BANK OF ENGLAND

Working Paper No. <xxx>

Sectoral shocks and monetary policy in the United Kingdom

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Abstract

We consider an open economy model of the UK based on Harrison *et al.* (2011). The paper models CPI sectors based on the COICOP classification. Using the UK CPI microdata, we calibrate a Generalised Taylor model of the economy, except for petrol, food and energy which are largely determined by international factors. Using UK data, we find that sectoral shocks are largely white noise, with macroeconomic factors driving the persistence found in inflation. We find that the optimal simple Taylor rule allowing for different sectoral responses does better than the rule which just targets aggregate CPI. However, the gain is small, and comes from ignoring the contribution of petrol to inflation.

Key words: CPI inflation, Sectoral inflation rates, Generalised Taylor economy

***JEL* classification**: E17, E31, E52

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This paper is a draft and should not be quoted without the expressed written consent of the authors.
The views expressed in this paper are those of the authors, and not necessarily those of the Bank of England.
The authors are extremely grateful to Haroon Mumtaz for his help and advice on the empirical section and for sharing the Matlab code from his previous work. The authors wish to thank seminar participants at the University of Manchester for useful comments. Any errors and omissions remain the fault of the authors. This paper was finalised on *dd mmm yyyy*.

The Bank of England's working paper series is externally refereed.

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ISSN 1749-9135 (on-line)

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1 Introduction

A key question for monetary policy makers is how to deal with 'relative price' shocks; that is, movements in individual prices that do not reflect aggregate inflationary pressure but that can, as a result of nominal rigidities, lead to temporary changes in inflation. This question has gained in importance in recent years as the United Kingdom has been affected by shocks to the price of food and energy, which fall into the category of relative price shocks. As emphasised in Dale (2011) the Monetary Policy Committee (MPC) adopted a policy of 'looking through' these shocks, setting monetary policy in light of where inflation was expected to be once the temporary effects of the shocks had worn off. But this implied a policy that was more expansive than would be implied by a conventional Taylor rule, where the central bank would react to high inflation whatever the cause.

This paper seeks develop a framework to integrate sectoral shocks into model of the UK economy. More specifically, we seek to link together sectoral shocks in the Consumer Price Index (CPI) data to the behaviour of the economy at the aggregate level. This will enable us to address several questions about the causal links between the aggregate and sectoral level as well as the practical policy issue in terms of how monetary policy should respond to sectoral shocks. There are several recent papers that model sectoral shocks in the United States, including Mackowiak *et al.* (2009) and Boivin *et al.* (2009), and in the UK, including Mumtaz *et al.* (2009). Boivin *et al.* (2009) find using US data that most of the fluctuations in monthly sectoral inflation rates are due to sector-specific factors (on average about 12% were due to macro factors). Mumtaz *et al.* (2009) arrive at a similar result using quarterly data (on average around 50% were due to macro factors). In addition, they find that whilst sectoral inflation fluctuations are persistent in the raw data, this persistence is due to common macro components and not to the sector specific disturbances. The sector specific shocks themselves are much less persistent. Therefore, the overall picture is one in which many sectoral prices fluctuate considerably in response to sector specific shocks, but respond sluggishly to aggregate macro shocks, such as monetary policy. As argued by Mackowiak *et al.* (2009), this could be due to the fact that firms focus mainly on what is going on in their sector, and pay rationally little attention to the macro factors.

The key innovation of this paper is to link the 12 CPI *Classification Of Individual Consumption by Purpose* (COICOP) sectors directly into a new Keynesian DGSE model of the UK economy. We achieve this by using the UK CPI microdata for the period 1996-2006 to calibrate a Generalized Taylor Economy (GT) for each of the 12 CIOCOP sectors. To do this we estimate the cross-sectional distribution of durations within each CPI sector using the Hazard function. (See Gabriel and Reiff (2008) and Dixon and Le Bihan (2011).) Thus, for each CPI sector we have the proportion of prices in that sector that have a duration of up to one month, one to two months and so on. This can then be represented by a 12-quarter GT model, and enable us to trace the effect of a shock in a particular CPI sector. The GT model of pricing is then embedded into the macroeconomic model. The United Kingdom is a much more open economy than the United States. To capture the openness of the United Kingdom, we have used the model of Harrison *et al.* (2011) and Millard (2011). Furthermore, we are able to separate food and energy out of the CPI sectors: these are both sectors where prices are largely determined outside the UK and have had a significant impact on inflation in specific periods.

The policy issue on which we focus is how monetary policy should respond to sectoral shocks. There are at least three possible views here. One, the CPI rule, is that policy should not respond directly to sectoral shocks at all. Rather, it should just react to aggregate CPI inflation: sectoral effects only matter indirectly through the aggregate inflation measure. Another is that since aggregate CPI inflation is simply an arithmetic average of sectoral inflation rates, it must be better to allow policy to respond directly to each sectoral inflation rate. This view must be true in the sense that freely optimizing over the sectoral rates will be better than optimizing over a liner combination such as the arithmetic average: the practical policy issue is whether the improvement is significant or not. Kara (2010) found that the improvement to be quite small in a simple model calibrated using US data. The third view is that monetary policy should concentrate on a measure of the underlying rate of inflation, ie, a measure of inflation that strips out the 'noise' induced by relative price movements and, so, provides information on the outlook for inflation over the medium term. Such measures – sometimes referred to as 'core' inflation – involve removing certain items from the CPI index or using statistical methods to try and extract the 'persistent' or underlying trend component.[1] In this paper, we look at two such measures: one that strips out the most volatile components of CPI inflation from the index and a second that strips out that part of CPI inflation that can be thought of as being 'external' to the United Kingdom, leaving only 'domestically-generated' inflation.[2]

We analyse optimal simple Taylor rules and find that as in Kara (2010), the optimal rule using sectoral rates only leads to a small improvement over the CPI rule. Most of this improvement comes from ignoring the contribution of petrol prices to inflation. However, we find that targeting DGI performs the worst: the optimal sectoral rule does not imply that we should totally ignore food prices or non-petrol energy prices.

The paper is structured as follows. In the next section, we carry out an empirical analysis of sector-specific shocks in the United Kingdom using the approach of Mumtaz *et al.* (2009). Given these empirical results, we then construct a theoretical model in Section 3 that can be used to think about the interaction of sectoral and aggregate shocks and sectoral and aggregate inflation. Section 4 discusses how we calibrate the model and Section 5 presents some results. Section 6 analyses the implications for monetary policy and Section 7 concludes.

2 Sector-specific shocks in the United Kingdom: An empirical analysis

In this section we investigate the empirical properties of quarterly sectoral inflation in the UK over the period 1988-2011. We disaggregate to the 13 COICOP level, with two additional sectors created taking splitting COICOP 1 into *Food* (1.1) and *Non-Alcoholic Beverages* (1.2), and also splitting up COICOP 4 into *Housing and Water* (4.1-4.4) and (4.5) – henceforth *EGF*. We have split off *Food* and *EGF* because the prices of these goods will reflect potential external shocks coming from world food and energy prices. The CPI data broken down by the categories listed above only goes back to 1996, however we have constructed data back to 1988 using ONS experimental COICOP CPI data and adjusting RPI data to split out *Food* and *EGF* (see Appendix 1 for a description of the data and how this was done). We first consider some stylised facts for this data. Next, we estimate a dynamic factor model to decompose each sectoral inflation rate into a macro component and a sector-specific shock and analyse some of the key features of these shocks. Sectoral inflation rates, and thus relative prices,

[1] For a discussion of 'core inflation', see Mankikar and Paisley (2002).
[2] There are many ways of calculating 'domestically-generated inflation'. One approach is to simply use the GDP deflator. A more sophisticated approach is described on pages 34 and 35 in Bank of England (2011). In this paper, we use a definition that is consistent with our model.

will also react differently to macroeconomic shocks. Two important external relative price shocks that have affected the UK in recent years have been through energy and import prices. To understand how changes in import and energy prices can affect relative prices, we then use the estimated factors in a Factor Augmented Vector Autoregression (FAVAR).

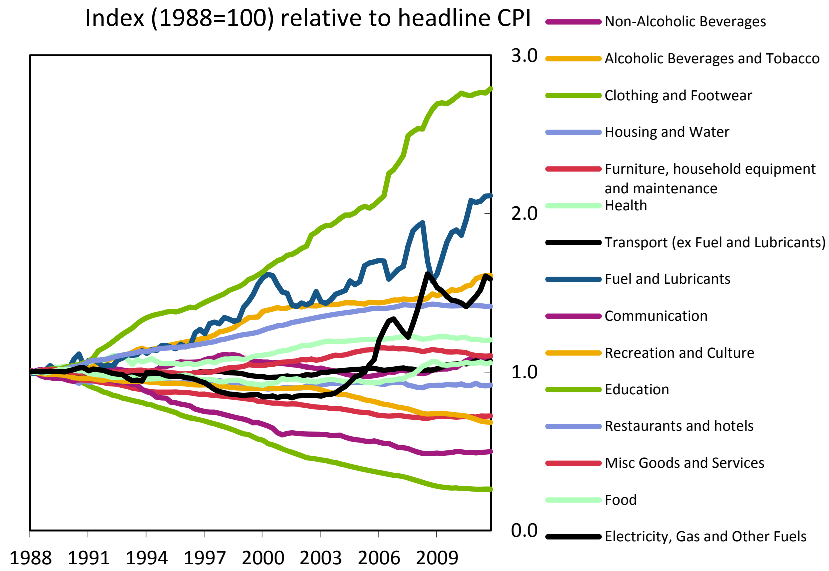
2.1 *Stylised facts on sectoral inflation*

First we can look at the long term trends in these sectoral prices as reflected in the COICOP sectors. Chart 1 shows how relative prices in the CPI basket have changed over time by considering the price index for each of the 15 COICOP categories above *relative* to headline CPI. As shown there is considerable variation in long-term trends across the sectoral price data implying there have been substantial relative price changes over time. Some sectors have been trending upwards, for example Education, Fuel and Lubricants, *EGF* and Alcoholic Beverages & Tobacco, whereas others have been trending downwards, for example Clothing & Footwear, Communication, Recreation and Culture and Furniture & Household Equipment. These long term trends over two decades no doubt reflect technological changes along with changes in consumer preferences.

Chart 2 presents the quarterly inflation rate for each of these 15 sectors. As shown they are all stationary; we provide the relevant statistics in Appendix 1, Table 1a.

Headline CPI inflation is a weighted mean of the sectoral inflation rates, so that the variance of Headline inflation can be seen as a pooled variance. Insofar as the sectoral inflation rates are uncorrelated with each other, we would expect the variance of sectoral inflation rates to be much larger than the variance of headline inflation; this is indeed what we find as shown in Table A. In Appendix 1 we give the covariance matrix, and we can see that the off diagonal terms are all small.

Chart 1: Sectoral price indexes relative to headline CPI, 1988Q1 to 2011Q4



While the sectoral inflation rates are volatile, they are not very persistent. If we model each sectoral inflation rate as an AR(4), we find that the sum of the autocorrelation coefficients are often insignificant and only two indicate half-lives beyond a quarter. This is shown in Table B, with a * indicating the half life extending beyond 1 quarter.

Chart 2: Quarter on quarter seasonally adjusted inflation rates, 1988Q1 to 2011Q4

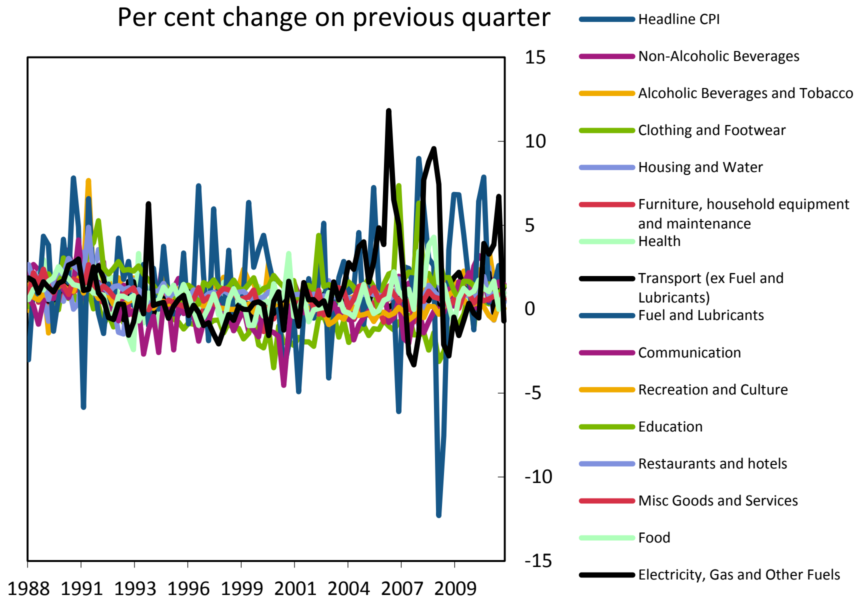


Table A: Standard deviations

Headline CPI	**0.52**
Sector average	**1.16**
Fuel and Lubricants	3.42
Electricity, Gas and Other Fuels	2.69
Communication	1.25
Education	1.1
Clothing and Footwear	1.06
Non-Alcoholic Beverages	1.02
Alcoholic Beverages and Tobacco	1.02
Food	0.99
Housing and Water	0.91
Health	0.89
Transport (ex Fuel and Lubricants)	0.71
Furniture, household equipment and maintenance	0.65
Restaurants and hotels	0.62
Recreation and Culture	0.59
Misc Goods and Services	0.52

Table B: Inflation persistence estimates

Headline CPI	**0.56**
Sector average	**0.27**
Non-Alcoholic Beverages	0.82
Electricity, Gas and Other Fuels	0.67*
Clothing and Footwear*	0.55
Recreation and Culture	0.55*
Communication	0.47
Transport (ex Fuel and Lubricants)	0.33
Restaurants and hotels	0.31
Education	0.28
Food	-0.02
Fuel and Lubricants	-0.32
Health	-0.55
Alcoholic Beverages and Tobacco	-
Housing and Water	-
Furniture, household equipment and maintenance	-
Misc Goods and Services	-

** The 2010 price collection methodology change is likely to affect estimates of persistence in this category.*

The instantaneous cross-correlations of the sectoral inflation rates are in general small: these are in Table A1.1 in Appendix 1. Most cross-correlations are less than 0.2. Out of 105 cross-correlations, only two are above 0.5: between *Housing and Water* and *Transport* (excluding Fuel and lubricants) have a cross-correlation of 0.8 and *Non-Alcoholic Beverages* and *Housing and Water* 0.6.

While the raw data on sectoral inflation gives us some indication of what sectoral shocks might look like, it is not complete. Some of the variation in sectoral inflation will come from common macroeconomic shocks, and some from sector-specific shocks. Of course, the macroeconomic shocks may affect different sectors differently, so this is an issue that requires some careful analysis.

2.2 Estimating sector-specific shocks

Sectoral prices are likely to be affected by macroeconomic factors and sector-specific shocks. Following Mumtaz *et al.* (2009), Boivin et al (2007) and Bernanke et al (2005), we use a dynamic factor model to decompose each sectoral inflation rate. This approach uses a large dataset of economic indicators, including the sectoral inflation rates, and estimates a set of principal components which best summarise the information in that dataset. These principal components, or common factors (C_t), are then regressed against the sectoral inflation rates (X_{it}) in order to estimate a set of factor loadings, Λ. The sector-specific shocks are thus modelled as the residual in equation **(1)**.

$$X_{it} = \Lambda C_t + e_{it} \qquad \textbf{(1)}$$

Chart 3: Factor 1 and quarter on quarter GDP growth, 1997Q2 to 2011Q4

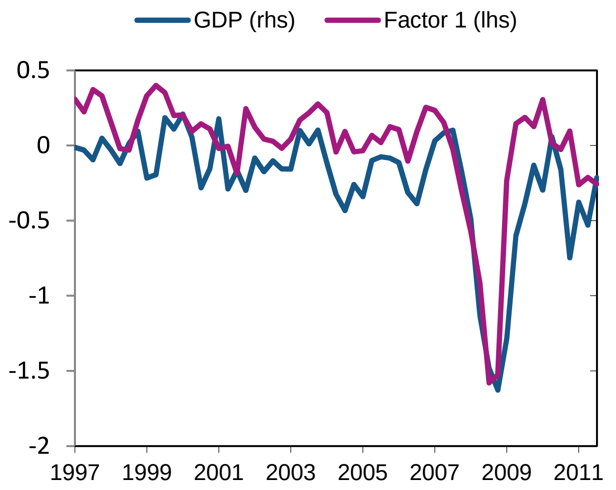
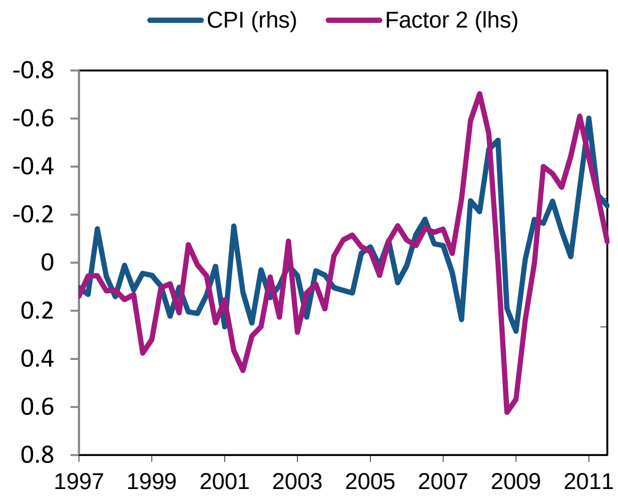


Chart 4: Factor 2 and quarter on quarter seasonally adjusted CPI, 1997Q2 to 2011Q4



Our dataset comprised around 350 macroeconomic UK data series, listed in Appendix 1, Table 1b, from 1997Q1 to 2011Q4[3]. This included inflation rates for the 15 sectors listed above, a range of aggregate and disaggregated activity measures such as GDP, consumption and industrial production, various price indicators including CPI, RPI and PPI, and money and asset price data. Where appropriate each series was seasonally adjusted, log-differenced to induce stationarity and normalised. In this application we selected the first eight principal components to make up $\mathbf{C}_t$; however the results are not particularly sensitive to the number of principal components chosen. The first two principal components can be interpreted as measures of real activity and inflation respectively, as shown in

[3] Our dataset is restricted to 1997 to incorporate larger range of data and Blue Book consistent series.

Charts 3 and 4. The full set of estimated principal component, or factors, are shown in Appendix A1 Table A1.X.

There are two key features of the estimated sector-specific shocks worth noting. First, sector-specific shocks are more important in explaining sectoral inflation rates than macroeconomic factors. Table C shows the proportion of the variance of each sectoral inflation rate that can be explained by the common factors. Whilst around 76% of the variance of headline CPI inflation can be explained by macroeconomic factors, they only explain an average of around 39% across the sectors. However, there is heterogeneity across sectors: in 5 sectors the macroeconomic factors are more important. Mumtaz *et al.* (2009) use the disaggregated consumption deflator rather than sectoral CPI series, and data from 1977 to 2006, but obtain similar results. They find that around 81% of the variation in headline CPI can be explained by macroeconomic factors and an average of around 50% across the disaggregated consumption deflator. Boivin *et al.* (2007) use monthly US data from 1976 to 2005 and find around 77% of the Personal Consumption Expenditure (PCE) can be explained by macroeconomic factors compared to around an average of 12% across the disaggregated PCE.

Table C: R^2 estimates	
Headline CPI	**0.76**
Sector average	**0.39**
Fuel and Lubricants	0.64
Food	0.56
Transport (ex Fuel and Lubricants)	0.54
Non-Alcoholic Beverages	0.50
Electricity, Gas and Other Fuels	0.49
Furniture, household equipment and maintenance	0.48
Clothing and Footwear	0.45
Housing and Water	0.43
Restaurants and hotels	0.41
Alcoholic Beverages and Tobacco	0.36
Communication	0.29
Health	0.26
Recreation and Culture	0.21
Education	0.13
Misc Goods and Services	0.08
** The 2010 price collection methodology change is likely to affect estimates of persistence in this category.*	

Second, sector-specific shocks exhibit very little persistence and behave similar to 'white noise' processes. In fact, it is the macroeconomic component that is generating most of the persistence found in the sectoral inflation rate. Table D presents the sum of coefficients in estimated AR(4) models for the macroeconomic component and sector-specific shock for each sector. In 10 out of 15 sectors the sectoral shocks are white noise; in the remaining 5 sectors there is a statistical evidence of some autocorrelation, but nothing of any quantitative significance. Only in *Recreation and* Culture do we find that the sector specific and aggregate persistence have the same magnitude. These results are consistent with Mumtaz *et al.* (2009) and Boivin *et al.* (2007) who both also find that sector-specific shocks exhibit little or no persistence. The macroeconomic factors on the other hand do generate significant persistence in some sectors (in 5 sectors the sum of AR(4) coefficients exceeds 0.5), whilst in others it does not (in 3 sectors there is no statistically significant macro induced persistence). In Appendix Table A1.2 we also report the cross-correlations of the estimated sectoral shocks. These are all 'induced' since we are assuming that there is no structural cross-correlation. Interestingly, these are all small with the exception of a cross-correlation of 0.8 between the *Housing and Water* shock and the *Transport* shock, exactly the same anomaly we found when looking at the cross-correlations in the raw inflation. In general, as we would expect, the cross-correlations are smaller than in the inflation data; this is because common macro factors will induce additional cross correlation.

Table D: Inflation persistence estimates

	Macro component	**Sector-specific shock**
Headline CPI	**0.69**	**0.00**
Sector average	**0.37**	**0.02**
Non-Alcoholic Beverages	0.36	-
Alcoholic Beverages and Tobacco	-	-
Clothing and Footwear	0.45	-
Housing and Water	0.77	-
Furniture, household equipment and maintenance	0.56	-
Health	0.00	-
Transport (ex Fuel and Lubricants)	0.45	-
Fuel and Lubricants	0.60	-0.33
Communication	0.75	0.31
Recreation and Culture	0.44	0.45
Education	-	-
Restaurants and hotels	0.39	-
Misc Goods and Services	-0.39	-
Food	0.65	-0.34
Electricity, Gas and Other Fuels	0.45	0.18

** The 2010 price collection methodology change is likely to affect estimates of persistence in this category.*

A critique of this methodology has been made by De Graeve and Walentin (2011), who argue that all sources of noise in (1) are attributed to the sector-specific shock. In practice, some of this noise comes from 'measurement error' or sources such as sales and product substitutions occurring in the CPI data collection process. Furthermore, these factors have little persistence. Whilst sales are clearly important, it is not clear that we should ignore them when it comes to explaining inflation: whilst individual sales might sometimes be 'random', the pattern and structure of sales forms an enduring part of pricing behaviour and should not be edited out.

2.3 The impact of external prices on relative prices: the FAVAR approach

Following the methodology of Mumtaz et al (2009), Boivin et al (2007) and Bernanke et al (2005), the estimated factors from equation **(1)** can be used within the Factor-Augmented Vector Auto Regression (FAVAR). The approach assumes that the estimated aggregate factors are able to summarise the information contained in a large dataset of macro-variables in order to give a more parsimonious representation. The previous studies listed above have focussed on estimating the impact of monetary policy, through shocks to the interest rate.

In this application we are principally interested estimating the impact of changes to external price pressures, namely oil and import prices, on relative prices in the CPI basket. To do this we estimate the reduced form system described in equation **(2)**. The system assumes that the estimated factors from equation **(1)** (F_t), the exchange rate (E_t) and the interest rate (R_t) are endogenous. It also assumes that the key external macro variables we are interested in, the oil price (O_t) and import price (I_t) are exogenous. In other words, they are affected by world factors and not domestic UK factors.

The system is estimated using monthly data between January 1997 and 2011[4]. We follow the estimation procedure of Mumtaz *et al.* (2009) and estimate equation **(2)** using a Bayesian estimator (BVAR).

$$\begin{bmatrix} F_t \\ E_t \\ R_t \end{bmatrix} = \mathrm{A}(L).\begin{bmatrix} F_{t-1} \\ E_{t-1} \\ R_{t-1} \end{bmatrix} + \mathrm{B}(L).O_t + \mathrm{B}(L).I_t + \upsilon_t \qquad \textbf{(2)}$$

The aim is to use the estimated coefficients in **(2)** to to examine the effect of a change in oil and import prices on the factors (F_t). We can then use the loading matrix estimated in equation **(1)** to map any changes in these factors (F_t) on to the variables of interest in our large dataset, including the CPI sectoral inflation rates. The advantage of using the BVAR approach is that it allows us to use the posterior distribution to generate confidence bands, measured as 1 standard deviation, around the median responses of the variables of interest.

Appendix A.1.3 presents three sets of results. First, we examine the impact of a monetary policy shock to examine how our model responds compared to previous studies. Here we identify a monetary policy shock using a standard Cholesky ordering, where the interest rate, R_t, is ordered last. We find a modest response of CPI to a monetary contraction, broadly a monetary contraction of around 15 basis points delivers a peak reduction in annual CPI inflation of around 0.05pp after a year – this is equivalent to a reduction in annual CPI inflation of around 0.3pp after a year from a 100 basis point contraction. This is broadly inline with the results of Mumtaz *et al*. (2009) who find that 100 basis point contraction has a peak of -0.1 to -0.4pp depending on whether a Cholesky or Sign Restriction approach is used to identify the monetary policy shock. However, it is important to note that there is great deal of uncertainty around these estimates as shown by confidence bands around the median estimate.

Second, we look at the impact of a 10% increase in oil prices. The response of aggregate CPI suggests oil prices have a fast impact on CPI, peaking at around 0.2pp within the first year. Most of this comes through an increase in Fuels & Lubricants inflation, but Electricity, Gas & Other Fuels also increases with a lag. We also find that prices in other sectors respond, often with more of a lag, suggesting that higher energy costs are passed through to higher prices in other sectors.

Third, we examine the impact of a 10% increase in import prices (excluding energy). The estimates around the estimated coefficients are a lot less precise, indicated by the wider confidence bands around the median estimates. Nonetheless, the median response suggests a considerable response of CPI which peaks at around 0.3pp on CPI inflation after 18 months. The cumulative effect on the price level

[4] The 2011 ONS Blue Book included a change in the industrial classification used from SIC03 to SIC07 from 1997. Therefore, in order to exploit as much of the available information across industries we use monthly data from 1997.

after 3 years is around 2.5%. The response across sectors is varied, with notable increases in import intensive sectors such as Food and Clothing & Footwear. Fuels & Lubricants and Electricity, Gas & Other Fuels also increase substantially.

A weakness of this estimation strategy is that oil and import prices (excluding energy) are well correlated. Since oil often forms a key input into other goods and services which are then imported to the UK. This means that some of the effect of changes in oil prices may be being captured by changes in import prices and vice versa. This could be the reason why Fuels and Lubricants and Electricity, Gas and Other Fuels inflation responds so strongly to a 10% increase in import prices (excluding energy).

3 The Theoretical Model.

In this section we outline the empirical model of the UK based on Harrison *et al.* (2011) and Millard (2011). This has several features which are relevant for the UK but not contained in models such as Smets and Wouter's Euro area model (2003). Most notably is the small open economy nature of the UK economy. Whilst Harrison *et al.* and Millard introduces an external element in the form of energy prices (whose dollar price is determined in world markets), we also introduce food prices as being determined in world markets.

3.1 Households

Households consume four final goods and supply differentiated labour to the firms. They are also assumed to own the capital stock and make decisions about capital accumulation and utilisation. This assumption, now standard in the business cycle literature, is done in order to simplify the firms' decision problem. The full set of equations is presented in an appendix B: for expositional purposes we present the log-linearised version here.

The following set of equation determines the household's choice of aggregate consumption, capital accumulation and utilisation:

$$\hat{c}_t = \frac{\psi_{hab}(1-\sigma_c)}{1+\psi_{hab}(1-\sigma_c)}\hat{c}_{t-1} + \frac{1}{1+\psi_{hab}(1-\sigma_c)}E_t\hat{c}_{t+1} - \frac{\sigma_c}{1+\psi_{hab}(1-\sigma_c)}\left(i_t - E_t\pi_{c,t+1} - \left(\frac{1}{\beta}-1\right)\right) \quad \textbf{(3)}$$

$$\left(i_t - E_t\pi_{c,t+1} - \left(\frac{1}{\beta}-1\right)\right) = \left(\frac{\varepsilon_k}{1-\delta+\chi_z} + (1+\varepsilon_k)\right)\chi_k\hat{k}_{t-1} - \left(\frac{(1+\varepsilon_k)}{1-\delta+\chi_z}+1\right)\chi_k\hat{k}_t + \frac{\chi_k}{1-\delta+\chi_z}E_t\hat{k}_{t+1} - \chi_k\varepsilon_k\hat{k}_{t-2} + \frac{\chi_z}{1-\delta+\chi_z}E_t\hat{w}_{k,t+1} \quad \textbf{(4)}$$

$$\hat{w}_{k,t} = \phi_z\hat{z}_t \quad \textbf{(5)}$$

where c is consumption, i is the nominal interest rate, π_c is the inflation rate of consumer prices, w_k is the rental rate for capital, z is the capital utilisation rate and k is the end-of-period capital stock. Variables without time subscripts refer to their steady-state values and 'hatted' variables represent log deviations from trend. In terms of the parameters, ψ_{hab} represents the degree of habit formation in consumption, σ_c is the intertemporal elasticity of substitution, β is the discount rate, χ_k scales the costs of adjusting the capital stock, χ_z is the steady-state rental rate for capital, δ is the depreciation rate for capital and ϕ_z is the inverse elasticity of the capital utilisation cost function.

Equation **(3)** is the consumption Euler equation. Consumption depends on past consumption due to external habit formation. As a result, the elasticity of consumption to the interest rate depends not only on the elasticity of substitution but also on the degree of habit formation parameter. Equation **(4)** is the capital accumulation equation in which lagged capital appears due to the assumption of capital adjustment costs. Equation **(5)** determines capacity utilisation as a function of the rental rate of capital. Aggregate consumption, c, is composed of consumption of food (which is imported), c_f, petrol, c_p, utilities, c_u, and 'non food or energy' (NFE), c_n.[5] Consumption of 'energy', c_e, will be given by:

$$\hat{c}_{e,t} = (1-\psi_p)\left(\frac{c_u}{c_e}\right)^{\frac{\sigma_p - 1}{\sigma_p}} \hat{c}_{u,t} + \psi_p \left(\frac{c_p}{c_e}\right)^{\frac{\sigma_p - 1}{\sigma_p}} \hat{c}_{p,t} \qquad \textbf{(6)}$$

and, hence, aggregate consumption will be given by:

$$\hat{c}_t = (1-\psi_e - \psi_f)\left(\frac{\kappa_c c_n}{c}\right)^{\frac{\sigma_e - 1}{\sigma_e}} \hat{c}_{n,t} + \psi_e \left(\frac{\kappa_c c_e}{c}\right)^{\frac{\sigma_e - 1}{\sigma_e}} \hat{c}_{e,t} + \psi_f \left(\frac{\kappa_c c_f}{c}\right)^{\frac{\sigma_e - 1}{\sigma_e}} \hat{c}_{f,t} \qquad \textbf{(7)}$$

The numeraire is NFE. Relative prices in numeraire terms will be given by inverting the demand functions to express prices as a function of types of consumption:

$$\hat{p}_{f,t} - \hat{p}_{c,t} = \frac{1}{\sigma_e}\left(\hat{c}_t - \hat{c}_{f,t}\right) \qquad \textbf{(8)}$$

$$\hat{p}_{u,t} - \hat{p}_{c,t} = \frac{1}{\sigma_e}\left(\hat{c}_t - \hat{c}_{e,t}\right) + \frac{1}{\sigma_p}\left(\hat{c}_{e,t} - \hat{c}_{u,t}\right) \qquad \textbf{(9)}$$

and

$$\hat{p}_{u,t} - \hat{p}_{p,t} = \frac{1}{\sigma_p}\left(\hat{c}_{p,t} - \hat{c}_{u,t}\right) \qquad \textbf{(10)}$$

Where p_f is the price of food relative to NFE, p_c is the price of the aggregate consumption good relative NFE, p_u is the price of utilities relative to NFE and p_p is the price of petrol relative to NFE.

Households also have the option of holding either foreign or domestic bonds but trade in foreign bonds incurs quadratic costs. This results in the UIP condition:

$$E_t \hat{s}_{t+1} - \hat{s}_t = -\left(i_t - \left(\frac{1}{\beta} - 1\right)\right) - \chi_{bf} b_{f,t} \qquad \textbf{(11)}$$

[5] NFE represents all other consumer CPI basket *excluding* food and energy.

where s is the nominal exchange rate and χ_{bf} is a parameter determining the cost of holding foreign bonds, b_f. As a normalisation, we denote foreign bond holdings as a proportion of non-energy output and we assume, without loss of generality, that the supply of domestic government bonds is zero in all periods; that is, the government balances its budget via lump-sum taxes on consumers.

Each household is a monopoly supplier of differentiated labour. Thus, they set their real wages, w, as a mark-up over their marginal rate of substitution between leisure and consumption (percentage deviation denoted by mrs), subject to nominal wage stickiness and partial indexation of wages to inflation. Hence, wage inflation will be given by:

$$\dot{W}_t = \frac{\xi_w}{1+\beta\xi_w}\dot{W}_{t-1} + \frac{\beta}{1+\beta\xi_w}E_t\dot{W}_{t+1} - \frac{\psi_w(1-\beta(1-\psi_w))}{\left(1+\frac{\sigma_w}{\sigma_h}\right)(1-\psi_w)(1+\beta\xi_w)}(\hat{w}_t - mrs_t) \quad \textbf{(12)}$$

where $\dot{W}$ is nominal wage inflation. Here ψ_w is the share of household members able to re-optimise their wages and ξ_w governs the extent to which non-optimised wages are indexed to past inflation. The steady-state wage mark-up is given by $\frac{\sigma_w}{\sigma_w - 1}$ and σ_h denotes the Frisch elasticity of labour supply.

The equations defining the marginal rate of substitution and the real consumption wage are:

$$mrs_t = \frac{1}{\sigma_h}\hat{h}_t + \frac{1}{\sigma_c}(\hat{c}_t + \psi_{hab}(\sigma_c - 1)\hat{c}_{t-1}) \quad \textbf{(13)}$$

$$\hat{w}_t = \dot{W}_t + \hat{w}_{t-1} - \pi_{c,t} \quad \textbf{(14)}$$

where h is total hours worked.

3.2 Non food and energy producing firms

The representative non food and energy (NFE) producing firm is assumed to have the following production function for output q:

$$\hat{q}_t = (1-\alpha_q)\left(\frac{\kappa_q(1-\phi_q)B}{q}\right)^{\frac{\sigma_q - 1}{\sigma_q}}\hat{B}_t + \alpha_q\left(\frac{\kappa_q\phi_q e}{q}\right)^{\frac{\sigma_q - 1}{\sigma_q}}\hat{e}_t \quad \textbf{(15)}$$

Output is produced from two intermediates: B and energy e. B is the intermediate output ('bundle') produced from value-added V_n, and intermediate imported goods, M_n according to the simple Cobb-Douglas function:

$$\hat{B}_t = (1-\alpha_B)\hat{V}_{n,t} + \alpha_B\hat{M}_{n,t} \quad \textbf{(16)}$$

The energy input in this sector is produced by a Leontief production so that:

$$\hat{e}_t = \hat{I}_{p,t} = \hat{I}_{u,t} \qquad \textbf{(17)}$$

where I_p is the input of petrol and I_u is input of utilities to the NFE sector.

Cost minimisation implies the following demand curves for value-added, imports and energy:

$$\hat{V}_{n,t} = \hat{\mu}_t - \hat{p}_{vc,t} - \left(\tau_{VAT,t} - \tau_{VAT}\right) + \frac{1}{\sigma_q}\hat{q}_t + \frac{\sigma_q - 1}{\sigma_q}\hat{B}_t \qquad \textbf{(18)}$$

$$\hat{M}_{n,t} = \hat{\mu}_t - \hat{p}_{m,t} - \left(\tau_{VAT,t} - \tau_{VAT}\right) + \frac{1}{\sigma_q}\hat{q}_t - \left(\frac{1}{\sigma_q} - 1\right)\hat{B}_t \qquad \textbf{(19)}$$

$$\hat{e}_t = \sigma_q\hat{\mu}_t + \hat{q}_t - \sigma_q\left(\frac{\psi_n p_p \hat{p}_{p,t} + (1-\psi_n)p_u\hat{p}_{U,t}}{\psi_n p_p + (1-\psi_n)p_u} + \left(\tau_{VAT,t} - \tau_{VAT}\right)\right) \qquad \textbf{(20)}$$

where μ is real marginal cost, p_{vc} is the 'competitive' price of value-added (the marginal cost of producing it), p_m is the price of imported intermediates, $\tau_{VAT,t}$ is the rate of VAT at time t and τ_{VAT} is the steady-state rate of VAT. Adding VAT in this way enables us to consider the effects of temporary VAT increases or decreases. To examine the effects of a permanent increase in the rate of VAT, we need to solve the model's steady state for the initial VAT rate and the final VAT rate and then examine the transitional dynamics between the two steady states.

An important point to note is that except for the sector specific shocks, which we describe below, real marginal cost μ is common across all firms in the NFE sector: they all share the same technology and factor prices. We do not attempt to construct a structural model of the NFE sector itself over and above the basic structure of the GT which can be thought of as 'duration' sectors superimposed on the CPI sectors within the NFE.

We set up each of the COICOP sectors within the non-energy sector as in the GT model as in Dixon and Kara (2010). Firms in each of the twelve NFE subsectors are divided up into K sub-subsectors, where sub-subsector $k= 1, \ldots K,$ denotes those firms whose prices change every k periods. We first note that the optimal flexible (basic) price in any sub-subsector will simply be a mark-up over marginal cost in that sub-subsector. We assume that, after factors of production have already been allocated, the COICOP subsectors experience relative productivity shocks (that will cause relative prices to move). Hence, marginal cost within a COICOP subsector will be given by $\mu_t + \varepsilon_{k,t}$ with where ε_k is the *relative* productivity shock in COICOP subsector k and γ_k is the weight of subsector k in NFE. Given our earlier results, we assume that these shocks are white noise, ie, $E_t\varepsilon_{k,t+j} = 0\forall j \geq 1$ and furthermore we also assume that they are uncorrelated across COICOP sectors.

Note that we are assuming that there are 12 sectoral shocks: one per sector. In effect, this is because we are looking at the shocks as relative to the *NFE* sector as a whole. Clearly there is an adding up restriction, so there is no 'sector wide' *NFE* shock included in the model, as seems appropriate since we are treating *NFE* as the numeraire. An alternative methodology would have been to have included a sector-wide *NFE* shock and then allowed for 12 sector specific shocks that added up to zero. These two approaches are of course linked: we can think of the shocks ε_k in terms of the mean shock (the sector wide element) and the deviation form mean. Conceptually, a technological improvement in *Clothing and Footwear* does not in itself imply that other sectors should get better or worse. However, *NFE* as a whole will experience a technological improvement if the shocks across the COICOP sectors tend to be more positive than negative.

Now, the optimal flexible (market) price in GTE subsector *k* of COICOP sector *z* at time *t+j* (relative to numeraire at time t) will be given by:

$$\hat{p}^*_{z,k,t+j} = \hat{\mu}_{t+j} + \varepsilon_{z,t+j} + \left(\tau_{VAT,t+j} - \tau_{VAT}\right) + \sum_{i=1}^{j} \pi_{t+i} \qquad \textbf{(21)}$$

where $\sum_{i=1}^{j} \pi_{t+i}$ captures the effect of inflation in the sense that the NFE *i* periods ahead may be more expensive. Not that the sectoral shock $\varepsilon_{k,t}$ is not the same as the sectoral shock estimated in section 2. The sectoral shock here can be regarded as how much the nominal price in the sector would respond *if it the price was perfectly flexible*. In the data, since prices are sticky in the NFE sectors, what we observe is a partial muted response. The theoretical shocks in (20) would have to be considerably larger in terms of variance in order to be consistent with the shocks we observe in the inflation data. These shocks can either be considered as real shocks to marginal cost, or as markup shocks (these cannot be distinguished in our model setup).

Given the optimal price in each period, a firm in GT duration subsector *k* of COICOP sector *z* that is able to reset their price in period *t* will set it to:

$$\hat{x}_{z,k,t} = \frac{E_t \sum_{j=0}^{k-1} \beta^j \left(\hat{p}^*_{z,k,t+j}\right)}{\sum_{j=0}^{k-1} \beta^j} \qquad \textbf{(22)}$$

$\hat{x}_{z,k,t}$ is the real reset price: over time it will be eroded by inflation (since it is the nominal price that is kept constant). This is captured by the inflation terms added to the RHS of equation **(21)**: higher expected future inflation will raise the real reset price. Notice that deviations of the price from the optimal price are less costly to the firm the further they are in the future since the firm is maximising the present discounted value of future profits and not the undiscounted sum. The denominator ensures that the weights put on deviations of price from the optimal price sum to one. Note that in the GT, as in the simple Taylor model, when it sets its price the firm knows exactly how long the price will last. Whilst some firms who expect their price to last for many periods will be far-sighted, firms who expect the price to last just one month will be myopic in their pricing decision. This contrasts to the Calvo model, where firms face a distribution of probabilities over possible durations for their price, so have to be more forward looking on average when it comes to setting their price.

Hence, the average price prevailing in GT subsector *k* of COICOP sector *z* (relative to *P*) will be given by:

$$\hat{p}_{z,k,t} = \frac{1}{k}\left(\hat{x}_{z,k,t} + \sum_{j=1}^{k-1}\left(\hat{x}_{z,k,t-j} - \sum_{i=0}^{j-1}\pi_{t-i} \right)\right) \qquad \textbf{(23)}$$

Averaging these prices will result in the overall price of COICOP sector *z*:

$$\hat{p}_{z,t} = \sum_{k=1}^{K}\gamma_{zk}\hat{p}_{z,k,t} \qquad \textbf{(24)}$$

And, finally, the price of non food and energy (the numeraire) will be given by:

$$\sum_{z=1}^{Z}\gamma_{z}\hat{p}_{z,,t} = 0 \qquad \textbf{(25)}$$

Whilst we have used the GT framework to allow for us to model different levels of nominal rigidity across the sectors using the microdata, they are otherwise identical except for the sector specific shocks. Clearly, there will be substantial real differences between the sectors that we have not modelled: *Hotels and Restaurants* have a different technology and market structure to *Communications*. These un-modelled factors might affect the inflation we observe in the data but not in the model simulations.

3.3 Value-added sector

'Value-added' producers use labour and capital to produce value-added, *V*:

$$\hat{V}_t = (1-\alpha_v)\left(\frac{h}{V}\right)^{\frac{\sigma_v - 1}{\sigma_v}}\hat{h}_t + \alpha_v\left(\frac{k}{V}\right)^{\frac{\sigma_v - 1}{\sigma_v}}\left(\hat{k}_{t-1} + z_t\right) + \varepsilon_{a,t} \qquad \textbf{(26)}$$

The term in *z* shows that the capital effectively used in production depends on the intensity of capital utilisation and ε_a represents a shock to productivity.

Cost minimisation by value-added producers implies the following demand curves for capital and labour:

$$\hat{h}_t = \hat{V}_t + (\sigma_v - 1)\varepsilon_{a,t} + \sigma_V\left(\hat{p}_{vc,t} - \hat{w}_t\right) \qquad \textbf{(27)}$$

$$\hat{k}_{t-1} + \hat{z}_t = \hat{V}_t + (\sigma_v - 1)\varepsilon_{a,t} + \sigma_V\left(\hat{p}_{vc,t} - \hat{w}_{k,t}\right) \qquad \textbf{(28)}$$

3.4 Petrol producers

Petrol, q_p, is produced using inputs of crude oil, I_o, and value-added, V_p. We assume a simple Leontieff production function:

$$\hat{q}_{p,t} = \hat{I}_{o,t} = \hat{V}_{p,t} \tag{29}$$

The motivation for this choice of production function is that it is not clear how adding more and more workers to a given amount of oil could physically increase the amount of petrol that can be produced from it. Firms in this sector are not subject to nominal rigidities in their price-setting, that is, we assume that petrol prices are perfectly flexible. Hence, petrol prices will be set as a constant mark-up over marginal cost:

$$\hat{p}_{pb,t} = \frac{\psi_{qp} p_{vc} \hat{p}_{vc,t} + (1-\psi_{qp})\hat{p}_{o,t}}{\psi_{qp} p_{vc} + 1 - \psi_{qp}} \tag{30}$$

where p_o is the price of oil and p_{pb} is the basic (pre-tax and duty) price of petrol.

We assume that the fiscal authority levies a duty on petrol that is not changed over time. If we let d denote petrol duty, we obtain:

$$\hat{p}_{p,t} = (\tau_{VAT,t} - \tau_{VAT}) + \frac{p_{pb}}{p_{pb} + d}\hat{p}_{pb,t} \tag{31}$$

That is, since it is held constant, the petrol duty has no role other than to reduce the impact of a change in petrol producers' other costs on the final price of petrol paid by consumers.

3.5 Utilities producers

Output of utilities, q_u, is produced using inputs of gas, I_g, and value-added, V_u. We again assume a simple Leontieff production function:

$$\hat{q}_{u,t} = \hat{I}_{g,t} = \hat{V}_{u,t} \tag{32}$$

Again, the motivation for this choice of production function is that it is not clear how adding more and more workers to a given amount of natural gas could physically increase the amount of gas and electricity that can be produced from it. Firms in this sector are subject to nominal rigidities in their price-setting. We assume that they are able to optimally change their price in any given quarter with probability χ_u. The resulting NKPC is:

$$\pi_{ub,t} = \beta E_t \pi_{ub,t+1} + \frac{(1-\chi_u)(1-\beta\chi_u)}{\chi_u}\hat{\mu}_{u,t} \tag{33}$$

where π_{ub} represents the inflation rate for basic (ie, pre-VAT) utility prices.

Real marginal cost in this sector will be given by:

$$\hat{\mu}_{u,t} = \frac{\psi_u p_{vc}\hat{p}_{vc,t} + (1-\psi_u)\hat{p}_{g,t}}{\psi_u p_{vc} + 1 - \psi_u} - \hat{p}_{u,t} \qquad \textbf{(34)}$$

where p_g is the price of gas and p_u is the price of utilities (where we have assumed that the rate of VAT charged on utilities does not change over time). We can note that by definition:

$$\pi_{ub,t} = \pi_t + \hat{p}_{u,t} - \hat{p}_{u,t-1} \qquad \textbf{(35)}$$

3.6 Monetary and fiscal policy

Monetary policy is assumed to follow a Taylor rule with the central bank responding to deviations of inflation from target and value-added from flexible-price value-added, y_{FP}:

$$i_t - \left(\frac{1}{\beta} - 1\right) = \theta_{rg}\left(i_{t-1} - \left(\frac{1}{\beta} - 1\right)\right) + (1-\theta_{rg})(\theta_{pdot}\pi_{c,t} + \theta_y \hat{y}_{FP,t}) + \varepsilon_{i,t} \qquad \textbf{(36)}$$

where ε_i is a monetary policy shock. Flexible-price value-added is defined as what value-added would be in a flexible-price version of the model given the estimated values of the shocks.

Since, we assume, as said earlier, that the government balances its budget using lump-sum taxes on consumers (denoted by T), we can write the government's budget constraint as:

$$c_{g,t} = \tau_{VAT,t}(q_t + p_{p,t}q_{p,t}) + (1+\tau_{VAT,t})\frac{d}{1-d}p_{pb,t}q_{p,t} + \tau_u p_{u,t}c_{u,t} + T_t \qquad \textbf{(37)}$$

This equation, when combined with the households' budget constraint and the definition of firms' profits results in the market clearing condition for non food and energy output shown later.

3.7 Foreign sector

We assume that the United Kingdom is a small open economy. Hence, world prices are exogenous. We assume that oil and gas prices adjust immediately to their world prices:

$$\hat{p}_{o,t} = \varepsilon_{p_o} - \hat{s}_t \qquad \textbf{(38)}$$

$$\hat{p}_{g,t} = \varepsilon_{p_g} - \hat{s}_t \qquad \textbf{(39)}$$

where ε_{p_o} is a shock to world oil prices and ε_{p_g} is a shock to world gas prices. These two shocks represent 'relative price shocks'.

UK food and non food and energy import prices, on the other hand, take time to adjust to purchasing power parity. This results in the NKPCs for food prices and for import prices ex food and energy:

$$\pi_{f,t} = \frac{\iota_{pf}}{1+\beta\iota_{pf}}\pi_{f,t-1} + \frac{\beta}{1+\beta\iota_{pf}}E_t\pi_{f,t+1} + \frac{(1-\xi_{pf})(1-\beta\xi_{pf})}{(1+\beta\iota_{pm})\xi_{pf}}\left(\varepsilon_{p_f} - \hat{s}_t - \hat{p}_{f,t}\right) \quad \textbf{(40)}$$

$$\pi_{m,t} = \frac{\iota_{pm}}{1+\beta\iota_{pm}}\pi_{m,t-1} + \frac{\beta}{1+\beta\iota_{pm}}E_t\pi_{m,t+1} + \frac{(1-\xi_{pm})(1-\beta\xi_{pm})}{(1+\beta\iota_{pm})\xi_{pm}}\left(\varepsilon_{p_{mf}} - \hat{s}_t - \hat{p}_{m,t}\right) \quad \textbf{(41)}$$

where π_f is the rate of inflation of food prices, π_m is the rate of inflation of non food and energy import prices, ε_{p_f} is a shock to world food prices and ε_{p_m} is a shock to the world price of our imports. Again, these two shocks represent 'relative price shock'.

Finally, we assume the following demand function for our exports of non-energy goods, x_n:

$$\hat{x}_{n,t} = \psi_z\hat{x}_{n,t-1} - (1-\psi_z)\eta_x\hat{s}_t \quad \textbf{(42)}$$

3.8 Market clearing

We close the model with the following market-clearing conditions:

$$\hat{p}_{c,t} + \hat{c}_t = \frac{c_n}{c}\hat{c}_{n,t} + \frac{c_f}{c}\left(\hat{p}_{f,t} + \hat{c}_{f,t}\right) + \frac{p_u c_u}{c}\left(\hat{p}_{U,t} + \hat{c}_{U,t}\right) + \frac{p_p c_p}{c}\left(\hat{p}_{P,t} + \hat{c}_{P,t}\right) \quad \textbf{(43)}$$

$$V_t = \frac{V_n}{V}\hat{V}_{n,t} + \frac{V_u}{V}\hat{V}_{u,t} + \left(1 - \frac{V_n}{V} - \frac{V_u}{V}\right)\hat{V}_{p,t} \quad \textbf{(44)}$$

$$\hat{q}_{P,t} = \frac{c_P}{q_P}\hat{c}_{P,t} + \left(1 - \frac{c_P}{q_P}\right)\hat{I}_{P,t} \quad \textbf{(45)}$$

$$\hat{q}_{U,t} = \frac{c_U}{q_U}\hat{c}_{U,t} + \left(1 - \frac{c_U}{q_U}\right)\hat{I}_{U,t} \quad \textbf{(46)}$$

$$\hat{I}_{O,t} = -\frac{X_o}{I_o}\hat{X}_{O,t} \quad \textbf{(47)}$$

$$\hat{I}_{G,t} = -\frac{X_g}{I_g}\hat{X}_{G,t} \quad \textbf{(48)}$$

$$\hat{q}_t = \frac{c_n}{q}\hat{c}_{n,t} + \frac{k}{q}\hat{k}_t - \frac{(1-\delta)k}{q}\hat{k}_{t-1} + \frac{\chi_z k}{q}\hat{z}_t + \frac{c_g}{q}\varepsilon_{g,t} + \frac{\kappa_x}{q}\hat{x}_{n,t} \quad \textbf{(49)}$$

where $\varepsilon_{g,t}$ is a government spending shock.

$$b_{f,t} = \frac{1}{\beta} b_{f,t-1} + \frac{x_n}{q}\hat{x}_{n,t} + \frac{X_g}{q}\left(\hat{p}_{g,t} + \hat{X}_{g,t}\right) + \frac{X_o}{q}\left(\hat{p}_{o,t} + \hat{X}_{o,t}\right) - \frac{M_n}{q}\left(\hat{p}_{m,t} + \hat{M}_{n,t}\right) - \frac{c_f}{q}\left(\hat{p}_{f,t} + \hat{c}_{f,t}\right) \quad \textbf{(50)}$$

4 Calibration

4.1 Standard parameters

Many of the parameters in our model are standard; when calibrating these parameters we typically followed the values used in Harrison *et al.* (2011). The values we used are given in Table E.

Table E: Parameter values

Parameter	Value	Description	Source/Comment
β	0.9925	Discount factor	Harrison *et al.* (2011) implies an annual real interest rate of roughly 3%
σ_c	0.66	Intertemporal elasticity of substitution	Harrison *et al.* (2011)
ψ_{hab}	0.69	Degree of habit persistence in consumption	Harrison *et al.* (2011)
χ_{bf}	0.01	Cost of adjusting portfolio of foreign bonds	Harrison *et al.* (2011)
δ	0.013	Depreciation rate	Harrison *et al.* (2011)
χ_z	$=1/\beta-(1-\delta)$	Scales the effect of capital utilisation on the depreciation rate	Harrison *et al.* (2011) ensures capital utilisation equals 1 in steady state
ϕ_z	0.56	Inverse elasticity of capital utilisation costs	Harrison *et al.* (2011)
χ_k	201	Scale of capital adjustment costs	Harrison *et al.* (2011)
ε_k	0.5	Degree of persistence in capital adjustment costs	Harrison *et al.* (2011)
σ_h	0.43	Frisch elasticity of labour supply	Harrison *et al.* (2011)
σ_w	3.89	Elasticity of demand for differentiated labour	Harrison *et al.* (2011) implies a wage mark-up of 1.35 in steady state
ψ_w	0.25	Probability of being able to change wages	Harrison *et al.* (2011) implies that wages are reset once a year on average
ξ_w	0.58	Degree of wage indexation	Harrison *et al.* (2011)
χ_u	0.5	Probability of being able to change price in the utilities sector	Implies that utility companies change their prices twice a year on average, in line with recent UK experience
α_v	0.25	Capital's share in value-added production	Harrison *et al.* (2011) implies a labour share of GDP of 0.65
σ_v	0.5	Elasticity of substitution between labour and capital in value-added production	Harrison *et al.* (2011)
σ_e	0.4	Elasticity of substitution between non-energy and energy in consumption	Harrison *et al.* (2011)
σ_p	0.1	Elasticity of substitution between petrol and utilities in energy consumption	Harrison *et al.* (2011)
σ_q	0.15	Elasticity of substitution between energy and everything else in non-energy production	Harrison *et al.* (2011)
ϕ_q	0.99	Affects how the share of energy in production changes over time	Harrison *et al.* (2011)
κ_q	66.83	Scaling parameter on non-energy production function	Harrison *et al.* (2011)
η	20	Elasticity of substitution between differentiated goods in any one sector	Harrison *et al.* (2011) implies a steady-state mark-up of 1.05 across the economy

Table E (continued): Parameter values

Parameter	Value	Description	Source/Comment
η_x	1.5	Elasticity of demand for exports	Harrison *et al.* (2011)
ψ_x	0.24	Degree of persistence in export demand	Harrison *et al.* (2011)
ψ_{pf}	0.5	Probability of not being able to change price: food importers	Authors' Estimate
ι_{pf}	0	Degree of indexation: food importers	Authors' Estimate
ψ_{pm}	0.6	Probability of not being able to change price: importers	Harrison *et al.* (2011)
ι_{pm}	0.17	Degree of indexation: importers	Harrison *et al.* (2011)
τ_{VAT}	0.2	Value added tax rate	Current rate in United Kingdom
τ_u	0.05	Value added tax rate on utilities	Current rate in United Kingdom
θ_{pdot}	1.5	Taylor rule coefficient on inflation	Taylor (1993)
θ_y	0.125	Taylor rule coefficient on output	Taylor (1993)
θ_{rg}	0.8	Degree of interest rate smoothing in Taylor rule	Harrison *et al.* (2011)

We set the discount rate, β, to imply a real interest rate of roughly 3% per annum in steady state. The elasticity of intertemporal substitution in consumption is set to 0.66 and the degree of habits in consumption to 0.69. The parameter χ_{bf} has no effect on the steady state of the model, and an effect on the model's dynamics that hardly varies across a range of its values, but is needed to ensure that the model is stable. Given that, we chose a small value – 0.01 – for this parameter. The depreciation rate is set to 1.3% per quarter. The elasticity of substitution between labour and capital in the model is set equal to 0.5, implying much less substitutability than in the Cobb-Douglas case. The capital share parameter, α_v, is set so that the model generates a labour share of GDP equal to 0.65 in steady state, close to its average value in UK data. The parameters governing the capital adjustment costs and capital utilisation costs were set to the values in Harrison *et al.* (2011), which were similar to those found in Smets and Wouters (2003 and 2007). The Frisch elasticity of labour supply was set to 0.43 and the implied steady-state wage mark-up to 1.35.

Wages are assumed to be reset once a year on average and wage inflation is assumed to have some persistence, with the degree of indexation set to 0.58. Utilities companies are assumed to reset their prices twice a year on average, based on recent UK experience, and food importers are also assumed to reset their prices twice a year on average, which is based on our own estimates of equation **(39)**. Non food and energy importers reset their prices every seven and a half months on average. There is also a small amount of indexation in this sector. As we said earlier, petrol prices and the domestic prices of oil and gas are assumed to be completely flexible.

There are a number of parameters in the model governing the elasticity of substitution between various production inputs. Here we follow Harrison *et al.* (2011) in setting the elasticity of substitution between our different consumption goods to 0.4 – implying that a rise in food or energy prices will lead to a fall in consumption of non food and energy – that between petrol and utilities in energy output to 0.1, and that between energy and non energy in the production of non food and energy output to 0.15. Finally, we set the elasticity of substitution between different non food and energy goods to 20 implying a steady-state mark-up in that sector of 1.05.

4.2 Steady-state weights and shares

In this subsection, we discuss how we use data on the steady-state shares of various items in consumption and production to calibrate the remaining parameters of our model. To start, we use the appropriate CPI weights (as of 2011) – as shown in Table F – to give us the weights of each of our sectors in consumption.

We need the weights of gas in utilities output and oil and duty in petrol output. From the 2008 SUTs, (*Supply and Use Tables*) we can note that inputs of 'oil and gas extraction' into 'electricity production and distribution and gas distribution' was £24,987 million and into 'coke ovens, refined petroleum and nuclear fuel' was £23,194 million. The total output of these industries at basic prices was £82,580 million and £30,552 million, respectively. This gives us shares of 0.3026 and 0.7592, respectively. Total value-added of 'oil and gas extraction' at basic prices was £34,955. This compares with gross value added at basic prices (GDP) for the whole economy of £1,295,663 and implies a share of 'oil and gas extraction' output of 2.6978%. If we assume that the relative proportions of 'oil' and 'gas' equal the relative proportions used as inputs into 'petrol' and 'utilities', respectively, then we get shares of 0.0130 for 'oil' in GDP and 0.0140 for 'gas' in GDP.

Table F: CPI Weights

Sector	Weight (per cent)
Non-alcoholic beverages	1.5
Alcohol and tobacco	4.2
Clothing and footwear	6.1
Housing and water	8.5
Furniture, household equipment and maintenance	6.1
Health	2.4
Transport excluding fuels and lubricants	11.6
Communication	2.6
Recreation and culture	14.7
Education	1.8
Restaurants and hotels	12.0
Miscellaneous goods and services	9.5
Food	10.3
Electricity, gas and other fuels (utilities)	4.4
Fuels and lubricants (petrol)	4.3

We also need the weight of energy in non food and energy output. We define 'food' as sectors 1, 3 and 8 through 17 in the SUTs.[6] Total final demand of the food sector (so defined) was £93,326 million in 2008. Total final demand for all industries was £1,906,245 million. From this, we take out total final demand for 'food', ' oil and gas extraction' (£19,943 million), 'utilities' (£32,322 million) and 'petrol' (£52,148 million) to get total final demand at purchasers' prices of the 'non food and energy sector' of £1,708,506 million.

[6] Agriculture, Fishing, Meat processing, Fish and fruit processing, Oils and fats, Dairy products, Grain milling and starch, Animal feed, Bread and biscuits, Sugar, Confectionary and Other food products.

Now, total intermediate demand for oil and gas extraction was £52,324 million. Of this, the 'food' sector used zero, and the oil and gas extraction sector used £4,079 million. So, the weight of energy inputs into production of utilities, petrol and non food and energy will equal 0.0269. Total intermediate demand for utilities was £50,102 million and for petrol was £32,841 million. Of this, the 'food' sector used £1,736 million of utilities and £2,429 million of petrol; the oil and gas extraction sector used £720 million of utilities and £241 million of petrol; the utilities sector used £26,299 million of utilities and £2,232 million of petrol; and the petrol sector used £2,232 million of utilities and £1,417 million of petrol. Putting all this together, we get an input of utilities into non food and energy of £19,115 million and of petrol into non food and energy of £26,162 million. So the shares are 0.01119 for utilities and 0.01531 for petrol. The ratio of the two is then 1.3682.

We next calculate the share of non food and energy imports in non food and energy output. Total imports of goods are services were £460,665 million in 2008. Of these, £31,122 million were food, £26,942 million were oil and gas extraction, £21,142 million were petrol and £552 million were utilities. So imports of non food and energy were £380,907 million. So the share of non food and energy imports in non food and energy output was 22.29%. Next up are the remaining final expenditure shares. The 2008 SUTs suggest that final consumption of central and local government was equal to £314,044 and that this consisted entirely of spending on non food and energy. Hence, the share of government spending in non food and energy is equal to 18.38%. Finally, to calculate the share of petrol duty in pre-VAT petrol prices we noted that petrol duty currently stands at 58p per litre and that the price of a litre of petrol is roughly £1.40 at the pumps. With VAT at 20% this implies a weight of duty in the pre-VAT price of petrol of roughly 50%.

Given these shares, we can then set our remaining parameters so that the model generates these shares in steady state.[7] Doing so results in the parameter values shown in Table G.

4.3 Shock processes

In order to evaluate the model's ability to match the stylised facts on sectoral inflation presented in Section 2, as well as stylised facts about aggregate inflation and output, we need to calibrate the processes driving the 20 exogenous shocks in our model: aggregate productivity, monetary policy, government spending, the VAT rate, the world prices of oil, gas, food, and intermediates and productivity in each of the 12 NFE sectors.

The results reported in Table D in Section 2 suggest that we can reasonably model the 12 sectoral shocks as white noise. For the standard deviations of these shocks, we then used the standard deviations of the estimated sectoral shocks coming from Equation **(1)**. These are shown in Table H.

[7] The equations governing the steady state of the model are laid out in an appendix.

Table G: Parameter values set to match expenditure and cost shares

Parameter	Value	Description	Comment
κ_x	0.6434	Exports of non-energy	Normalises the exchange rate, s, to equal unity in steady state
κ_c	1.4143	Scale parameter on consumption aggregator	Normalises the relative price of consumptino, p_c, to equal unity in steady state
κ_h	1.2313	Relative utility of leisure	Normalises total hours, h, to equal unity in steady state
α_b	0.2970	Parameter governing share of non-energy imports in non food and energy production	Ensures that the steady-state share of non food and energy imports in non food and energy output is 22.29%.
α_q	0.9993	Parameter governing share of energy in non food and energy production	Ensures that the steady-state share of energy in non food and energy output is 2.9%.
ψ_e	0.0011	Parameter governing share of energy in consumption	Ensures that the steady-state share of energy in consumption spending is 8.7%.
ψ_n	0.3723	Parameter governing share of petrol in non food and energy production	Ensures that the steady-state ratio of petrol to utility input in non food and energy output is 1.3682.
ψ_p	0.0004	Parameter governing share of petrol in consumption	Ensures that the steady-state share of petrol in consumption spendnig is 4.3%.
ψ_{qp}	0.2039	Parameter governing share of oil in petrol production	Ensures that the steady-state share of oil in petrol production is 0.7592.
ψ_u	0.6856	Parameter governing share of gas in utility production	Ensures that the steady-state share of gas in utility production is 0.3026.
ψ_f	0.0057	Parameter governing share of food in consumption	Ensures that the steady-state share of food in consumption spending is 10.3%.
d_p	1.0486	Parameter governing share of petrol duty in petrol price	Ensures that the steady-state share of duty in Pre-VAT petrol prices is 50%
$\overline{O}$	0.0175	Economy's endowment of oil	Ensures that the steady-state share of oil in GDP is 1.3%.
$\overline{G}$	0.0189	Economy's endowment of gas	Ensures that the steady-state share of gas in GDP is 1.4%.
c_g	0.4202	Government purchases of non food and energy	Ensures that the steady-state share of government spending in non food and energy demand is 18.38%.

Table H: Standard deviations of sectoral shocks (per cent)	
Non-Alcoholic Beverages	0.64
Alcoholic Beverages and Tobacco	0.62
Clothing and Footwear	0.70
Housing and Water	0.53
Furniture, household equipment and maintenance	0.42
Health	0.32
Transport (ex Fuel and Lubricants)	0.44
Communication	0.94
Recreation and Culture	0.35
Education	1.09
Restaurants and hotels	0.21
Misc Goods and Services	0.41

For the world shocks we used quarterly data from 1996 Q1 to 2011 Q4 on world food prices, world oil prices, world gas prices and the world price of UK non food and energy imports. To construct a world price index for food, we multiplied the implicit price deflator for UK consumption of imported food, beverages and tobacco (*BQAR*/*BPIA*) by *SERI*, the sterling effective exchange rate index (*ERI*). Similarly, to construct a world price index for our imports excluding food and energy, we calculated an implicit price deflator in sterling by stripping out imports of food (*BQAR* for values, *BPIA* for volumes) and energy (*BQAT* for values, *BPIC* for volumes) from total imports (*IKBI* for values, *IKBL* for volumes), and then multiplied this deflator by the sterling ERI. We then took logs and HP-filtered the resulting series. Finally we estimated the following AR(1) processes for the HP-Filtered series:

$$\varepsilon_{p_f,t} = 0.74\varepsilon_{p_f,t-1} + \nu_{p_f,t}, \sigma_{p_f} = 0.0278 \quad \textbf{(51)}$$

$$\varepsilon_{p_g,t} = 0.60\varepsilon_{p_g,t-1} + \nu_{p_g,t}, \sigma_{p_g} = 0.2426 \quad \textbf{(52)}$$

$$\varepsilon_{p_o,t} = 0.75\varepsilon_{p_o,t-1} + \nu_{p_o,t}, \sigma_{p_o} = 0.1479 \quad \textbf{(53)}$$

$$\varepsilon_{p_{mf},t} = 0.75\varepsilon_{p_{mf},t-1} + \nu_{p_{mf},t}, \sigma_{p_{mf}} = 0.0136 \quad \textbf{(54)}$$

For the monetary policy shock we assumed that the shock was white noise. In that case, equation **(36)** and the calibration given in Table E implies:

$$\varepsilon_{i,t} = (i_t - i) - 0.8(i_{t-1} - i) - 0.2 * (1.5(\pi_{c,t} - \pi_c) + 0.125\hat{y}_{FP,t}) \quad \textbf{(55)}$$

Where i is the steady-state nominal interest rate and π_c is the steady-state inflation rate. Using quarterly UK data from 1996 Q1 to 2011 Q4 for the nominal interest rate (*AMIH*), CPI inflation and GDP (*ABMM*), we constructed an implied series for the monetary policy shock based on equation **(55)**. Inflation and the interest rate were both demeaned and we used HP-filtered GDP as a measure of the output gap. The standard deviation of this series was equal to 0.002 and we use this value for the standard deviation of the monetary policy shock in our model.

In a similar vein, we used quarterly UK data over the same time period on GDP, total hours worked (*YBUS*) and the capital stock to construct a time series for our productivity shock.[8] Specifically, we used a version of equation **(26)** in which capacity utilisation was always at its steady state together with the calibration in Table E to obtain:

$$\varepsilon_{a,t} = \hat{V}_t - 0.75\left(\frac{V}{h}\right)\hat{h}_t - 0.25\left(\frac{V}{h}\right)\hat{k}_{t-1} \quad \textbf{(56)}$$

In the steady state of our calibrated model $\frac{V}{h} = 1.2368$ and $\frac{V}{k} = 0.2895$. Given these values, and HP-filtered GDP, total hours worked and capital, we constructed ε_a and estimated the AR(1) process:

$$\varepsilon_{a,t} = 0.77\varepsilon_{g,t-1} + \nu_{a,t}, \sigma_a = 0.0063 \quad \textbf{(57)}$$

[8] For a description of how the capital services series we used was constructed see Oulton and Srinivasan (2003).

To construct the government spending shock, we estimated the following AR(1) model using HP-filtered real government consumption (NMRY), over the same time period:

$$\varepsilon_{g,t} = 0.54\varepsilon_{g,t-1} + \nu_{g,t}, \sigma_g = 0.0079 \quad \textbf{(58)}$$

Finally, we assumed that, unless announced otherwise by the government (eg, as in 2009), agents assume that any change in the rate of VAT is permanent.

4.4 Estimation of the sectoral GT weights for the 12 NFE sectors.

Table I: The Sectoral GT weights in NFE

Duration	Non-Alc bev.	Alcohol	Cloth&F	H&W	Furn	Health	Transport	Comm	Education.	Rec&Cult	R&H	MISC
1	0.1330	0.3797	0.3996	0.0763	0.4460	0.1355	0.0624	0.3551	0.0000	0.3427	0.1232	0.228735
2	0.1314	0.2792	0.2608	0.1117	0.2014	0.1482	0.1119	0.3062	0.0000	0.2053	0.1757	0.201782
3	0.1353	0.2217	0.1155	0.1201	0.0983	0.1662	0.1260	0.1112	0.0000	0.1361	0.2065	0.151314
4	0.1657	0.0395	0.0862	0.1223	0.0769	0.1778	0.1567	0.0730	1.0000	0.1114	0.1811	0.146841
5	0.0699	0.0240	0.0423	0.0635	0.0493	0.0912	0.0609	0.0584	0.0000	0.0505	0.1004	0.066827
6	0.0608	0.0133	0.0316	0.0760	0.0345	0.0809	0.0817	0.0848	0.0000	0.0462	0.0584	0.052105
7	0.0721	0.0071	0.0180	0.0692	0.0217	0.0424	0.0794	0.0075	0.0000	0.0298	0.0486	0.044068
8	0.0541	0.0054	0.0158	0.0650	0.0197	0.0290	0.0742	0.0039	0.0000	0.0157	0.0331	0.029924
9	0.0450	0.0051	0.0091	0.0407	0.0139	0.0249	0.0307	0.0000	0.0000	0.0147	0.0223	0.0199
10	0.0161	0.0044	0.0077	0.0391	0.0110	0.0237	0.0432	0.0000	0.0000	0.0121	0.0183	0.01808
11	0.0383	0.0091	0.0031	0.0471	0.0065	0.0071	0.0414	0.0000	0.0000	0.0074	0.0120	0.005926
12	0.0783	0.0114	0.0104	0.1691	0.0209	0.0731	0.1316	0.0000	0.0000	0.0281	0.0204	0.034498
Mean	5.04	2.38	2.58	6.23	2.77	4.53	5.98	2.48	4.00	3.14	4.04	3.71

The data for the sectoral GTs is taken from Dixon and Tian (2012), adjusted for the splitting off of *Fuel and lubricants* from *Transport* and *Food* from *Food and Non-alcoholic beverages*. The sectoral GT is based on the cross-sectional distribution of completed price-spell lengths. The starting point for estimating these sectoral weights is the sectoral hazard function. This is estimated from the UK data 1996-2006 representing the 'great moderation' period using the ONS price-micro-data described by . The derivation of the 12x12 matrix of sectoral duration coefficients γ_{ji} is based on the steady-state identities derived in Dixon (2012). It seems reasonable to use these identities in the moderation period. By averaging out over the 10 years, issues such as seasonality will wash out. Following Dixon and Le Bihan (2012), we estimate the sectoral hazard rates excluding left-censored spells, and treating right-censored spells as price-changes. The CPI data for education is not available from the ONS: casual empiricisms indicates that these are prices set annually, so we have set the share of 4Q spells equal to 1 and the rest to zero[9]. The modal duration is highlighted in yellow, the median[10] duration is underlined and the arithmetic mean is in the bottom row. The mean duration across the *NFE* sectors using CPI weights is 4.04 quarters. Two factors need to be noted: first the NFE sector accounts for 81% of the CPI and the remaining 19% are mostly flexible prices, so that the UK mean would be

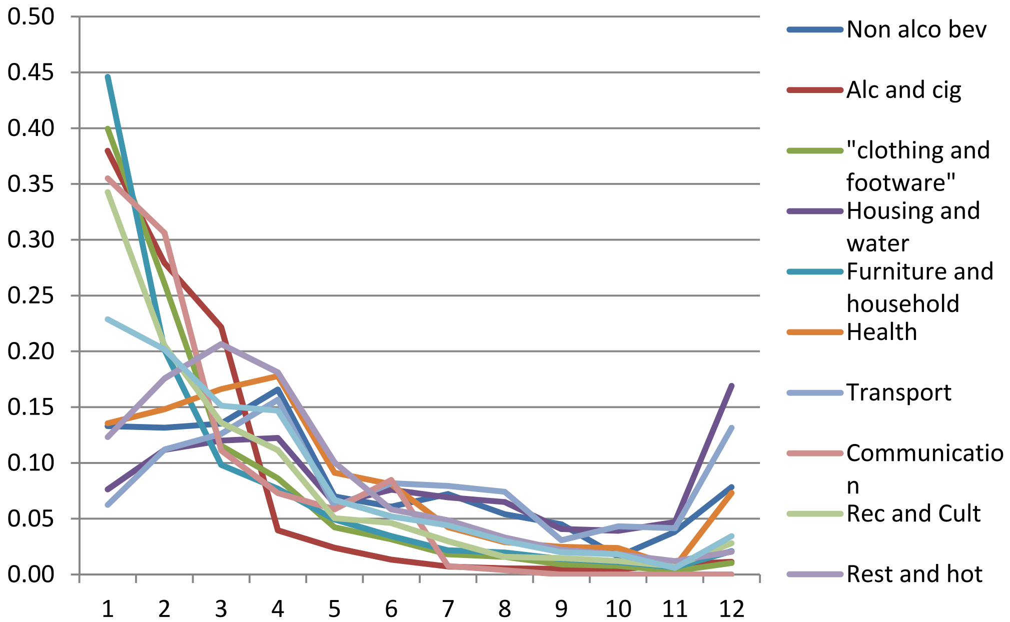
[9] In the data, the price changes in Education are not spread out evenly over the four quarters, but mostly happen in September and October. However, as Jullard et al (2012) show, the steady-state assumption is a good approximation in terms of how the model behaves.
[10] The median occurs within the duration specified. Thus, duration i means the median duration is between i-1 and I, hence the first cell in a column that exceeds 0.5 contains the median.

lower; second, the distribution is truncated at 12Q which reduces the mean. Overall, the mean estimated by Dixon and Tian (2012) across all sectors excluding education is 10.9 months.

As we can see, if we look across the first row, the share of 'flexible' prices in each sector can be quite large. These prices will respond immediately to any shock in that sector. However, in most sectors with the exception of *Communications* and *Education*, there is a long tail of prices which have a duration beyond 2 years. Note that we have 'split off' flexible parts of the CPI from NFE: *Food* from *Alcohol*, *Petrol and Diesel* from *Transport*, and '*Gas Electricity and other Fuels*' from *Housing and Water*. This accounts for the big reduction in the share of flexible prices in these three categories as compared to the results reported in Dixon and Tian (2012). We can see that there is considerable heterogeneity across sectors. The modes are shaded yellow: the NFE stectors fall into two main groups: ones for which the one quarter duration is the mode (*Alcohol, Clothing and Footwear, Furniture, Recreation and Culture, Miscellaneous*), and ones for which the mode is one year (*Non-alcoholic beverages*, *Health*, *Transport* and *Education*). The exceptions are *Restaurants and hotels*, which peaks at 3Q, and *Housing and Water* which peaks at 12Q. The arithmetic mean durations vary quite a lot as well: the longest are Housing and Water and Transport, both with means of about 6Q and the lowest are Alcoholic Beverages (2.4Q) and Communications (2.5Q). This heterogeneity is of course common in CPI data (see for example Klenow and Malin 2011). Medians and modes are usually consecutive or coincide, except for *Housing and Water* and *Miscellaneous*.

The sectional distributions are depicted in Chart 5. The duration in quarters is on the horizontal axis. The vertical axis is the proportion of prices in the sector which have that duration. We have excluded education, since its spike at 4Q dominates too much. Note that there is a local maximum at 12Q for most categories. This is because all durations longer than 12Q are included in this (recall, we estimated up to 48 months).

Chart 5: Sectoral distributions



5 Results

In this section, we first solve and simulate our model using *dynare* and assess its ability to match the stylised facts presented in Tables A through C in Section 2.[11] We then consider the responses of sectoral inflation and aggregate output and inflation to sectoral and foreign (ie, 'relative price') shocks.

5.1 Stylised facts in the model

We first consider the implications of our model for the relative volatility of sectoral and aggregate inflation. Recall that in the data, aggregate inflation was less volatile than inflation in all of our 15 sectors. Table J reports the asymptotic standard deviations of aggregate and sectoral inflation given our model calibration. As can be seen the model does not generate as much volatility as we see in the data (with the exception of petrol price inflation). The model also predicts that aggregate inflation is less volatile than inflation in most sectors, though not all (as in the data). The lower volatility in sectoral inflation in the model is unsurprising, since in the empirical work we identified residual movements in sectoral inflation rather than the sectoral shocks themselves; to the extent that sectoral inflation is slow to respond to sectoral shocks, given some price stickiness, then we would expect the variance of the estimated shocks to underestimate the variance of the true shocks. The high volatility in the model for *Fuel and Lubricants* and *Electricity, Gas and other Fuels* is due to the rapid pass-through from world prices that we assume.

Table J: Standard deviations (per cent)

	Model	Data
Headline CPI	**0.35**	**0.52**
Sector average	**0.96**	**1.16**
Fuel and Lubricants	6.28	3.42
Electricity, Gas and Other Fuels	2.99	2.69
Communication	0.62	1.25
Education	0.22	1.1
Clothing and Footwear	0.53	1.06
Non-Alcoholic Beverages	0.24	1.02
Alcoholic Beverages and Tobacco	0.48	1.02
Food	1.25	0.99
Housing and Water	0.17	0.91
Health	0.21	0.89
Transport (ex Fuel and Lubricants)	0.16	0.71
Furniture, household equipment and maintenance	0.41	0.65
Restaurants and hotels	0.21	0.62
Recreation and Culture	0.32	0.59
Misc Goods and Services	0.28	0.52

Table K reports the first-order autocorrelation coefficient of quarterly aggregate and sectoral inflation rates as implied by the model. Unlike in the data, aggregate inflation has no persistence in this model. In terms of sectoral inflation rates, there is also little persistence, though this is in line with the data.

[11] For a description of *dynare*, and to download the programme, see http://www.dynare.org/.

Table K: Inflation persistence	
Headline CPI	**0.03**
Sector average	**0.18**
Non-Alcoholic Beverages	0.17
Electricity, Gas and Other Fuels	0.20
Clothing and Footwear	-0.20
Recreation and Culture	0.08
Communication	-0.23
Transport (ex Fuel and Lubricants)	0.54
Restaurants and hotels	0.54
Education	0.58
Food	0.31
Fuel and Lubricants	-0.12
Health	0.44
Alcoholic Beverages and Tobacco	-0.12
Housing and Water	0.43
Furniture, household equipment and maintenance	-0.09
Misc Goods and Services	0.17

Table L reports the model implied cross correlation matrix for inflation rates in our 15 sectors and the aggregate inflation rate. Only petrol inflation is highly correlated with aggregate CPI inflation contemporaneously. This reflects the fact that, since petrol prices are flexible and volatile, movements in petrol prices have a large influence in current measured aggregate inflation. In terms of correlations between sectors, there is more correlation than we would have expected given our sectoral shocks are uncorrelated by assumption. This result suggests that much of the volatility in inflation rates in the model results from aggregate volatility. Recall that in the model all of the NFE sectors are identical except for the duration shares of the GT and that the macroeconomc factors tend to drive the persistence we find in actual inflation.

This story is confirmed in Table M, which decomposes the variance in sectoral inflation rates into that resulting from aggregate shocks – which, importantly, include shocks to the world prices of *oil*, *gas* and *imported intermediates* – and that resulting from idiosyncratic (sectoral) shocks. Table M suggests that – given our calibration and model – we would expect sectoral shocks to be particularly important in explaining inflation in the *furniture, household equipment and maintenance, clothing and footwear, alcoholic beverages and tobacco,* and *communication* sectors. The results reported in Table C in Section 2 suggest that sectoral shocks appear to be more important in other sectors as well. This will reflect in part the lack of idiosyncratic shocks in the petrol, utilities and food sectors in the model as well as our assumptions that the cost of imported intermediates is the same in all non food and energy sectors. In terms of aggregate inflation, roughly 75% of its variance in the model results from oil, gas and food price shocks. In the data, at least some of this is going to reflect shocks within the United Kingdom that affect the relationship between petrol prices and oil prices, utilities prices and gas prices and UK food prices relative to world food prices, none of which are captured in the model.

Table L: Cross-correlations of sectoral inflation rates

	CPI	NAB	A&T	C&F	H&W	HH goods	Health	Trans.	Comm.	R&C	R&H	Misc	Edu	Petrol	Utils	Food
CPI	1.0	0.3	0.3	0.3	0.4	0.3	0.4	0.4	0.2	0.4	0.4	0.4	0.3	0.8	0.4	0.2
NAB		1.0	0.4	0.4	0.7	0.5	0.7	0.7	0.3	0.6	0.7	0.6	0.6	0.0	0.0	-0.2
A&T			1.0	0.3	0.5	0.4	0.5	0.5	0.3	0.5	0.6	0.5	0.4	0.0	0.0	-0.2
C&F				1.0	0.4	0.4	0.5	0.4	0.3	0.4	0.5	0.4	0.3	0.0	0.0	-0.2
H&W					1.0	0.5	0.8	0.8	0.4	0.7	0.8	0.7	0.7	0.0	0.0	-0.2
HH goods						1.0	0.6	0.6	0.3	0.6	0.6	0.6	0.4	0.0	0.0	-0.2
Health							1.0	0.8	0.4	0.7	0.9	0.7	0.7	0.0	0.0	-0.3
Trans.								1.0	0.4	0.7	0.9	0.7	0.8	0.0	0.0	-0.3
Comm.									1.0	0.4	0.4	0.4	0.3	0.0	0.0	-0.2
R&C										1.0	0.8	0.7	0.5	0.0	0.0	-0.3
R&H											1.0	0.8	0.8	0.0	0.0	-0.3
Misc.												1.0	0.6	0.0	0.0	-0.3
Edu.													1.0	0.0	0.0	-0.2
Petrol														1.0	0.0	0.0
Utils.															1.0	0.0
Food																1.0

Table M: Variance decomposition (per cent)

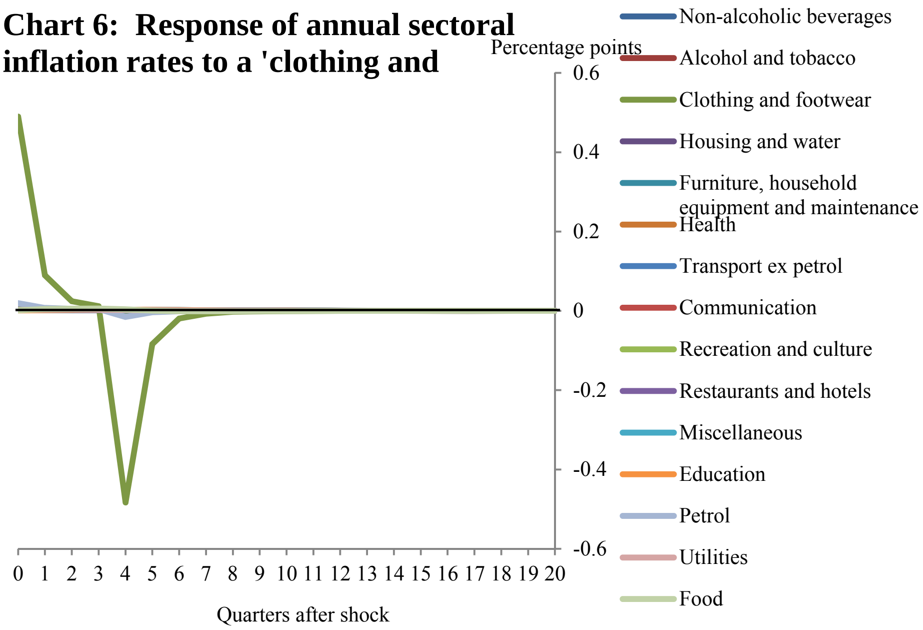
	Aggregate shocks	Idiosyncratic shock
Headline CPI	**97.62**	**2.38**
Sector average*	**62.10**	**37.90**
Fuel and Lubricants	100.00	-
Food	100.00	-
Transport (ex Fuel and Lubricants)	85.56	14.44
Non-Alcoholic Beverages	56.66	43.34
Electricity, Gas and Other Fuels	100.00	-
Furniture, household equipment and maintenance	49.52	50.48
Clothing and Footwear	29.38	70.62
Housing and Water	76.10	23.90
Restaurants and hotels	94.13	5.87
Alcoholic Beverages and Tobacco	37.23	62.77
Communication	21.00	79.00
Health	84.80	15.20
Recreation and Culture	64.85	35.15
Education	80.08	19.92
Misc Goods and Services	65.87	34.13

* Excluding fuel and lubricants, food and electricity, gas and other fuels.

5.2 *The effects of relative price shocks*

In this subsection, we look at the effect of a shock in one sector on the other NFE sectors: we take as our examples (i) *Clothing and Footwear*, (ii) *Recreation and Culture*. *Clothing and Footwear* represents about 6% of the CPI, with a mean price-spell of 2.6 quarters. However, there is a large proportion flexible prices with almost 40% changing price every month. *Recreation and Culture* represents a much larger share of the CPI, just under 15%. This has a longer mean duration (3.4Q) and a lower (but still substantial) flexible sector.

Chart 6: Response of annual sectoral inflation rates to a 'clothing and



Turning first to *Clothing and Footwear*, the effect of the 1% shock in the clothing sector leads to a within sector response of just under 0.5% in that sector. Some firms from all duration sectors will adjust: all of the flexible price firms, half of the 2Q firms., and an ith of the iQ firms. The effect dies away quite quickly but is clearly non-zero up to quarter 3 reflecting the staggered price-setting within the sector. At 4 quarters the initial impact effect effect 'drops out' of the annualised inflation rate, and in the next two quarters the following inflation effects drop out, so that by Quarter 7 there is very little effect left (less than -0.01%). The response in other sectors is very small: mostly between 0.01-0.03% on impact. This reflects the fact that *Clothing and Footwear* is relatively small in the CPI, and also that the general equilibrium linkages are not that strong. This dies away almost entirely by 6 months.

If we turn to *Recreation and Culture*, the picture is similar, but the magnitudes differ.

Chart 7: Response of annual sectoral inflation rates to a 'recreation and culture' shock

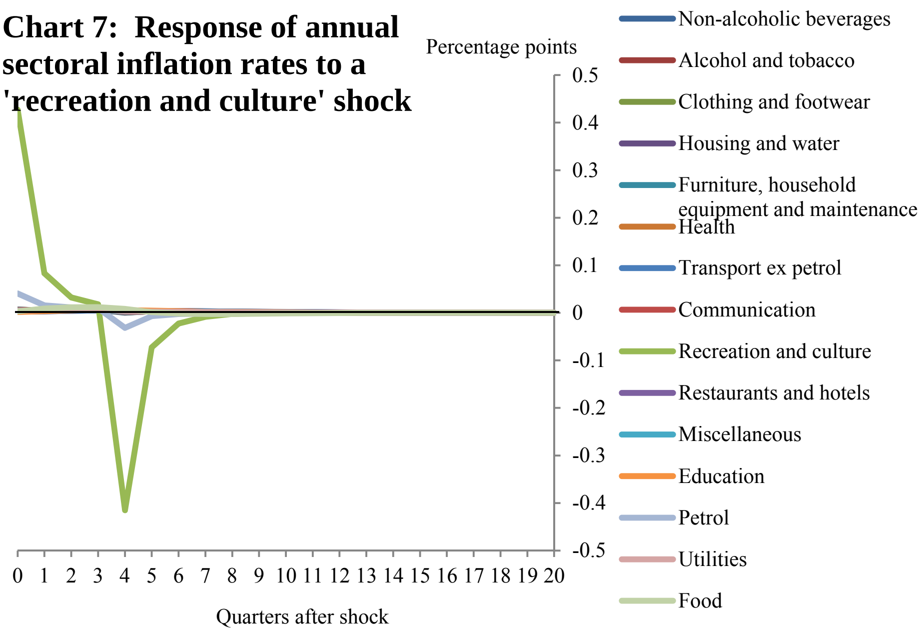


Chart 8: Response of annual CPI inflation to a 'Clothing and Footwear' shock.

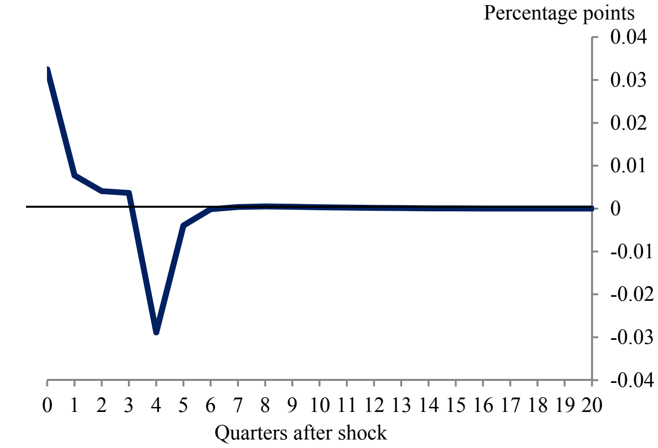
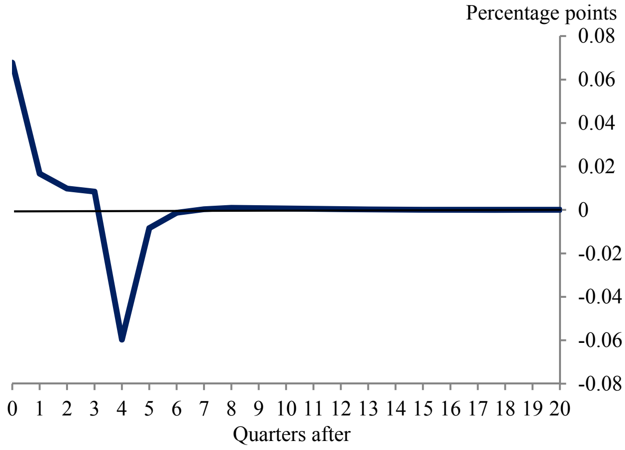


Chart 9: Response of annual CPI inflation to a 'Recreation and Culture' shock.



The within sector story is almost exactly the same as in *Clothing and Footwear*: the initial response is over 0.4%, but dies away quickly over the next three quarters. There is then another 3 quarters of negativity when these effects 'drop out' and from 7Q on there is almost no effect. However, the effect on the other sectors, though still small, is more pronounced. This reflects the greater significance of *Recreation and Culture* in the CPI.

What is the effect of these sectoral shocks on Aggregate CPI inflation and indeed the aggregate economy as a whole? The impulse response function for inflation after a *Clothing and Footwear* shock there is a 0.07 percentage point impact effect which rapidly dies away over the next two quarters, which is mirrored by the drop out over the next three quarters, with almost no effect after 6 quarters.

The effects of the sectoral shocks on output, the interest rate and the exchange rate are also similar in shape but different in magnitude. We report them for *Recreation and Culture*:

Chart 10: Response of exchange rate to a 'Recreation and culture' shock.

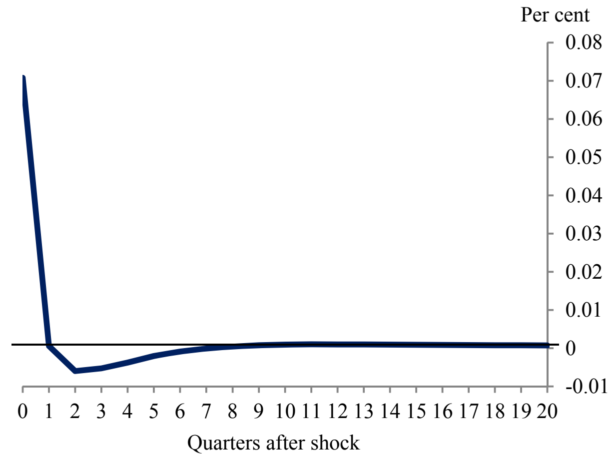


Chart 11: Response of interest rate to a 'Recreation and Culture' shock.

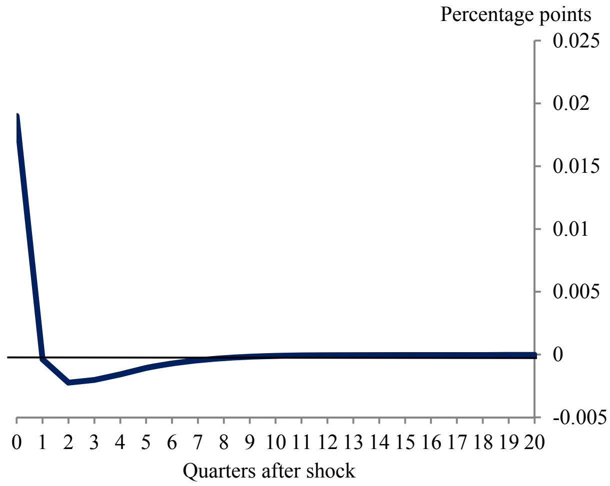
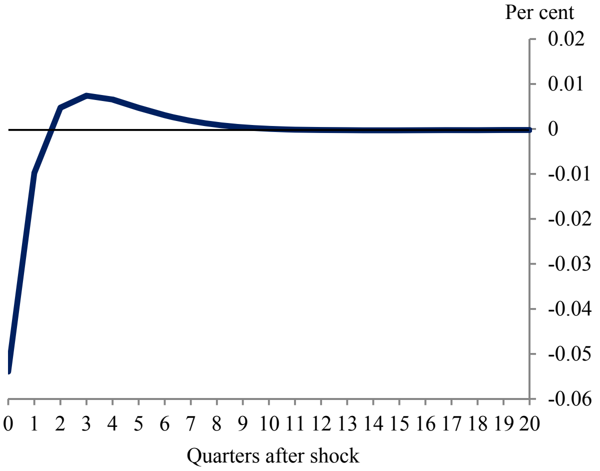


Chart 12: Response of GDP to a 'Recreation and culture' shock.



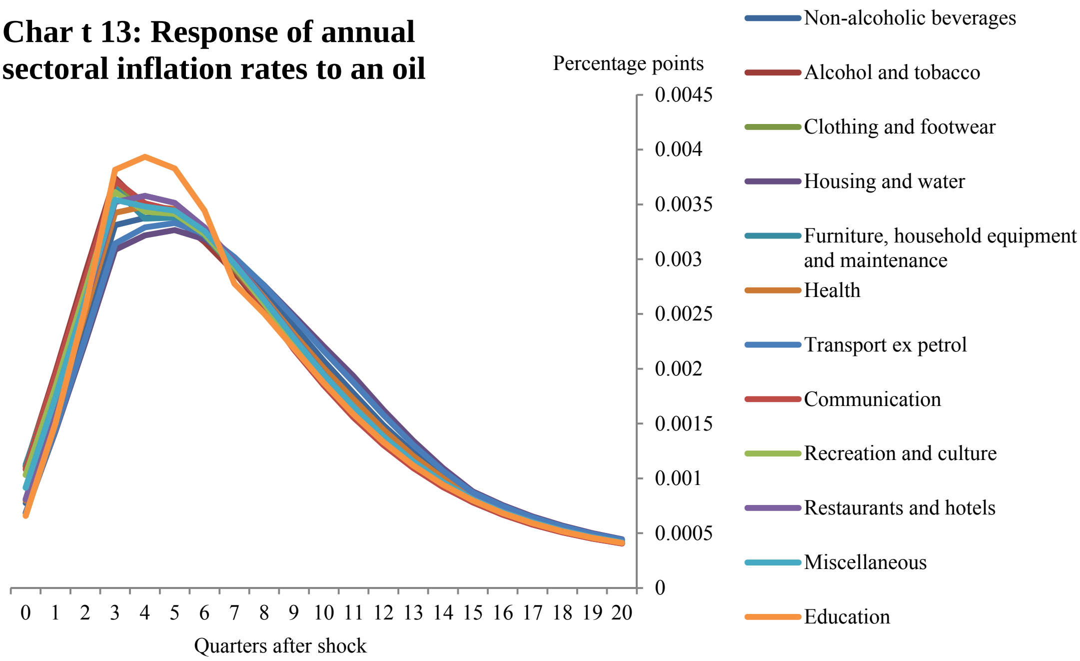
We can see that the sectoral shock has a small effect on the interest rate, exchange rate and output. There is an immediate jump effect for the exchange rate and the interest rate (both positive as we would expect), which then falls into reverse with overshooting which dies away so that nearly all of the effect is gone after 8 quarters. It is different with output: there is a (negative) jump on impact, but the effect stays positive for 2 quarters, before overshooting and dying away. Again, there is almost no effect on output after 7 quarters. Note that the effect on the exchange rate tends to *dampen* the effect of the sectoral shock on aggregate CPI inflation. An appreciation follows the sectoral shock which leads to lower sterling prices of goods priced in dollars (oil and gas immediately, food and non food and energy import prices stickily). Furthermore, the lower output will have the standard 'Philips curve' effect on prices. It is possibly this counteracting effect which means that the cross-sector effects appear to be so small. That is why the effect of the sectoral shock on inflation is less than you would expect from simply taking the arithmetic contribution of the sector: *ceteris paribus* a 1% shock to *Recreation and Culture* would cause about a 0.15% increase in CPI inflation. The effect is smaller, because of nominal rigidity in the sector (the increase in inflation within the *Recreation and Culture* sector is only 0.4%), and also because the currency and output effects work in the opposite direction so that the overall effect on CPI is only 0.067%, which is less than half of the *ceteris paribus* magnitude.

To summarise, sectoral shocks primarily have their impact on annualised inflation within their own sector. The shock has a particular shape: it is positive for 3Q, there is a negative 'drop out' effect at 4Q, and this remains negative for a further 3Q, with the effect lasting in total at most 7Q. There is a small spillover to other sectors which is larger the bigger the CPI share of the sector is: sectors with more flexible prices are affected more by the spillover. As we might expect, the effect of a sectoral shock on the whole economy is small: it causes an effect on impact, which is reversed after 1 quarter (interest rate and exchange rate) or 2 (output) and dies out almost completely by 6 quarters.

5.3 The effect of External shocks.

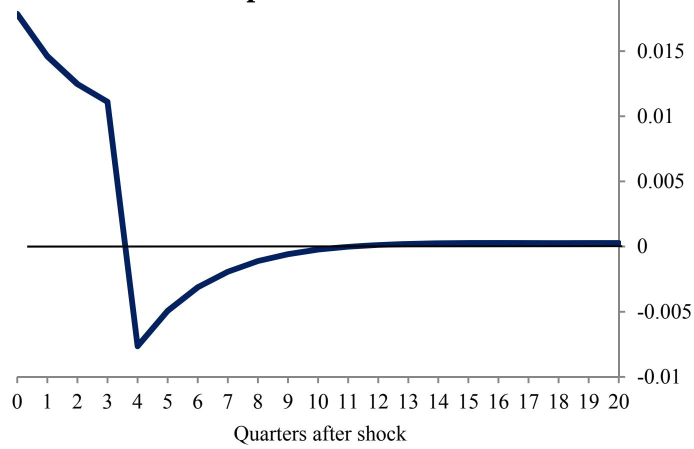
In this section we will look at the effect of shocks to prices that our outside the UK: *Oil*, *Food*, *Import Prices* and *Gas*. Turning first to an oil price shock, we have excluded *Petrol*, which of course has a quantitative response that is greater in magnitude and similar to the response of CPI inflation. All of the *NFE* sectors have a hump shaped response to the oil price shock, which peaks at 4-5 quarters: the effect of the GT is to spread out the effects slightly. However, the effect of oil is very small on the NFE sectors. In particular, oil might be expected to have a big impact on some sectors such as *Transport* which is not captured in our model because all sectors face the same marginal cost. The effect on the *NFE* sectors is in general small: a 10% shock in the oil price has a peak impact of just 0.04% . However, whilst small it is cumulative (the effects are always positive over the 20 quarters): for example, in *Non-Alcoholic Beverages* the cumulative effect over 20Q is 1%.

Char t 13: Response of annual sectoral inflation rates to an oil



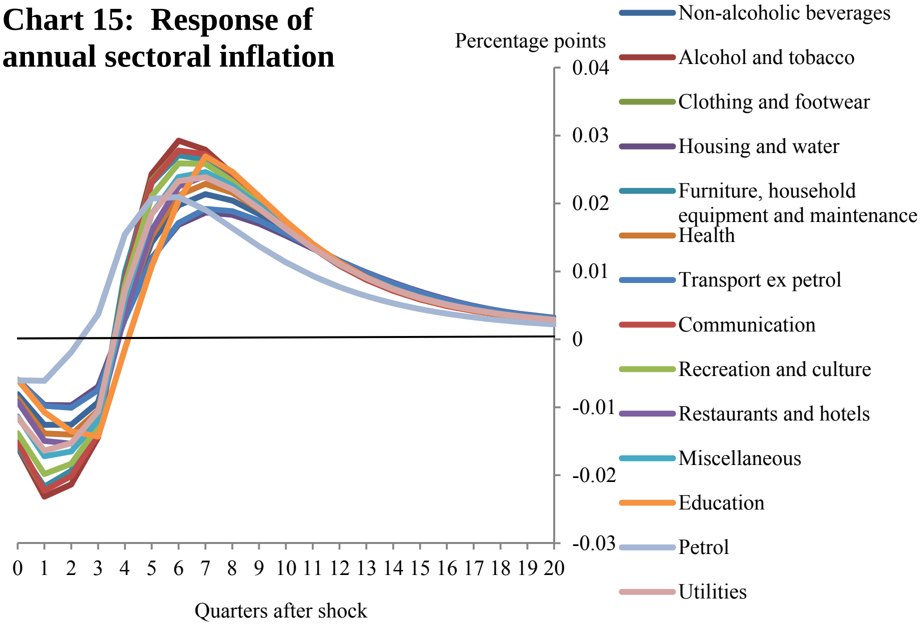
The response of CPI inflation to an oil shock is much larger in magnitude, and is driven primarily by *Petrol* and a little by *Food* and *Utilities*. A 10% shock increase in the world oil price generates an extra 0.17% to CPI in the first quarter, falling to 0.11% by quarter 4, after which these partially drop out. The cumulative effect over 20Q is just 1%.

Chart 14: Response of annual CPI inflation to an oil price shock



The impact of food on sectoral inflation rates follows a similar pattern across all sectors: there is a fall in inflation for 4 quarters, which is then reversed, with a cumulatively positive effect over the 20 quarter horizon. Recall that the model is calibrated to ensure that an increase in Food leads to a fall in consumption of *NFE*.

Chart 15: Response of annual sectoral inflation



The mechanism here is that there is a short lived appreciation of the exchange rate and fall in GDP as the interest rate increases n response to the *Food* shock, which is reversed after 4 quarters. Annual inflation is positive for the first three quarters, drops back to zero at 4 quarters, and the effect has (almost) died away by 9 quarters.

Chart 16: Response of annual CPI inflation to a food price shock

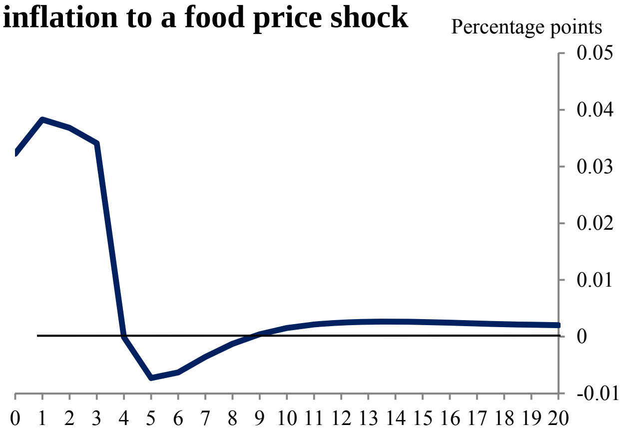
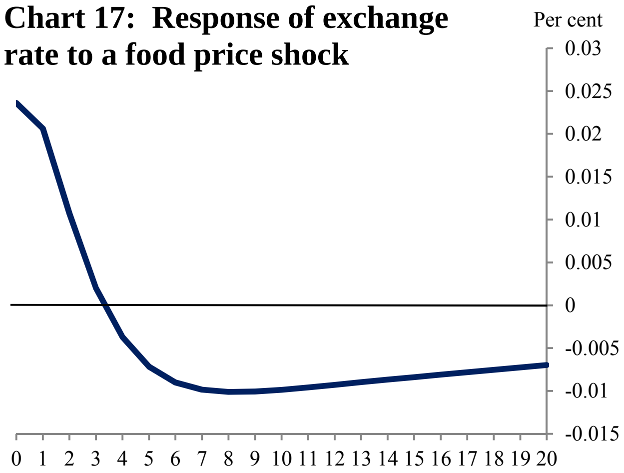


Chart 17: Response of exchange rate to a food price shock



Imports enter into the production of value added and, hence, an import price shock leads to a hump shaped response from all sectors, mostly peaking at 4 quarters and dropping out over quarters 5 and 6 so that it is is very small or negative by quarter 7. This is more or less the same pattern for CPI inflation.

Chart 18: Response of sectoral contributions to annual CPI inflation to an import price shock

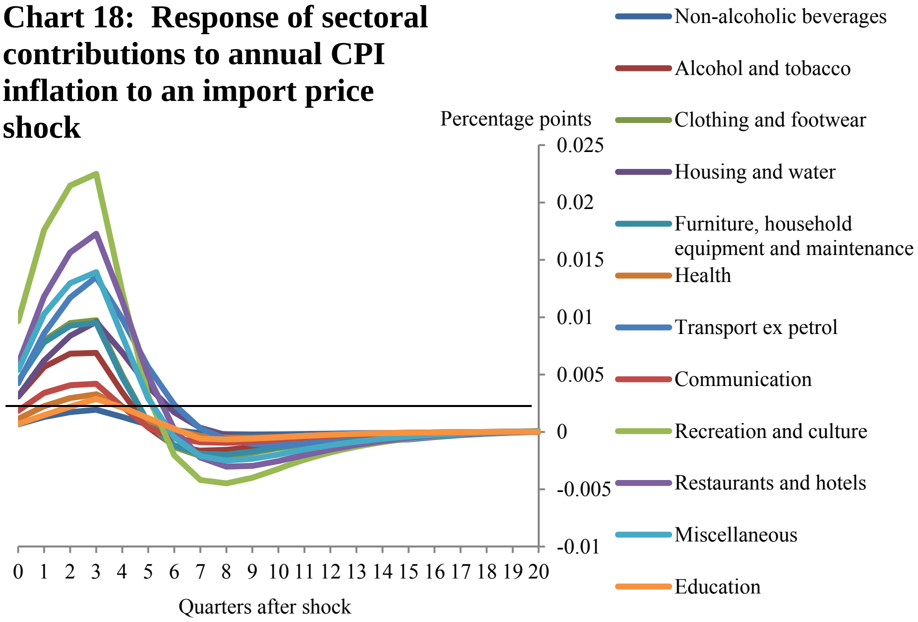


Chart 19: Response of annual CPI inflation to an import price shock

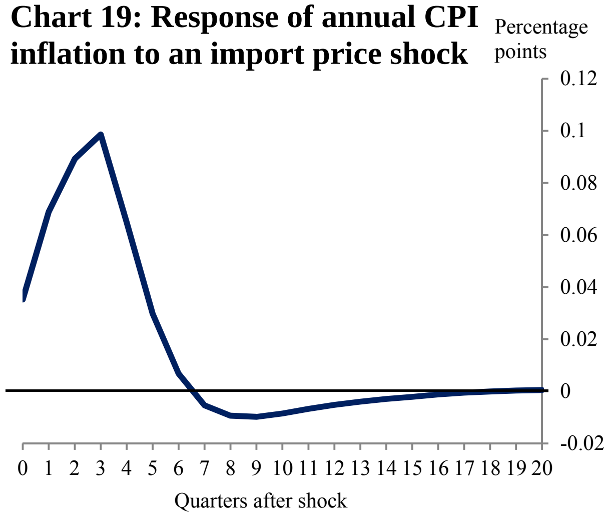
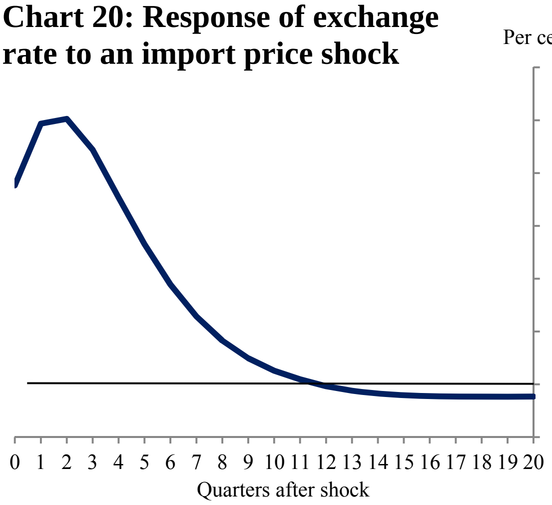


Chart 20: Response of exchange rate to an import price shock



The exchange rate has a humped shape response mirroring the interest rate: there is a jump appreciation that then peaks at quarter 3, and then gradually declines.

6 Implications for monetary policy

In this section, we investigate the implications of relative price shocks for optimal monetary policy. In particular, we investigate whether monetary policy should respond to such shocks or should follow the approach of looking through them and responding only to aggregate shocks. There are typically two approaches to optimal stabilisation policy in the literature. One relies on computing the fully optimal 'Ramsey' policy, the other relies on optimal simple rules (OSR). Here, we use the OSR approach as OSRs have been shown to be robust and close to the optimal rules in many models. (See, eg, Taylor and Williams (2011).) Before using dynare to numerically derive the optimal simple rule, we first derive a loss function for the central bank. Here, we follow Rotemberg and Woodford (1998) and take a second-order approximation of the consumers' utility function around the (non-stochastic) steady state.

Their utility function is:

$$U_t = \frac{1}{1-\frac{1}{\sigma_c}}\left(\frac{c_t}{c_{t-1}^{\psi}}\right)^{1-\frac{1}{\sigma_c}} - \frac{\kappa_h}{1+\frac{1}{\sigma_h}} h_t^{1+\frac{1}{\sigma_h}} \quad \textbf{(59)}$$

The second-order expansion of the utility function around the (non-stochastic) steady state will be given by:

$$\begin{aligned} U_t - \overline{U} &= c^{1-\frac{1}{\sigma_c}(1+\psi(\sigma_c-1))}\left(\hat{c}_t - \psi\hat{c}_{t-1}\right) - \kappa_h \hat{h}_t - \frac{1}{2\sigma_c} c^{1-\frac{1}{\sigma_c}(1+\psi(\sigma_c-1))}\hat{c}_t^2 - \psi\left(1-\frac{1}{\sigma_c}\right)c^{1-\frac{1}{\sigma_c}(1+\psi(\sigma_c-1))}\hat{c}_t\hat{c}_{t-1} \\ &+ \frac{\psi\left(1+\psi\left(1-\frac{1}{\sigma_c}\right)\right)}{2} c^{1-\frac{1}{\sigma_c}(1+\psi(\sigma_c-1))}\hat{c}_{t-1}^2 - \frac{\kappa_h}{\sigma_h}\hat{h}_t^2 \end{aligned} \quad \textbf{(60)}$$

where $\overline{U}$ is steady-state period utility. Taking unconditional expectations of this expression gives:

$$E\left(U_t - \overline{U}\right) = \left(\frac{\psi\left(1+\psi\left(1-\frac{1}{\sigma_c}\right)\right)}{2} - \frac{1}{2\sigma_c} - \psi\left(1-\frac{1}{\sigma_c}\right)\rho_{c_t c_{t-1}}\right)c^{1-\frac{1}{\sigma_c}(1+\psi(\sigma_c-1))}Var(\hat{c}) - \frac{\kappa_h}{\sigma_h}Var\left(\hat{h}\right) \quad \textbf{(61)}$$

where $\rho_{\mathrm{CtCt-1}}$ is the first-order autocorrelation coefficient for consumption. Using our calibration we get:

$$E\left(U_t - \overline{U}\right) = \left(-0.5132 - 0.3408\rho_{c_t c_{t-1}}\right)Var(\hat{c}) - 2.8635 Var\left(\hat{h}\right) \quad \textbf{(62)}$$

Now $\rho_{\mathrm{CtCt-1}}$ will be a function of the policy rule applied, creating a circularity. However, we can note that it has to lie between 0 and 1 and, so, the size of the coefficient on the variance of total hours relative to the variance of consumption must lie between 3.3896 and 5.6815. So, as an approximation, we set the relative weight on hours to 4.5. That is, we consider the loss function:

$$L = Var(\hat{c}) + 4.5 Var\left(\hat{h}\right) \quad \textbf{(63)}$$

We consider the following simple policy rules:

$$i_t - i = \theta_\pi \pi_{c,t} + \theta_y \hat{V}_t \quad \textbf{(64)}$$

$$i_t - i = \theta_\pi \pi_{c,t} + \sum_{j=1}^{15}\theta_j \pi_{j,t} + \theta_y \hat{V}_t \quad \textbf{(65)}$$

$$i_t - i = \theta_\pi \pi_t + \theta_y \hat{V}_t \quad \textbf{(66)}$$

$$i_t - i = \theta_\pi \pi_{vc,t} + \theta_y \hat{V}_t \quad \textbf{(67)}$$

Equation **(64)** represents a standard Taylor rule, in which the central bank responds to aggregate CPI inflation and value-added output relative to trend. Equation **(65)** is similar, except that we allow the central bank to respond separately to inflation in each of our 15 COICOP sectors. Equation **(66)** considers a Taylor rule in which the central bank responds to non food and energy inflation.[12]

[12] We can think of this as the central bank targeting 'core' inflation, where our definition of core inflation is based on excluding the most volatile components of CPI inflation from the index. We can note that food inflation is much more

Equation **(67)** considers a rule in which the central bank responds to the rate of inflation of the competitive price of value-added, which, in our model, corresponds to 'domestically generated' inflation (DGI).

Table N: Optimal simple rules

	Standard Taylor rule	Policy responding to sectoral inflation rates	Policy responding to non food and energy (core) inflation	Policy responding to DGI
θ_{π}	1.51112	1.50161	1.53944	1.68519
θ_{y}	-0.03954	-0.00571	-0.07040	1.73920
$\theta_{\text{Non alcoholic beverages}}$	-	0.00659	-	-
$\theta_{\text{Alcohol and tobacco}}$	-	0.00456	-	-
$\theta_{\text{Clothing and footwear}}$	-	0.00463	-	-
$\theta_{\text{Housing and water}}$	-	0.00709	-	-
$\theta_{\text{Household goods}}$	-	0.00484	-	-
θ_{Health}	-	0.00633	-	-
$\theta_{\text{Transport (ex petrol)}}$	-	0.00709	-	-
$\theta_{\text{Communication}}$	-	0.00475	-	-
$\theta_{\text{Recreation and culture}}$	-	0.00517	-	-
$\theta_{\text{Restaurants and hotels}}$	-	0.00616	-	-
$\theta_{\text{Miscellaneous}}$	-	0.00572	-	-
$\theta_{\text{Education}}$	-	0.00659	-	-
θ_{Petrol}	-	-0.04959	-	-
$\theta_{\text{Utilities}}$	-	-0.01576	-	-
θ_{Food}	-	-0.00291	-	-
Autocorrelation				
Consumption	0.6698	0.7867	0.8254	0.8058
Standard deviations (per cent)				
Consumption	0.69	0.70	0.81	0.66
Total hours	0.58	0.52	0.49	0.90
Value-added output	0.83	0.72	0.81	0.38
CPI inflation	0.41	0.40	0.40	0.47
Loss				
As implied by Equation (68)	$1.3163*10^{-4}$	$1.1571*10^{-4}$	$1.2088*10^{-4}$	$2.6626*10^{-4}$
Relative to the optimal simple rule as a percentage of consumption	0.0054	-	0.0017	0.0506

Optimisation was carried out numerically using the 'OSR' *Dynare* module and our results are shown in Table N. The rule in which the central bank responds differently to inflation rates in the different

volatile in our model than it is in the data, where excluding it would make less sense. For much more discussion of 'core inflation', see Mankikar and Paisley (2002).

sectors outperforms the other rules (as it must), but the difference is not large: a standard Taylor rule results in a welfare loss equivalent to only 0.0054% of steady-state consumption relative to the more general sectoral rule. Our results also suggest that a rule based on core inflation outperforms the standard Taylor rule, though again the difference is small: using a standard Taylor rule results in a welfare loss equivalent to only 0.0037% of steady-state consumption relative to the rule based on core inflation.

In order to understand the significance of the numbers in the sectoral rule, note that the coefficient on aggregate CPI inflation has a coefficient of 1.5. The CPI weights on food, petrol, and utilities are 0.103, 0.044 and 0.043. Hence, in the case of petrol, the aggregate CPI 'indirect coefficient' on Petrol inflation is 0.065. In the optimal sectoral rule, this is reduced by -0.050, meaning that the total weight put on petrol is almost completely negated. A similar story holds for Utilities, but the effect is much smaller: the CPI effect is 0.046 and the sectoral coefficient is -0.16, so that there is still a significant overall reaction in the Taylor rule of 0.05. For Food the effect is almost negligible: the aggregate CPI coefficient is 0.15 and the sectoral reduction is only -0.003. In all of the other sectors, the sectoral effect is positive. In some cases this is a large effect. For example, *Non-Alcoholic beverages* has a CPI weight of 0.015, so the aggregate effect is 0.023, which is increased by 0.007 (29%) so that the total weight becomes 0.030. In other sectors, the effect is trivial: for example in *Restaurants and Hotels* the CPI weight is 0.15, so the Taylor rule has the implicit aggregate effect of 0.23: the sectoral adjustment is just 0.006. In Table 0 we show the significance of the sectoral affect for each sector.

Table 0: Sectoral and aggregate effects.

Sector	CPI	Taylor	Sectoral	Total	% change
Non-alcoholic beverages	1.5	0.0225	0.00659	0.02909	29
Alcohol and tobacco	4.2	0.063	0.00456	0.06756	7
Clothing and footwear	6.1	0.0915	0.00463	0.09613	5
Housing and water	8.5	0.1275	0.00709	0.13459	6
Furniture, household equipment and maintenance	6.1	0.0915	0.00484	0.09634	5
Health	2.4	0.036	0.00633	0.04233	18
Transport excluding fuels and lubricants	11.6	0.174	0.00709	0.18109	4
Communication	2.6	0.039	0.00475	0.04375	12
Recreation and culture	14.7	0.2205	0.00517	0.22567	2
Education	1.8	0.027	0.00616	0.03316	23
Restaurants and hotels	12	0.18	0.00572	0.18572	3
Miscellaneous goods and services	9.5	0.1425	0.00659	0.14909	5
Food	10.3	0.1545	-0.00291	0.15159	-2
Electricity, gas and other fuels (utilities)	4.4	0.066	-0.01576	0.05024	-24
Fuels and lubricants (petrol)	4.3	0.0645	-0.04959	0.01491	-77
Totals.	100	1.5	0.00126	1.50126	

It is interesting to consider the rule based on sectoral inflation rates as this can provide us with some intuition as to why the rule based on core inflation does well. We can observe that for non food and energy goods and services, the central bank will want to respond a little more aggressively to movements in sectoral inflation than it would if it were responding purely to aggregate inflation. Conversely, the central bank will want to respond less aggressively to movements in food or energy inflation than it would if it were responding purely to aggregate inflation. In other words, it is optimal for the central bank to partially accommodate movements in aggregate inflation that result from movements in inflation in one of these three sectors. This effect is particularly important for Petrol: the optimal rule indicates that the central bank should almost totally ignore the contribution of petrol prices to inflation.

Why is this? As we saw earlier, movements in petrol, utilities and food inflation are predominantly driven by movements in world prices. These represent relative price shocks that require real adjustments in the prices of these goods relative to other goods and services. The role of the central bank is to allow these adjustments to take place while imposing minimal costs on the rest of the economy and the way to do this is to allow the adjustment to happen via the most flexible prices, which are those of petrol, utilities and food. But, in order to do so, the central bank has to accommodate some of the movement in relative prices in aggregate CPI inflation. This same intuition helps to explain why an aggregate rule based on ‘core inflation’, which excludes energy and food prices, does better in welfare terms – albeit only marginally – than a rule based on aggregate CPI inflation.

Our results suggest that following a rule based on DGI results in a much larger welfare loss relative to the optimal simple rule: in this case, the loss is equivalent to 0.051% of steady-state consumption. This rule results in too much volatility in hours. The intuition here is simple. Stabilising DGI essentially means stabilising wage inflation (since labour forms the bulk of value-added). Stabilising wage inflation is likely to increase the volatility in hours. As this reduces utility for workers, a policy that causes this to happen will not be good for welfare.

Finally, there is an interesting difference between the optimal sectoral rule and the one based on aggregate CPI only. That is the weight on output (value added) is greatly reduced: a reduction of 85% from -0.04 to -0.006. This is because by stripping out the effect of Petrol in the CPI, there is less variation in output and hours worked induced by the Taylor rule, so less need to take output into account. The coefficient on output is negative, unlike the positive value normally found in closed economy models. The coefficients are very small in absolute terms and probably reflect the reaction of policy to value added as a proxy for getting at the underlying shocks. The DGI rule puts a big weight on both output and inflation: this succeeds in stabilizing value added, but only at the expense of excessive volatility in hours worked.

7 Conclusions

We have developed an open economy model which allows us to sensibly explore the question of how sectoral shocks fit into the inflation story of the UK and how optimal monetary policy should deal with sectoral shocks. The novelty of the paper lies in the fact that we model the COICOP components of the CPI as our ‘sectors’. Furthermore, we use the CPI price microdata to directly calibrate the nominal rigidity within each sector using the Generalised Taylor model.

In general, we find that when we look at the raw sectoral inflation rates, the sectoral rates have much bigger variances than aggregate CPI, which can be seen as a pooled variance. There is little cross-correlation of inflation across sectors. When we break down the raw sectoral inflation shocks into sector specific and aggregate components, we find that the persistence we observe in the raw data comes mainly from the effect of the aggregate factors with sectoral shocks being white noise.

The open economy model we use allows us to model some prices as being largely determined on international markets at $ prices, with others domestically produced and consumed (the non-food and energy sector), with a primitive structure of intermediate production as contained in Harrison et al (2011).

We find in this context the following conclusions:

1. A sectoral shock in NFE (CPI sectors excluding food and energy) has an immediate but short lived effect on its own sector. There is a very small effect on other sectors and the aggregate variables such as CPI inflation and output.
2. External shocks to oil, food or imported goods have effects which are similar in magnitude and pattern to Millard (2011) and consistent with the impulse response functions estimated in the data.
3. We analyse the optimal simple Taylor rule, where 'inflation' is interpreted as CPI inflation, Core inflation (CPI excluding more volatile elements) and DGI (using the inflation of NFE). Also, we allow for a Taylor rule that can respond differently to different sectors (different coefficients for COICOP sectors). We find that the optimal simple rule with sectoral coefficients is the best, which basically ignores the effects of petrol prices on inflation. The core inflation Taylor rule does next best, the CPI Taylor rule third and DGI the worst. However, there is not a big welfare gain.

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Appendix 1: Data

Table A1.1: Correlation coefficients of sectoral inflation rates

	NAB	A&T	C&F	H&W	HH goods	Health	Trans.	Petrol	Comm.	R&C	Edu.	R&H	Misc.	Food	Utils.
NAB	1.0	0.4	0.5	0.3	0.6	0.2	0.4	0.0	0.3	0.1	0.1	0.2	0.1	0.3	0.1
A&T		1.0	0.3	0.1	0.4	-0.1	0.1	0.1	0.1	0.1	-0.1	0.3	0.0	0.1	0.0
C&F			1.0	0.1	0.4	0.0	0.3	0.3	0.4	-0.1	-0.1	0.1	0.1	0.0	0.0
H&W				1.0	0.3	0.1	0.8	-0.3	0.2	0.0	0.0	0.2	0.0	0.2	0.2
HH goods					1.0	0.1	0.5	0.2	0.3	0.1	0.0	0.2	-0.1	0.4	0.1
Health						1.0	0.1	0.0	-0.2	0.1	0.1	0.0	0.1	0.1	0.0
Trans.							1.0	0.3	0.4	0.1	-0.1	0.2	-0.1	0.2	0.1
Petrol								1.0	0.1	0.1	-0.1	0.2	-0.1	-0.1	-0.1
Comm.									1.0	0.1	0.0	0.0	-0.1	0.0	0.0
R&C										1.0	0.0	0.0	-0.2	-0.1	-0.3
Edu.											1.0	0.0	0.0	0.3	0.1
R&H												1.0	0.1	0.3	0.2
Misc.													1.0	0.2	0.3
Food														1.0	0.4
Utils.															1.0

Table A1.2: Correlation coefficients of sectoral shocks

	NAB	A&T	C&F	H&W	HH goods	Health	Trans.	Petrol	Comm.	R&C	Edu.	R&H	Misc.	Food	Utils.
NAB	1.0	0.1	0.3	-0.1	0.3	0.2	-0.1	-0.2	0.1	0.1	0.0	0.1	0.0	0.1	-0.3
A&T		1.0	0.2	0.0	0.3	-0.2	-0.1	-0.1	0.0	0.2	-0.2	0.2	-0.1	-0.3	-0.1
C&F			1.0	-0.2	0.3	-0.1	-0.1	0.0	0.3	-0.2	-0.1	-0.2	0.2	-0.1	-0.2
H&W				1.0	-0.1	-0.1	0.8	-0.4	0.0	0.0	-0.1	0.1	-0.1	0.0	-0.2
HH goods					1.0	0.1	0.0	0.1	0.0	0.1	0.0	0.2	-0.2	0.2	-0.3
Health						1.0	0.0	0.0	-0.3	0.1	0.1	-0.1	0.0	0.1	0.0
Trans.							1.0	0.1	0.0	0.1	-0.1	0.1	-0.2	0.1	-0.3
Petrol								1.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0
Comm.									1.0	0.0	0.1	0.1	-0.1	-0.1	-0.1
R&C										1.0	0.1	0.3	-0.3	0.1	-0.2
Edu.											1.0	0.0	-0.1	0.1	0.0
R&H												1.0	0.1	0.3	0.0
Misc.													1.0	0.1	0.4
Food														1.0	0.0
Utils.															1.0

Figure A1.1: Estimated factors (quarterly)

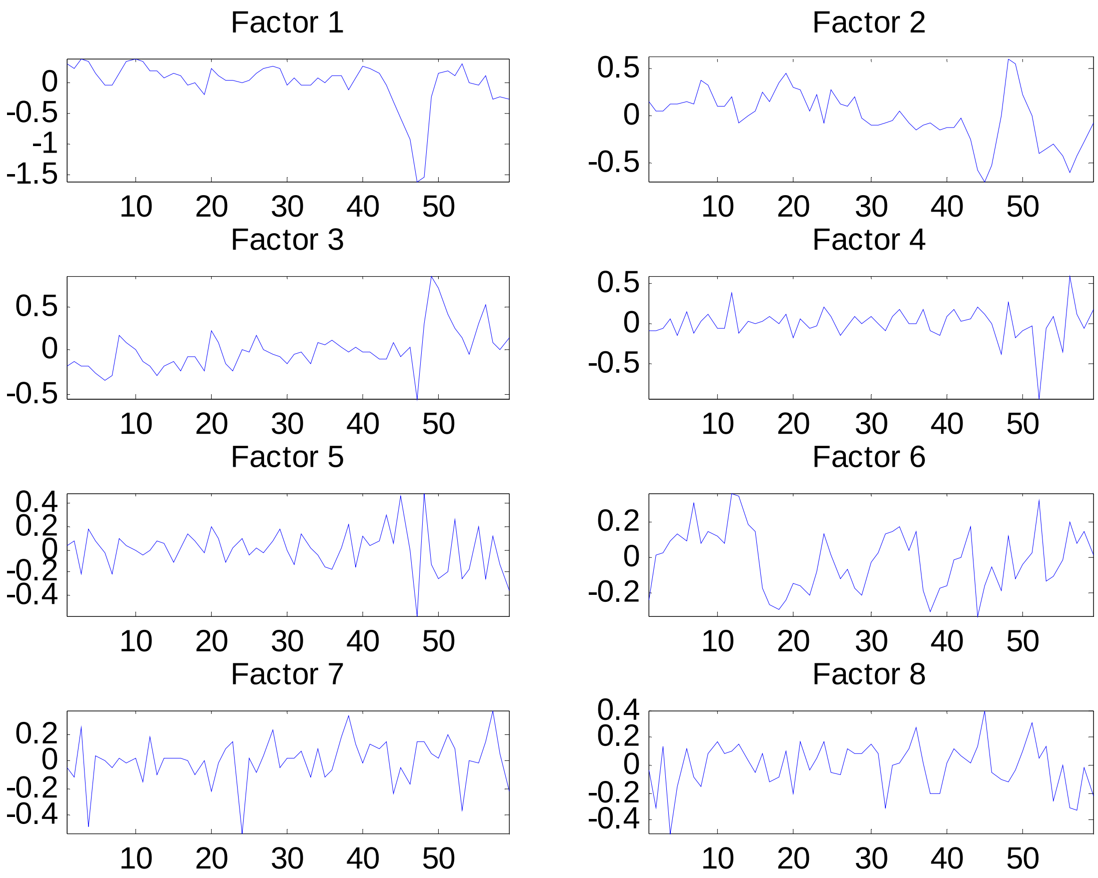


Figure A1.2: Estimated factors (monthly)

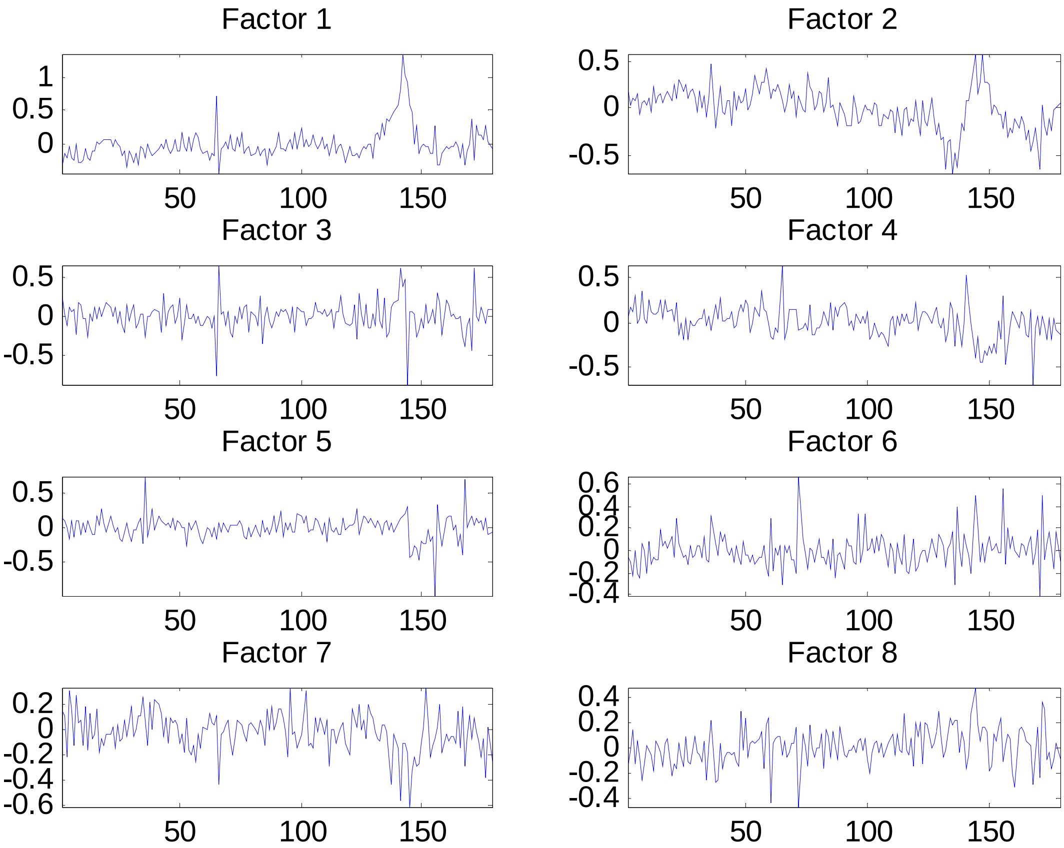
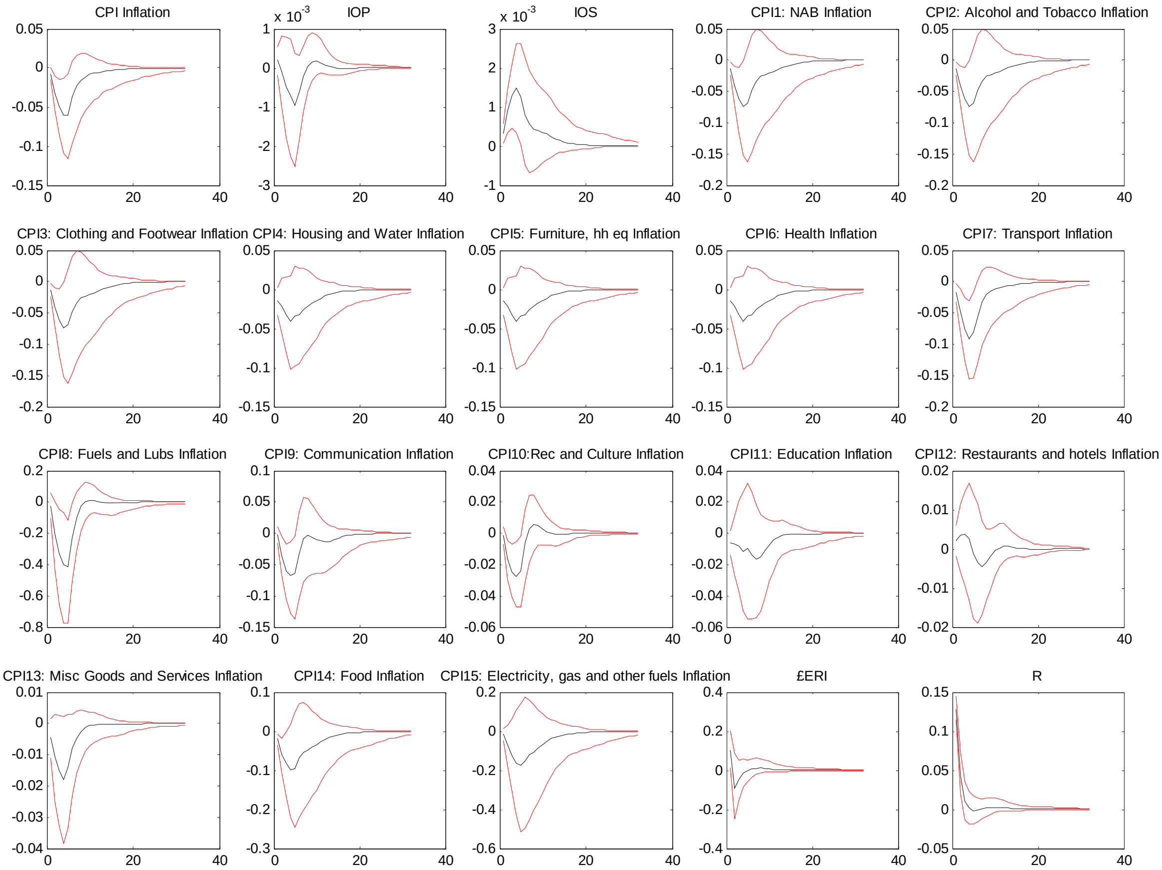


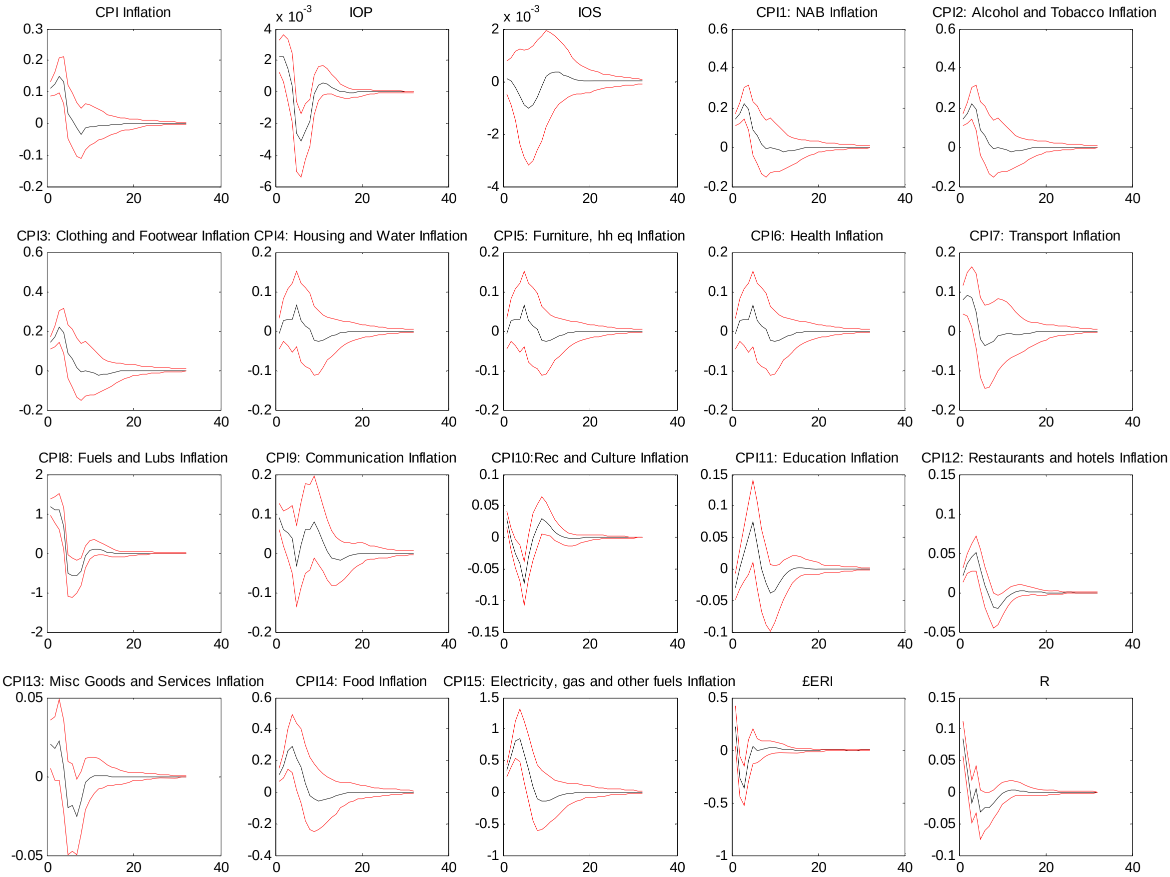
Figure A1.3: Impulse Response Functions from BVAR Estimates

All charts show the percentage change on the quarter a year earlier.

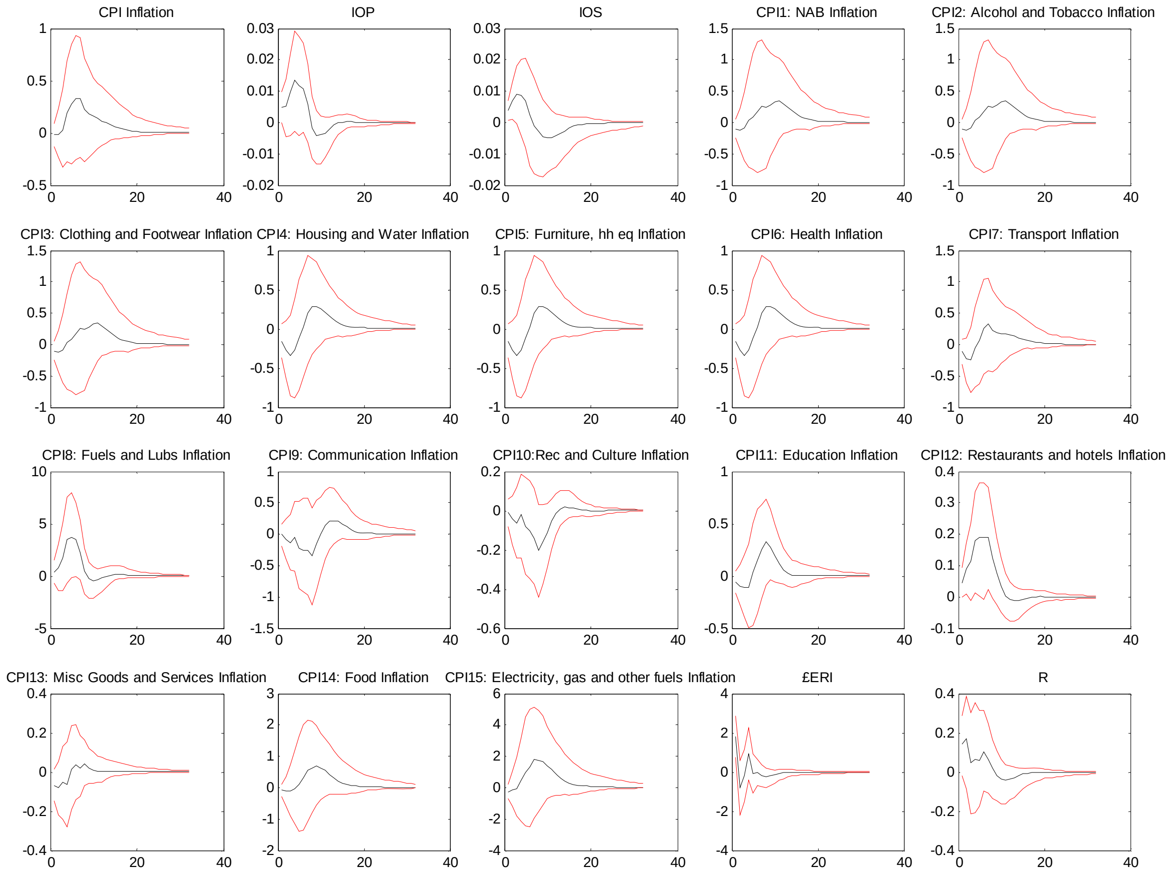
Monetary Policy Shock (1 s.d)



10% increase in Oil price



10% increase in Import prices, excluding energy



Appendix 2: The steady state

In order to calibrate the model in order to match average weights and shares in the date, we need to solve for the model's steady state. This means we need steady-state versions of the non-linear equations that underlie the model. Following the approach in Harrison *et al.* (2011) we assume CES functions for the consumption aggregators and production of non food and energy and 'value-added'. We normalise all foreign prices, the CPI, TFP and total hours worked in steady state to all equal unity. Once this is done, we are left with the following equations, where the numbers correspond to the equivalent 'out of steady state' equations in the main text:

$$1 = \beta(1+r) = \beta(1+r_F) \qquad \textbf{(1), (9)}$$

$$1 = \beta(1-\delta+\chi_z) \qquad \textbf{(2), (3)}$$

$$c_e = \kappa_e\left((1-\psi_p)c_u^{1-\frac{1}{\sigma_p}} + \psi_p c_p^{1-\frac{1}{\sigma_p}}\right)^{\frac{\sigma_p}{\sigma_p-1}} \qquad \textbf{(4)}$$

$$c = \kappa_c\left((1-\psi_e-\psi_f)c_n^{1-\frac{1}{\sigma_e}} + \psi_e c_e^{1-\frac{1}{\sigma_e}} + \psi_f c_f^{1-\frac{1}{\sigma_e}}\right)^{\frac{\sigma_e}{\sigma_e-1}} \qquad \textbf{(5)}$$

$$1 = \kappa_c^{\frac{\sigma_e-1}{\sigma_e}}\psi_f\left(\frac{c_f}{c}\right)^{-\frac{1}{\sigma_e}} \qquad \textbf{(6)}$$

$$p_u = \frac{\kappa_e^{\frac{\sigma_p-1}{\sigma_p}}(1-\psi_p)\left(\frac{c_u}{c_e}\right)^{-\frac{1}{\sigma_p}}}{\kappa_c^{\frac{\sigma_e-1}{\sigma_e}}\psi_e\left(\frac{c_e}{c}\right)^{-\frac{1}{\sigma_e}}} \qquad \textbf{(7)}$$

$$\frac{p_u}{p_p} = \frac{\psi_p}{(1-\psi_p)}\left(\frac{c_u}{c_p}\right)^{-\frac{1}{\sigma_p}} \qquad \textbf{(8)}$$

$$w = \frac{\sigma_w}{\sigma_w-1}\kappa_h^{-\frac{1}{\sigma_h}}c^{\frac{1}{\sigma_c}(1+\psi_{hab}(\sigma_c-1))} \qquad \textbf{(10) – (12)}$$

$$q = \kappa_q\left((1-\alpha_q)((1-\phi_q)B)^{1-\frac{1}{\sigma_q}} + \alpha_q(\phi_q e)^{1-\frac{1}{\sigma_q}}\right)^{\frac{\sigma_q}{\sigma_q-1}} \qquad \textbf{(13)}$$

$$B = V_n^{1-\alpha_B}M_n^{\alpha_B} \qquad \textbf{(14)}$$

$$e = \frac{I_p}{\psi_n} = \frac{I_u}{1-\psi_n} \qquad \textbf{(15)}$$

$$p_{vc}(1+\tau_{VAT})V_n = \mu\kappa_q^{1-\frac{1}{\sigma_q}}(1-\alpha_q)(1-\alpha_B)(1-\phi_q)^{1-\frac{1}{\sigma_q}}q^{\frac{1}{\sigma_q}}B^{1-\frac{1}{\sigma_q}} \qquad \textbf{(16)}$$

$$(1+\tau_{VAT})M_n = \mu\kappa_q^{1-\frac{1}{\sigma_q}}(1-\alpha_q)\alpha_B(1-\phi_q)^{1-\frac{1}{\sigma_q}}q^{\frac{1}{\sigma_q}}B^{1-\frac{1}{\sigma_q}} \qquad \textbf{(17)}$$

$$(\psi_n p_p + (1-\psi_n)p_u)(1+\tau_{VAT}) = \mu\kappa_q^{1-\frac{1}{\sigma_q}}\alpha_q\phi_q^{1-\frac{1}{\sigma_q}}\left(\frac{q}{e}\right)^{\frac{1}{\sigma_q}} \qquad \textbf{(18)}$$

$$\mu = \frac{\eta - 1}{\eta} \quad \textbf{(19) – (22)}$$

$$V = \left(1 - \alpha_V + \alpha_V k^{1-\frac{1}{\sigma_v}}\right)^{\frac{\sigma_v}{\sigma_v - 1}} \quad \textbf{(23)}$$

$$\frac{w}{p_{vc}} = (1 - \alpha_v) V^{\frac{1}{\sigma_v}} \quad \textbf{(24)}$$

$$\frac{\chi_z}{p_{vc}} = \alpha_v \left(\frac{V}{k}\right)^{\frac{1}{\sigma_v}} \quad \textbf{(25)}$$

$$q_p = \frac{I_o}{1 - \psi_{qp}} = \frac{V_p}{\psi_{qp}} \quad \textbf{(26)}$$

$$(\psi_{qp} p_{vc} + 1 - \psi_{qp}) \frac{\eta_p}{\eta_p - 1} = p_{pb} \quad \textbf{(27)}$$

$$p_p = (1 + \tau_{VAT})(p_{pb} + d) \quad \textbf{(28)}$$

$$q_u = \frac{I_g}{1 - \psi_u} = \frac{V_u}{\psi_u} \quad \textbf{(29)}$$

$$(\psi_u p_{vc} + 1 - \psi_u) \frac{\eta_u}{\eta_u - 1} = \frac{p_u}{1 + \tau_u} \quad \textbf{(30) – (32)}$$

$$x_n = \kappa_x \quad \textbf{(39)}$$

$$c = c_n + c_f + p_u c_u + p_p c_p \quad \textbf{(40)}$$

$$V = V_n + V_u + V_p \quad \textbf{(41)}$$

$$q_P = c_P + I_P \quad \textbf{(42)}$$

$$q_u = c_u + I_u \quad \textbf{(43)}$$

$$O = I_O + X_O \quad \textbf{(44)}$$

$$G = I_G + X_G \quad \textbf{(45)}$$

$$q = c_n + \delta k + c_g + x_n \quad \textbf{(46)}$$

$$x_n + X_g + X_o = M_n + c_f \quad \textbf{(47)}$$

Appendix 3: Estimating the GT coefficients

The method used for estimating the hazard function is the non-parametric Kaplin-Meier method (KM). One of the main issues in applying the method to the data is how to deal with censored data. It is best to think of the CPI data as a Panel with attrition and replacement. We can see the CPI categories as collections of rows spreading across the 120 months. There are about 600 products and services sampled, with about 100,000 observations per month: each product is sampled in a variety of locations and across different sellers in order to be 'representative'.

Within each CPI category there are sequences of price observations for each product. These can be identified as consecutive observations of the price of a particular product at a particular location: this is called a *trajectory*. The choice of products and locations reflects the ONS policy, as does the length of trajectory, and both can be treated as an exogenous 'act of God'. Within each trajectory is a sequence of price-spells. For the purpose of this study, we are looking at all price-spells including temporary sales. There are four main types of price-spells in terms of censoring. First there are spells which constitute a whole trajectory. For example, there are some pharmaceutical products in the Health category which have the same price for all 10 years. These are left and right censored: we do not see when they begin or end. Second, there is the first spell in a trajectory of two or more spells. We see the price persist for some time, but do not know when the spell began. This is a left-censored spell. Thirdly, there is the last spell in the trajectory, which we observe starting and persisting, but not ending. Fourthly, there are the rest of the price-spells which we see beginning, persisting, and ending. These are uncensored spells.

There are different ways of treating censored data which can have a large impact on the results. The 'classic' KM method (developed for analysing the data of medical trials) is to exclude all left-censored spells, include all right censored data, and treat the end of a right censored data as a non-price-change. A price-spell ends with a price-change. In the case of right-censored data, you do not observe that ending: it just falls out of the data because the ONS stopped looking at it. This treatment of right censored spells is not a good one in our context. In effect, we know that for our purposes all price-spells end at 12Q. In terms of the steady-state identities, not registering a price-change when the ONS stops looking it means that implicitly the price-spell extends to 12Q. The price has to change sometime and the classic KM treatment will lead to an under-estimate of the hazard for each period.

Censoring can only reduce the observed length of price-spells. As a better alternative to the classic KM method, we make two other assumptions:

(a) We exclude all censored data in estimating the hazard function. This can be justified if we believe that the censored spells and uncensored spells have the same properties. However, the nature of the process of observation means that longer spells are more likely to be censored. This will mean that there is a downward bias in the mean length of spells.
(b) Following Dixon and Le Bihan (2010), we can treat right-censoring as a price-change ('loss is failure' or LIF). This is the opposite extreme to the classic KM assumption and will almost certainly result in an overestimate of the hazard.

We have employed both methods and the results are quantitatively similar, so we followed (b). We illustrate the differences with two estimated hazards at the end of this section.

This gives us the hazard function for each COICOP sector j for months τ=1…35 *h(j,τ)* with *h(j,36)=1*. Following the steady-state identities outlined in Dixon (2012). The survival rate for period τ is defined as the proportion of spells surviving to the end of period τ. By definition, S(1)=1 (no price spell is observed to last less than one month). We then define:

$$S(\tau) = \prod_{i=1}^{\tau-1} (1 - h(j,i))$$

The corresponding monthly cross-sectional distribution (distribution across firms) is then defined by the steady-state relationship:

$$\gamma_{j\tau} = \tau . h(j,t). S(\tau). \bar{h}$$

where $\bar{h}(j) = 1/(\sum_{k=1}^{36} S(\tau))$. The corresponding quarterly distribution is then obtained by adding up the three months in that quarter. This yields the 12-vector $\gamma_j = (\gamma_{ji})_{i=1\ldots12}$.

To illustrate the magnitude of the differences in the estimation method, we take as an example the estimated monthly weights for the COICOP categoties *Food and Non-Alcoholic beverages* and *Transport*. For *Food and Non-Alcoholic beverages* the Classic KM method leads to all of the right-censored spells being allocated to the longest duration (36 months) and has a correspondingly lower share for the first 6 months. The two other methods are much more similar, although using only uncensored spells leads to a much higher weight on flexible prices (i=1). This reflects the fact that one-period spells are more likely to be uncensored. However, for *Transport*. the three methods yield more similar estimates: whilst there is a short fat 'tail' sticking up at the end for the Classic method, otherwise the three methods yield broadly similar results. For our purposes, we have used the two approaches of using only uncensored data and treating right censoring as a price-change and found that they make little difference: the main text and Calibration actually uses the 'loss is failure' method, treating right-censoring as a price change.

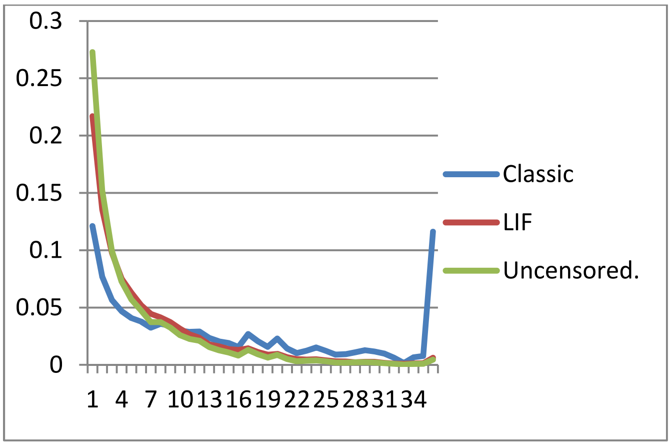
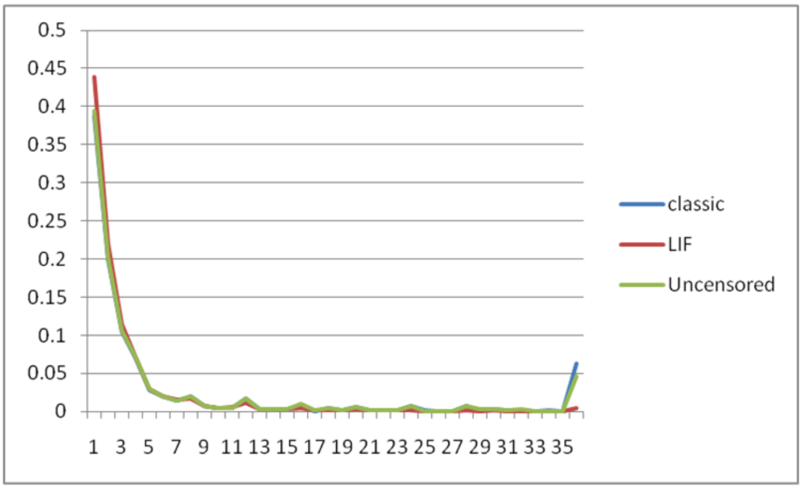


Figure A3.1: monthly duration shares for Food and non-alcoholic beverages.



FigureA3.21: Monthly distribution for Transport.

In the UK data, the following sectors have a very high (over 30%) proportion of right censored ('lost') spells: *Housing Water and Utilities*, *Miscellaneous goods*, *Furniture*, *Health*, *Recreation and culture*. In these cases, the Classic KM method is particularly misleading in this context.