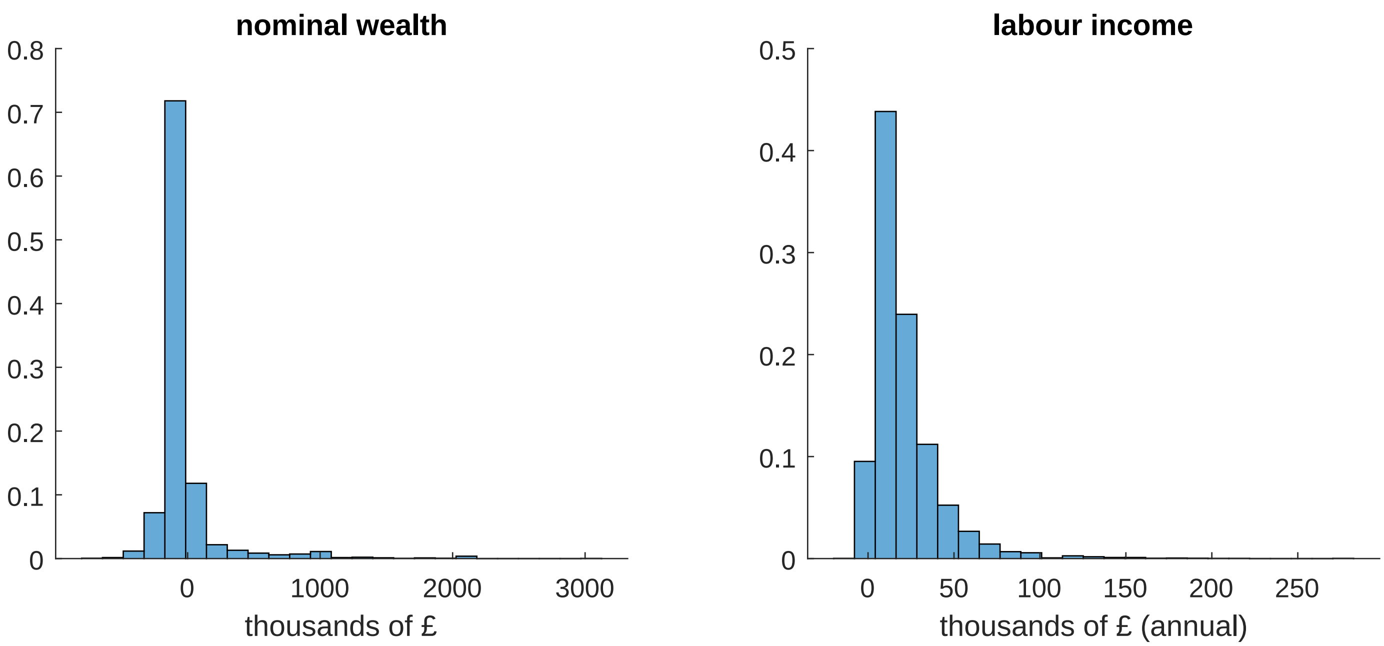
$$Q^{p0}_{k,t-1} - \frac{1}{R\left(1-\delta\right)} Q^{p0}_{k,t} = \left(1 - \frac{1}{R}\right) \int \frac{e}{E} \frac{R-1}{R} \frac{b\sigma\xi_k}{\left(\psi w n + \sigma e\right)} \left(\mathcal{Y}_t - \mathcal{Y}^*_t\right) +$$

$$\left(1 - \frac{1}{R}\right) \frac{\bar{\sigma}}{\bar{\sigma} + \bar{\psi}} \sum_l \left\{ \bar{\psi} \int \frac{e}{E} \frac{R-1}{R} \frac{b\sigma\xi_k}{\left(\psi w n + \sigma e\right)} \left(\frac{\bar{\psi}_l}{\bar{\psi}} - \xi_l\right) di - \bar{\sigma} Cov\left(\xi_k, \xi_l\right) \right\} \left(\hat{P}_{l,t} + \hat{A}_{l,t}\right)$$

$$+ \left(1 - \frac{1}{R}\right) \frac{\bar{\sigma}}{\bar{\sigma} + \bar{\psi}} \sum_l \left\{ \bar{\psi} \int \frac{e}{E_l} \frac{R-1}{R} \frac{b\sigma\xi_k}{\left(\psi w n + \sigma e\right)} \gamma_{e,l} \xi_l di + \bar{\sigma} \mathrm{Cov}\left(\xi_k, \gamma_{e,l} \frac{E\xi_l}{E_l}\right) \right\} \lambda_l \mu_{l,t} - \left(1 - \frac{1}{R}\right) Q^p_{k,t}$$

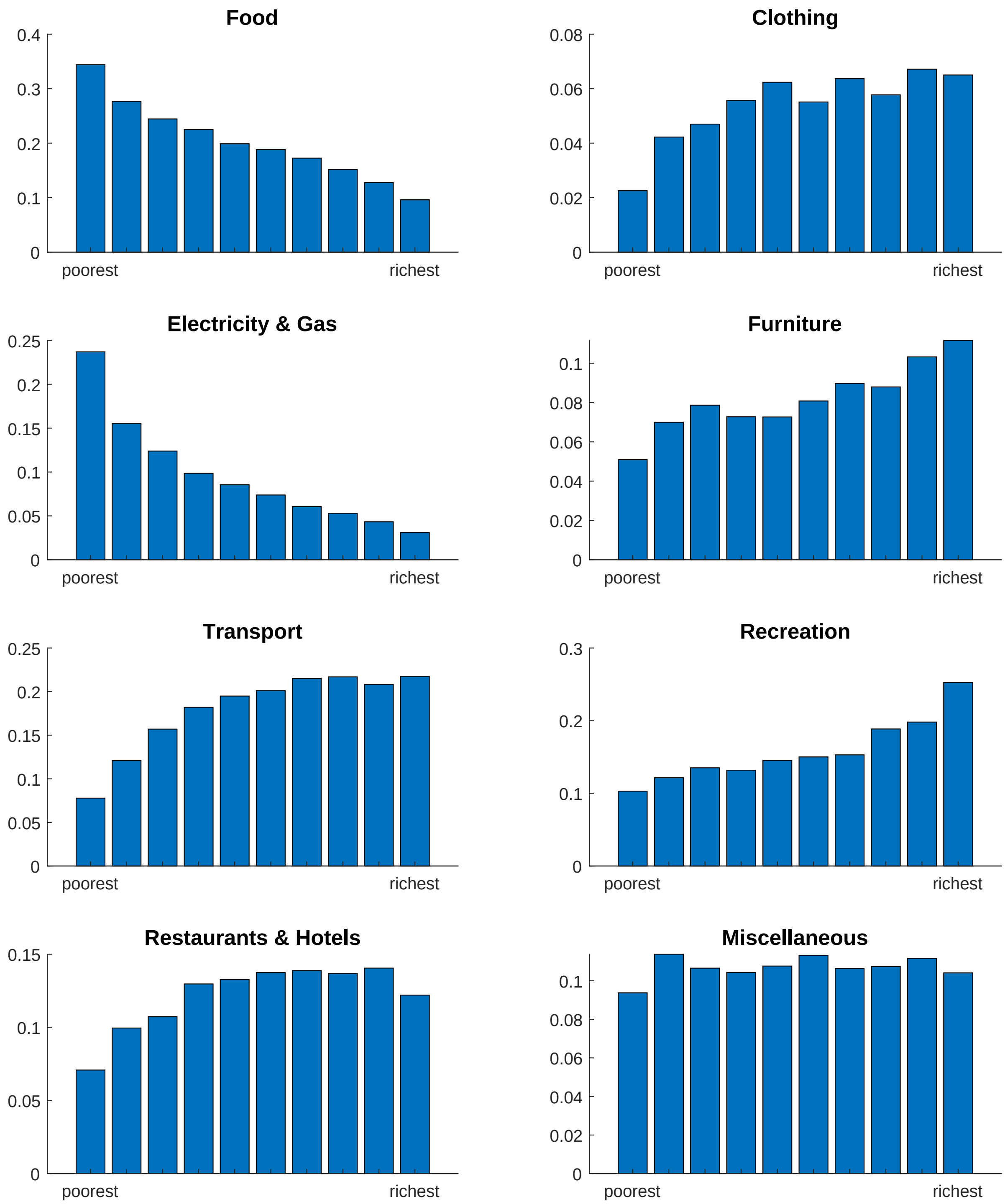
Figures

Figure 1. Steady-state distributions.



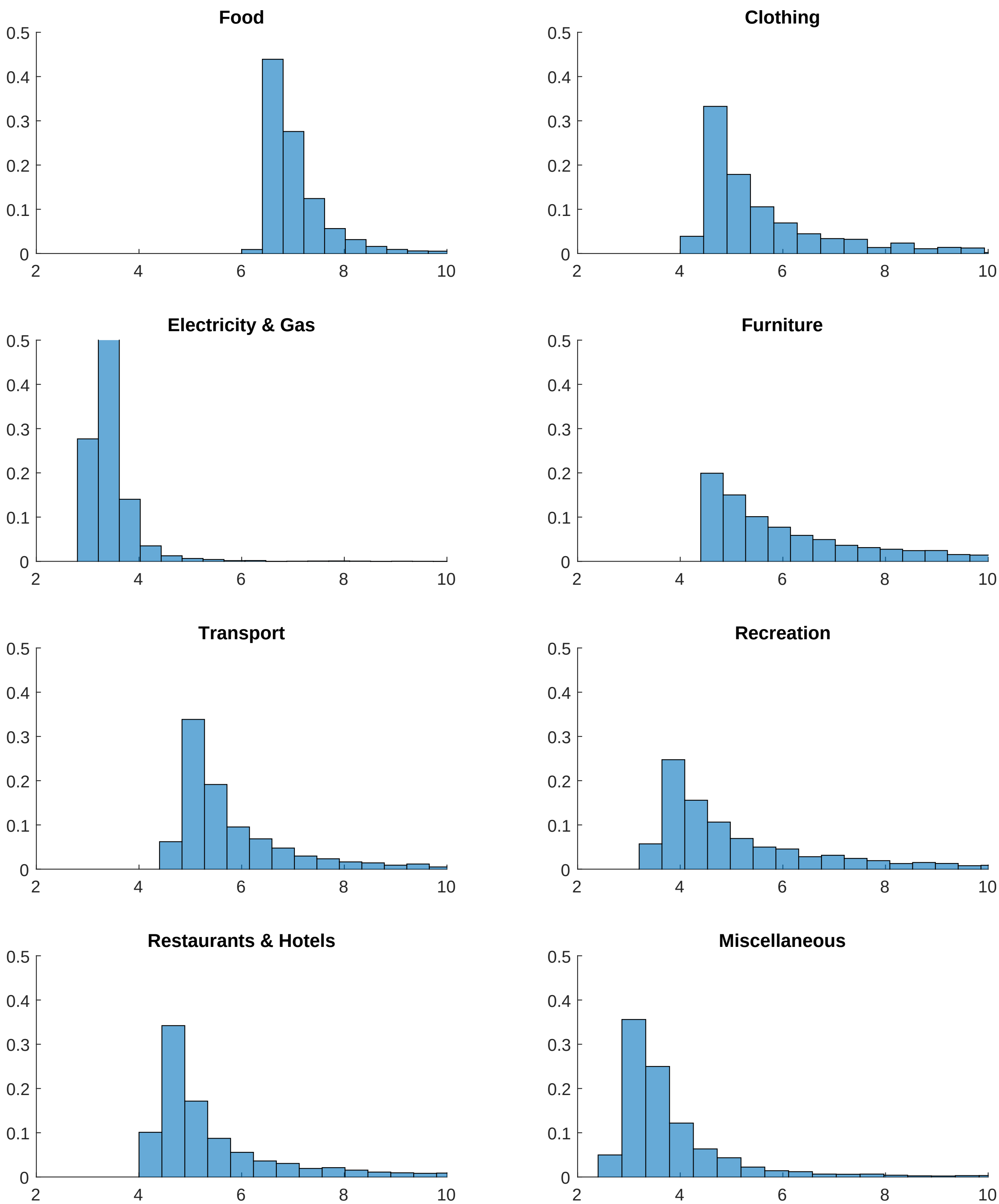
Notes: Data from Living Costs and Food Survey 2019 and authors' calculations, see main text.

Figure 2. Household budget shares by total expenditure decile.



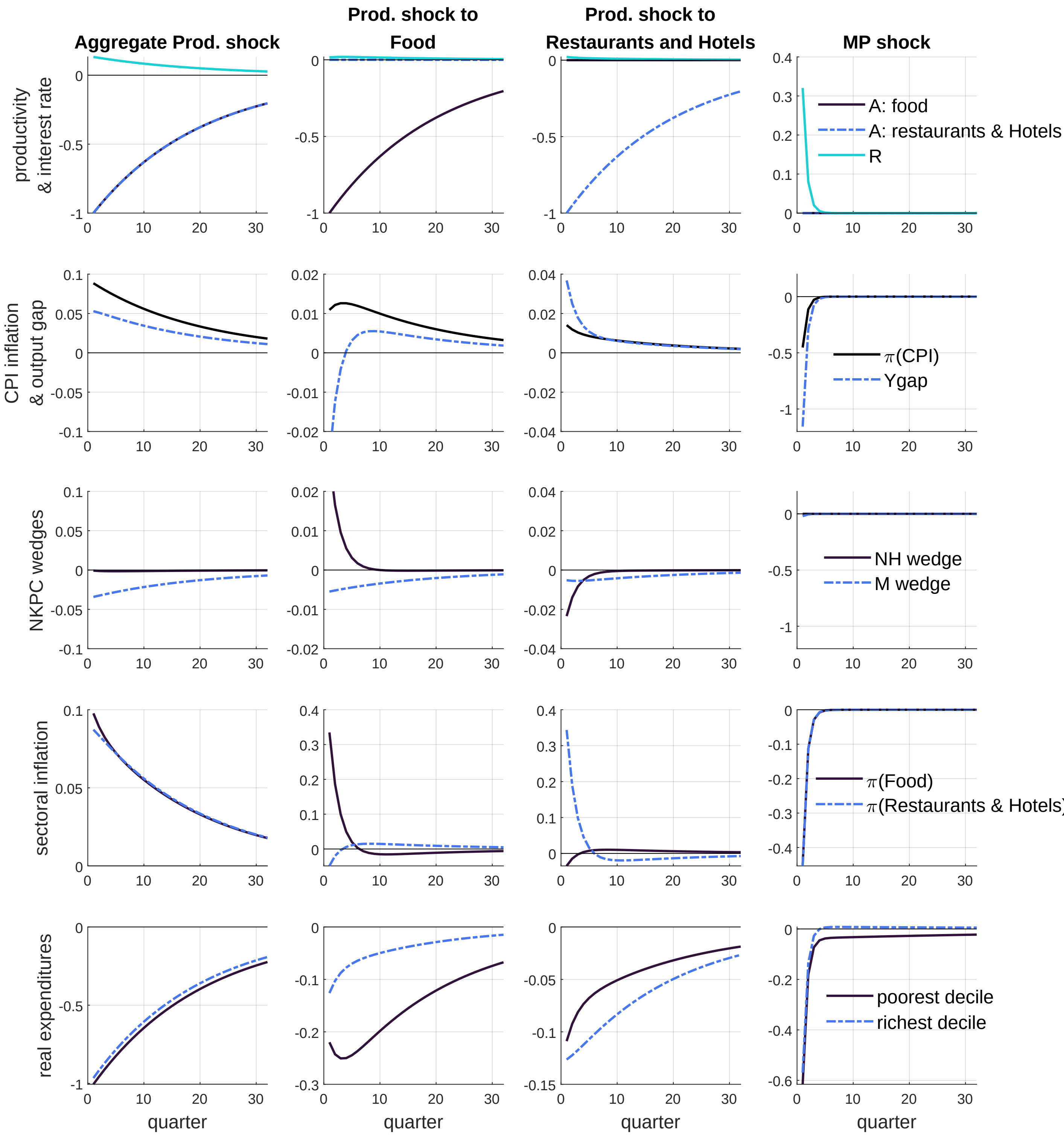
Notes: Average expenditure shares by deciles of total expenditure, ordered from poorest (lowest decile) to richest (highest decile). Source: Living Costs and Food Survey 2019.

Figure 3. Distribution of demand elasticities by sector.



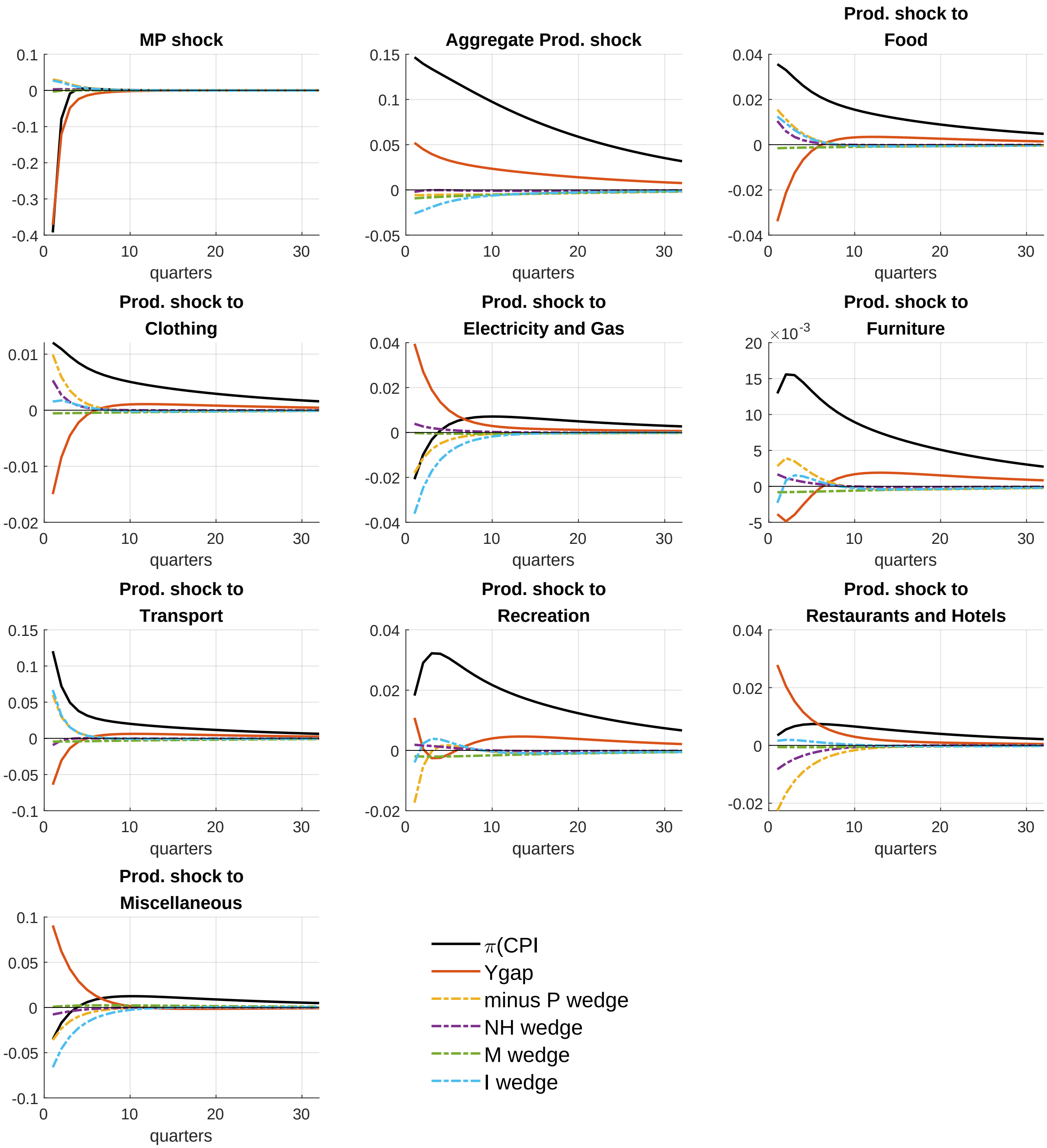
Notes: Histogram of $\epsilon_k(j)$, the demand elasticities across households (by sector).

Figure 4. Responses in the simplified model: selected shocks.



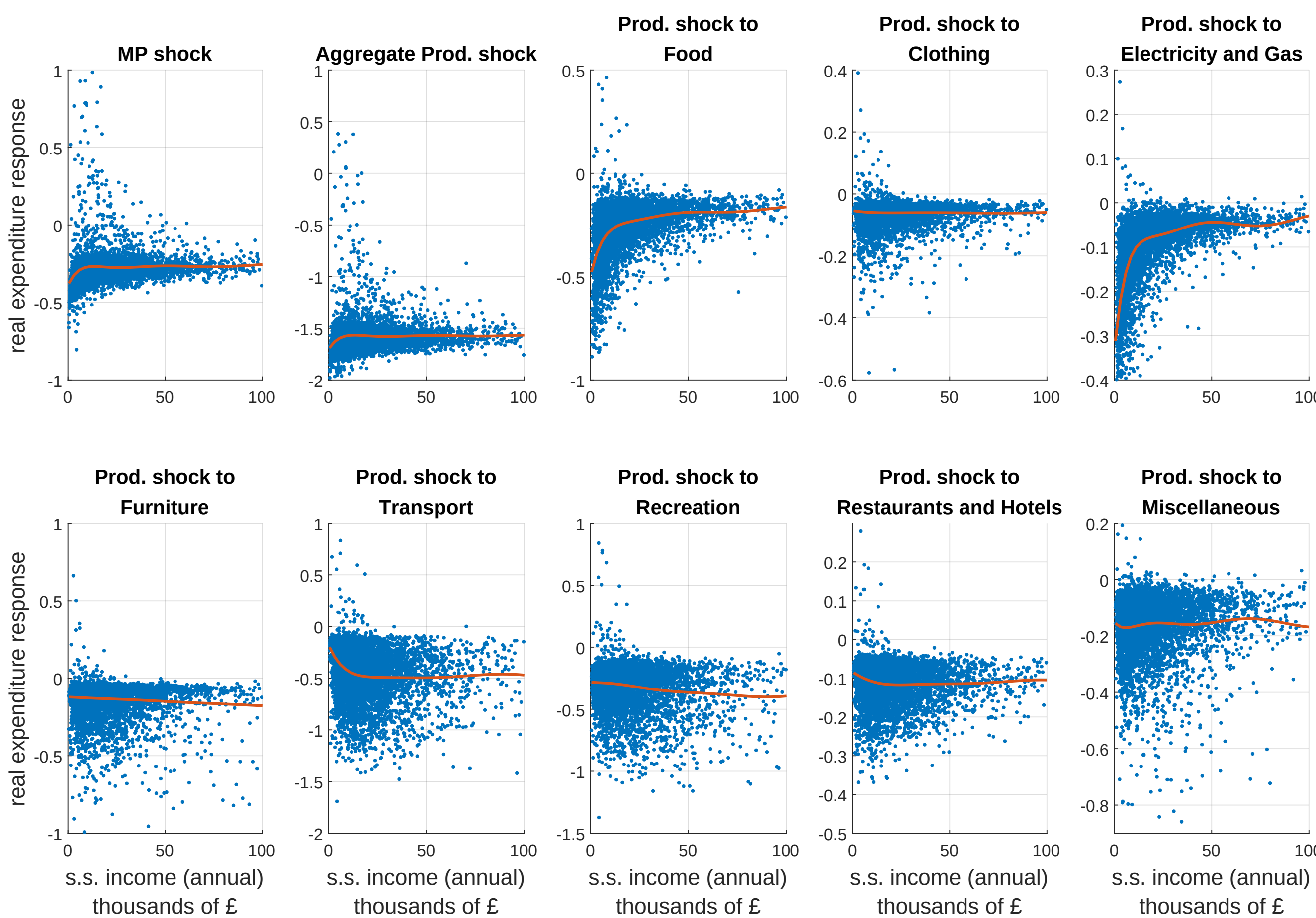
Notes: IRFs are generated from a version of the model with homogeneous Calvo probabilities across sectors and no intermediates in production.

Figure 5. Responses in the baseline model: all shocks.



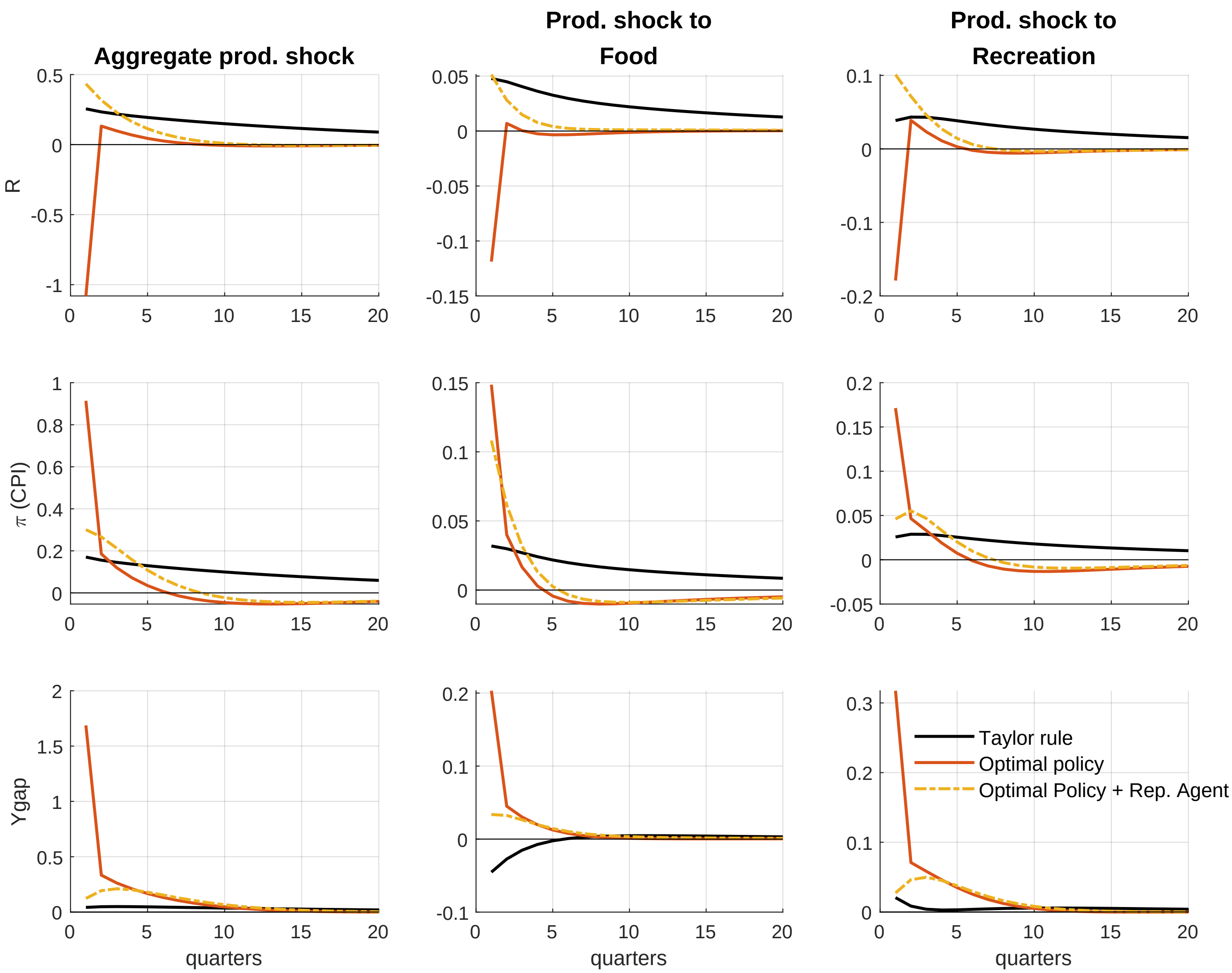
Notes: Impulse Response Functions are generated from the baseline the model with heterogeneous Calvo probabilities across sectors and input-output linkages in production. Horizontal axes denote quarters since the initial shock.

Figure 6. Heterogeneous consumption responses to aggregate and sectoral shocks.



Notes: Response of real expenditures by steady-state income, generated from the baseline model and averaged over first four quarters following the shock. Dots denote individual households. Red lines are fitted 10th order polynomials.

Figure 7. Responses under Taylor Rule and Optimal Policy.



Tables

Table 2. Aggregate parameter values.

Parameter	description	value
β	subjective discount factor	0.99
ψ	Frisch elasticity	1
σ	elasticity of intertemporal substitution	1
δ	death probability	0.0167
ϕ	Taylor rule coefficient	1.5
μ	cross-sector elasticity of substitution	4.2
ρ_R	persistence monetary policy shock	0.25
ρ_A	persistence productivity shocks	0.95

Table 3. Sector-level parameter values.

Sector	$\bar{\epsilon}_k$	$\bar{\eta}_k$	$\bar{s}_k$	$\bar{\bar{\xi}}_k$	$\bar{\gamma}_{e,k}$	θ_k	λ_k
Food	6.7832	3.8555	0.1551	0.1240	0.0145	0.4100	0.5130
Clothing	4.8346	2.5564	0.0597	0.0245	0.0285	0.3900	0.5761
Electricity & Gas	3.2852	1.5235	0.0619	0.0608	0.0618	0.6400	0.1237
Furniture	4.9751	2.6500	0.0949	0.0773	0.0269	0.4600	0.3836
Transport	5.1674	2.7783	0.2027	0.2496	0.0250	0.2600	1.2681
Recreation	4.0184	2.0123	0.1905	0.1625	0.0413	0.5100	0.2854
Restaurants & Hotels	4.7313	2.4876	0.1281	0.1757	0.0298	0.7200	0.0670
Miscellaneous	3.1713	1.4475	0.1071	0.1255	0.0663	0.6700	0.0995

Notes: $\bar{\epsilon}_k$: demand elasticity (household aggregate), $\bar{\eta}_k$: superelasticity (household aggregate), $\bar{s}_k$: budget share (household aggregate), $\bar{\bar{\xi}}_k$: marginal budget share (household aggregate), $\bar{\gamma}_{e,k}$: markup elasticity w.r.t. consumption (household aggregate), θ_k: Calvo probability, λ_k: Slope NKPC. See the main text for the precise definitions.

Table 4. Heterogeneous consumption responses & household characteristics.

	MP shock		*Aggregate A shock*		*A shock to: Food*	
	coef.	std.err.	coef.	std.err.	coef.	std.err.
constant	-0.2804***	(0.0236)	-1.6058***	(0.0319)	-0.4259***	(0.011)
region						
East Midlands	-0.0215	(0.0145)	-0.0166	(0.0195)	-0.0082	(0.0067)
London	-0.0254**	(0.0149)	0.0028	(0.02)	-0.0234***	(0.0069)
North east	-0.0371**	(0.0165)	-0.0313	(0.0223)	-0.0148*	(0.0077)
Northern Ireland	-0.0124	(0.0148)	-0.0016	(0.02)	-0.0158**	(0.0069)
North West and Merseyside	-0.0167	(0.0133)	-0.0038	(0.0179)	-0.0098	(0.0062)
Scotland	-0.0272**	(0.0125)	-0.0234	(0.0169)	-0.0211***	(0.0058)
South East	-0.0096	(0.0132)	-0.0046	(0.0178)	-0.0109*	(0.0061)
South West	-0.0103	(0.0137)	0.0012	(0.0185)	-0.0074	(0.0064)
West Midlands	-0.0124	(0.0142)	-0.0031	(0.0192)	-0.0077	(0.0066)
Wales	-0.0218	(0.0167)	-0.0161	(0.0225)	-0.002	(0.0078)
Yorkshire and the Humber	-0.0135	(0.0141)	0.0043	(0.019)	-0.0097	(0.0065)
housing						
owner - mortgage	-0.0651***	(0.0088)	-0.0939***	(0.0119)	-0.0184***	(0.0041)
renter - private	-0.0335***	(0.0091)	-0.0527***	(0.0123)	-0.0175***	(0.0043)
renter - social	-0.0501***	(0.0123)	-0.0609***	(0.0166)	-0.0534***	(0.0057)
family						
couple without child	-0.0009	(0.0086)	0.0035	(0.0116)	0.0334***	(0.004)
single with child	-0.0116	(0.0146)	-0.0109	(0.0197)	0.0306***	(0.0068)
single without child	-0.0072	(0.0105)	-0.0137	(0.0141)	0.0863***	(0.0049)
income						
decile 2	0.0349***	(0.0131)	0.0476***	(0.0177)	0.0846***	(0.0061)
decile 3	0.0271**	(0.0134)	0.0248	(0.0181)	0.1218***	(0.0063)
decile 4	0.0623***	(0.0138)	0.0786***	(0.0186)	0.1561***	(0.0064)
decile 5	0.0528***	(0.0141)	0.0619***	(0.019)	0.178***	(0.0066)
decile 6	0.0609***	(0.0145)	0.0692***	(0.0196)	0.1978***	(0.0068)
decile 7	0.0602***	(0.0147)	0.0657***	(0.0198)	0.2103***	(0.0068)
decile 8	0.0595***	(0.015)	0.0595***	(0.0202)	0.2292***	(0.007)
decile 9	0.062***	(0.0151)	0.0704***	(0.0203)	0.2484***	(0.007)
decile 10	0.0671***	(0.0154)	0.0596***	(0.0207)	0.277***	(0.0071)
age						
38-50	0.006	(0.0089)	0.0095	(0.012)	-0.0267***	(0.0042)
51-64	0.0259***	(0.0096)	0.026**	(0.013)	-0.0311***	(0.0045)
>=65	0.019**	(0.0108)	0.0236	(0.0145)	-0.0558***	(0.005)
race						
black	-0.0069	(0.0265)	-0.0235	(0.0358)	0.0144	(0.0123)
mixed race	-0.0068	(0.031)	-0.0094	(0.0419)	0.0246*	(0.0144)
white	-0.0106	(0.0161)	0.0106	(0.0217)	0.0081	(0.0075)
other	-0.006	(0.0371)	-0.0081	(0.05)	-0.0285*	(0.0173)

Notes: Regression coefficients of the consumption response in the model, averaged over the first four quarters, on household characteristics. The omitted category is Eastern/owner-outright/couple with child/lowest income decile/age<38/asian. Standard errors between brackets. ***: p<0.01, **:p<0.05, *:p<0.1.

Table 5. Heterogeneous consumption responses & household characteristics (continued).

	A shock to: Clothing		*A shock to: Electricity & Gas*		*A shock to: Restaurants & Hotels*	
	coef.	std.err.	coef.	std.err.	coef.	std.err.
constant	-0.0404***	(0.0044)	-0.2455***	(0.0068)	-0.0792***	(0.006)
region						
East Midlands	-0.005*	(0.0027)	-0.0051	(0.0042)	-0.0063*	(0.0037)
London	-0.0052*	(0.0028)	-0.0058	(0.0043)	-0.0198***	(0.0038)
North east	-0.006*	(0.0031)	-0.0057	(0.0047)	-0.0119***	(0.0042)
Northern Ireland	-0.0106***	(0.0028)	-0.0227***	(0.0043)	-0.0043	(0.0038)
North West and Merseyside	-0.0065***	(0.0025)	-0.0138***	(0.0038)	-0.0052	(0.0034)
Scotland	-0.0082***	(0.0023)	-0.0154***	(0.0036)	-0.0039	(0.0032)
South East	-0.0018	(0.0024)	0.0002	(0.0038)	-0.0048	(0.0033)
South West	-0.0033	(0.0025)	-0.0042	(0.0039)	-0.0074**	(0.0035)
West Midlands	-0.0036	(0.0026)	-0.0073*	(0.0041)	-0.0031	(0.0036)
Wales	-0.006*	(0.0031)	-0.0058	(0.0048)	-0.0046	(0.0042)
Yorkshire and the Humber	-0.0048*	(0.0026)	-0.0012	(0.004)	-0.0088**	(0.0036)
housing						
owner - mortgage	-0.0046***	(0.0016)	0.0004	(0.0025)	-0.0077***	(0.0022)
renter - private	-0.0042**	(0.0017)	0.0041	(0.0026)	-0.003	(0.0023)
renter - social	-0.0122***	(0.0023)	-0.0207***	(0.0035)	0.0013	(0.0031)
family						
couple without child	0.0047***	(0.0016)	0.0133***	(0.0025)	-0.0105***	(0.0022)
single with child	-0.0082***	(0.0027)	-0.0006	(0.0042)	0.0025	(0.0037)
single without child	-0.0004	(0.0019)	0.031***	(0.003)	-0.0068**	(0.0027)
income						
decile 2	-0.0078***	(0.0024)	0.0846***	(0.0038)	-0.0095***	(0.0033)
decile 3	-0.0105***	(0.0025)	0.1185***	(0.0039)	-0.0119***	(0.0034)
decile 4	-0.013***	(0.0026)	0.1453***	(0.004)	-0.018***	(0.0035)
decile 5	-0.0159***	(0.0026)	0.1579***	(0.0041)	-0.0193***	(0.0036)
decile 6	-0.0115***	(0.0027)	0.1712***	(0.0042)	-0.0201***	(0.0037)
decile 7	-0.0151***	(0.0027)	0.1829***	(0.0042)	-0.0204***	(0.0037)
decile 8	-0.0128***	(0.0028)	0.1905***	(0.0043)	-0.018***	(0.0038)
decile 9	-0.0161***	(0.0028)	0.1987***	(0.0043)	-0.0198***	(0.0038)
decile 10	-0.0147***	(0.0029)	0.2116***	(0.0044)	-0.0106***	(0.0039)
age						
38-50	-0.0004	(0.0017)	-0.006**	(0.0026)	0.0023	(0.0023)
51-64	0.0016	(0.0018)	-0.0154***	(0.0028)	0.0125***	(0.0024)
>=65	-0.0005	(0.002)	-0.0176***	(0.0031)	0.0168***	(0.0027)
race	-0.0108**	(0.0049)				
black			-0.0104	(0.0076)	0.0111*	(0.0067)
mixed race	-0.0087	(0.0058)	-0.0013	(0.0089)	-0.0026	(0.0079)
white	-0.0005	(0.003)	0.0006	(0.0046)	-0.0104**	(0.0041)
other	-0.0081	(0.0069)	-0.0157	(0.0107)	0.0111	(0.0094)

Notes: Regression coefficients of the consumption response in the model, averaged over the first four quarters, on household characteristics. The omitted category is Eastern/owner-outright/couple with child/lowest income decile/age<38/asian. Standard errors between brackets. ***: p<0.01, **:p<0.05, *:p<0.1.