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Sectoral shocks and monetary policy in the United Kingdom

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Abstract

In this paper, we use an open economy model of the United Kingdom to examine the extent to which monetary policy should respond to movements in sectoral inflation rates. To do this we construct a Generalised Taylor model that takes specific account of the sectoral make up of the consumer price index (CPI), where the sectors are based on the COICOP classification the UK CPI microdata. We calibrate the model for each sector using the UK CPI microdata and model the sectoral shocks that drive sectoral inflation rates as white noise processes, as in the UK data. We find that a policy rule that allows for different responses to inflation in different sectors outperforms a rule which just targets aggregate CPI. However, the gain is small and comes from partially looking through movements in aggregate inflation driven by movements in petrol price inflation, which is volatile and tends not to reflect underlying inflationary pressure.

Key words: CPI inflation, sectoral inflation rates, generalised Taylor economy.

JEL classification: E17, E31, E52.

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Summary

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. In order to get at this question, this paper develops a framework within which we can examine sectoral shocks, their effects on the UK economy and how monetary policy makers should respond to them. More specifically, our framework links together news in the consumer price index (CPI) data at the sectoral level and the behaviour of the economy at the aggregate level. Such a framework can be used to address several questions about the links between prices at the aggregate and sectoral levels as well as the particular issue of how monetary policy should respond to movements in sectoral prices.

Before constructing our model, we first investigate the empirical properties of quarterly sectoral inflation rates in the United Kingdom over the period 1988-2011. The idea is to generate some stylised facts with which we would like our model to be consistent. We find that the sectoral rates have much bigger variances than aggregate CPI inflation and that there is little cross-correlation of inflation across sectors. We also find that the persistence we observe in aggregate inflation comes mainly from the effect of the aggregate factors with sectoral shocks being white noise. Leaving aside food and energy, we find that sectoral shocks explain the majority of the variance of sectoral inflation rates, but explain little of the variance of aggregate inflation, which is mostly explained by macroeconomic factors.

We then use the UK CPI microdata for the period 1996-2006 to calibrate a ‘Generalized Taylor Economy’ (GTE) for each of the twelve *Classification Of Individual Consumption by Purpose* (COICOP) sectors. The idea of a GTE is that price changes are staggered with some firms in the sector changing their prices every quarter, some changing their prices every two quarters, and so on up to some who only change their price every twelve quarters. To calibrate the proportion of firms who change their prices every so many quarters, we estimate the cross-sectional distribution of firms whose prices have different durations within each COICOP sector. We can then use our model to trace out the effects of a productivity increase or decrease affecting a particular COICOP sector. The GTE model of pricing is then embedded into an open-economy macroeconomic model of the United Kingdom in which we separate food and energy out of the CPI sectors, giving them an independent role. We do this because these are both sectors where prices are largely determined outside the United Kingdom and have had a significant impact on inflation in specific periods. Doing so, in turn, enables us to examine the issue of the extent to which monetary policy should or should not respond to movements in food and energy prices.

The policy issue on which we focus is how monetary policy should respond to sectoral shocks, or whether it should concentrate instead on some measure of underlying inflation. 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.

In our model, we look at simple rules in which the central bank alters interest rates in response to movements in aggregate and sectoral inflation rates and output relative to trend. We find that the optimal rule in which interest rates respond to sectoral inflation rates leads to a small improvement over a rule in which interest rates only respond to aggregate inflation. However, this gain comes from partially looking through movements in aggregate inflation driven by movements in petrol price inflation, which is volatile and tends not to reflect underlying inflationary pressure.

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. In recent years this has led to 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 develops a framework to integrate sectoral shocks – which lead to relative price movements – into a model of the UK economy in order to examine more closely the implications of these shocks for inflation and the conduct of monetary policy. 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 levels, though in this paper we concentrate on the practical policy issue 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 United Kingdom, including Ellis *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). Ellis *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 while 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 Dynamic Stochastic General Equilibrium (DSGE) model of the UK economy. We achieve this by using the UK CPI microdata for the period 1996-2006 to calibrate a Generalized Taylor (GT) Economy for each of the 12 COICOP sectors. To do this we estimate the cross-sectional distribution of durations within each CPI sector using the Hazard function. (See Gabriel and Reiff (2010) and Dixon and Le Bihan (2012).) 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 a version of 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 United Kingdom 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. The first, 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 price movements only matter indirectly through their effect on the aggregate inflation measure.

The second view 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 linear combination such as the arithmetic average. In that vein, Eusepi *et al.* (2011) construct what they call a 'Cost-of-nominal-distortions index' (CONDI) that weights different sectoral inflation rates in such a way as to minimise the welfare costs of price stickiness in each sector. They argue that stabilising this price index is near optimal. Of course, the practical policy issue is whether the improvement is significant or not, particularly given how hard it would be to explain such a target. Kara (2010) found 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 measures of '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' (DGI).[2] Eusepi *et al.* (2011) show that targeting a particular measure core inflation approximates quite well a policy that targets their CONDI; and such a policy of targeting core inflation is, obviously, easier to explain to the general public. Aoki (2001) shows that a policy of targeting DGI is optimal in an open-economy context. Our approach is similar to his but our model is more general. In particular, we have multiple sectors, which Kara (2010) showed overturned Aoki's result that you should always target the stickiest sector.

In our model, we look at simple rules in which the central bank alters interest rates in response to movements in aggregate and sectoral inflation rates and output relative to trend. Although our approach is similar to that of Eusepi *et al.* (2011) and Aoki (2001), there are some differences, which we feel means our approach adds to this literature. In particular, we follow Aoki in using an open-economy model whereas Eusepi *et al.* used a closed-economy model; this distinction is likely to be important in the UK context given how open the UK economy is. We have a more complete and realistic input-output structure in our model than both Aoki and Eusepi *et al.*; again, we think it is particularly important to model this given the impact of movements in world energy, intermediates and food price inflation on UK CPI inflation over the past few years and we do not think it immediately obvious that the results of Aoki will go through in this more realistic setting. And finally, we model each of the 12 NFE COICOP sectors as GTE economies whereas Eusepi *et al.* use a single measure of price stickiness for each sector and Aoki lumps all the domestic producers together in one 'sticky-

[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 simply to 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.

price' sector. Again, we think it is instructive to examine whether the results of Aoki and Eusepi *et al.* go through in our more realistic setting.

In line with Kara (2010), we find that the optimal rule in which interest rates respond to sectoral inflation rates only leads to a small improvement in terms of extra consumption over a rule in which interest rates only respond to aggregate inflation. That said, the improvement still represents a 40% lower loss. Most of this improvement comes from partially looking through movements in aggregate inflation driven by movements in petrol price inflation, which is volatile and tends not to reflect underlying inflationary pressure. We also find that a policy that responds only to DGI improves on the standard Taylor rule by about 10%. This is in line with the results of Aoki (2001).

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 Ellis *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 that validate our use of the model. 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 12 COICOP sector level, with three additional sectors created by splitting COICOP 1 into *Food* (1.1) and *Non-Alcoholic Beverages* (1.2), splitting up COICOP 7 into *Transport ex Fuels and Lubricants* (7.1, 7.2.1, 7.2.3, 7.2.4 and 7.3) and *Fuels and Lubricants* (7.2.2) – henceforth *Petrol* – and also by splitting COICOP 4 into *Housing and Water* (4.1-4.4) and *Electricity, Gas and Other Fuels* (4.5) – henceforth *EGF*. We have split off *Food, Petrol* and *EGF* because the prices of these goods will more directly reflect potential external shocks coming from world food and energy prices than other COICOP categories. Whilst the official CPI data broken down by the categories listed above only goes back to 1996, we have constructed data back to 1988 using ONS experimental COICOP CPI data and adjusting RPI data to split out *Food* and *EGF*. 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, which we use later to motivate our modelling approach.

Table A shows the standard deviation of headline CPI inflation and the sectoral inflation rates, together with the average sectoral rate. 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 and this is indeed what we find as shown in Table A.

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.

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	1.10
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.*	

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, and we will want our theoretical model to match up with this. Following Ellis *et al.* (2009), Boivin *et al.* (2009) 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)**.

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

Our dataset comprised around 350 macroeconomic UK data series 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.[4] 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 Charts 1 and 2.

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

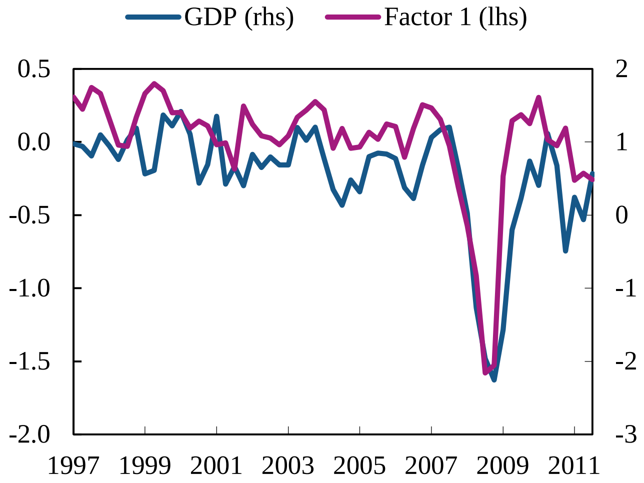


Chart 2: Factor 2 and quarter on quarter seasonally adjusted CPI, 1997Q2 to 2011Q4

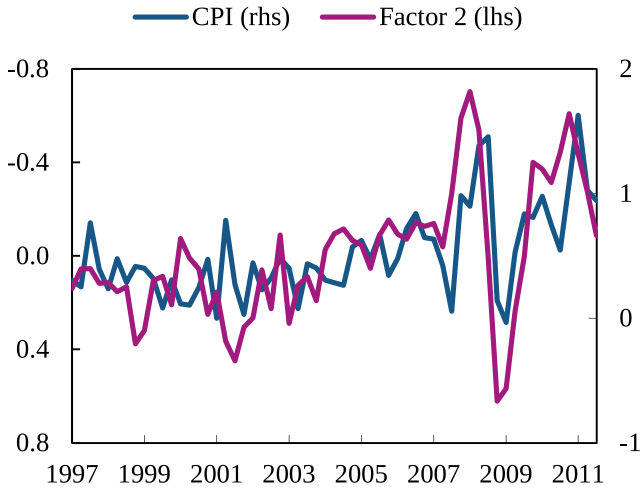


Table C: R^2 estimates

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.*

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

[3] Our dataset is restricted to 1997 to incorporate larger range of data and Blue Book consistent series.
[4] A list of all the variables we use is available on request.

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 five sectors the macroeconomic factors are more important. Ellis *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.* (2009) 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.

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 ten out of 15 sectors the sectoral shocks are white noise; in the remaining five 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 Ellis *et al.* (2009) and Boivin *et al.* (2009) 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 five sectors the sum of AR(4) coefficients exceeds 0.5), whilst in others it does not (in three sectors there is no statistically significant macro induced persistence). We use this stylised fact to justify assuming white-noise shocks in our model. We also use the estimated standard deviations for these shocks when we come to calibrate the standard deviations of the sectoral shocks within our model.

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 equation **(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.

3 The Theoretical Model

In this section we briefly outline our model of the United Kingdom, which is based on Harrison *et al.* (2011) and Millard (2011). The idea is to construct a model that we can use to analyse movements in sectoral inflation rates and the appropriate monetary policy response to them. In order to do this, we need a model in which there are a number of sectors and where the sectoral inflation rates of the model correspond in a meaningful way to the sectoral inflation rates that we observe in the real world.

Given that the model is described in full in Harrison *et al.* (2011), in what follows we concentrate on those areas in which our model is different compared with theirs.[5] There are two main differences between our model and theirs. First, we model food consumption and production. Specifically, in the model of Harrison *et al.* households consumer utilities, petrol and non-energy; in our model, they consume utilities, petrol, food and non food and energy (NFE). To keep things relatively simple, we follow Catao and Chang (2010) and assume that all food is imported. Second, we split NFE into 12 different goods, whose production differs only as a result of sector-specific productivity shocks and differences in the distribution of price stickiness across firms in each sector. We use the Generalised Taylor (GT) model of Dixon and Kara (2010) to generate these distributions of price stickiness as we think that simply using the median or mean duration of price changes ignores an important aspect of the microdata that may well have some effect on how monetary policy should respond to inflation in particular sectors. The result of these two alterations are that we are left with a model in which households consume 15 different goods, where these goods correspond to the 15 COICOP sectors we looked at in the empirical results above. Again, we do this so that we can use the model to assess whether a central bank would want to set monetary policy with respect to sectoral inflation rates, where we can equate the sectors in our model with sectors in the real world (ie, examine the response to sectoral inflation rates actually observed by the Bank of England).

As is the case in the Harrison *et al.* (2011) model, we assume that the domestic economy imports oil (which is combined with labour and capital to produce petrol), wholesale gas (which is combined with labour and capital to produce 'utilities', ie, retail gas and electricity), and other intermediate inputs (ie, non oil, gas and food imports). These intermediates are combined with labour, capital, petrol and utilities to produce output of the 12 NFE consumption goods. The capital stock is composed of NFE goods. The demand side of the economy is more standard with consumption and investment being driven by real interest rates and the central bank setting the nominal interest rate according to a Taylor rule

[5] Our Appendix 1 contains the complete equation listing.

3.1 Households

As in Harrison *et al.* (2011), households maximise utility subject to a budget constraint. They get utility out of consuming the bundle of 15 goods and leisure. We assume that households own the capital stock and that they make decisions about capital accumulation and utilisation. These assumptions, now standard in the business cycle literature, are made in order to simplify the firms' decision problem. Aggregate consumption, c, is composed of consumption of food (which, as we said earlier, is imported), c_f, petrol, c_p, utilities, c_u, and 'non food or energy' (NFE), c_n.[6] The consumption aggregator is given by:

$$c_t = \kappa_c \left(\psi_f c_{f,t}^{1-\frac{1}{\sigma_e}} + \psi_n c_{n,t}^{1-\frac{1}{\sigma_e}} + (1-\psi_f-\psi_n) \left(\kappa_e \left(\psi_p c_{p,t}^{1-\frac{1}{\sigma_p}} + (1-\psi_p) c_{u,t}^{1-\frac{1}{\sigma_p}} \right)^{\frac{\sigma_p}{\sigma_p-1}} \right)^{1-\frac{1}{\sigma_e}} \right)^{\frac{\sigma_e}{\sigma_e-1}} \quad \textbf{(2)}$$

We set the price of non food and energy to be our numeraire. The aggregate price level (relative to the numeraire), p, is defined as the minimum amount of expenditure required to obtain one unit of consumption:

$$p_t c_t = c_{n,t} + p_{f,t} c_{f,t} + p_{p,t} c_{p,t} + p_{u,t} c_{u,t} \quad \textbf{(3)}$$

Where p_f is the price of food (relative to the numeraire), p_u is the relative price of utilies and p_p is the relative price of petrol. Solving this minimisation problem gives the relative demand for each of the goods in terms of their relative prices.

Unlike Harrison *et al.* (2011), we assume perfectly-competitive spot labour markets in which each household takes wages and prices as given. So, real wages, w, will equal the marginal rate of substitution between leisure and consumption:

$$w_t = \left(\frac{h_t}{\kappa_h} \right)^{\frac{1}{\sigma_h}} c_t^{\frac{1}{\sigma_c}} \quad \textbf{(4)}$$

where h is total hours worked.

3.2 Non food and energy producing firms

The representative non food and energy (NFE) producing firm uses labour, capital, intermediate imported goods, petrol and utilities to produce output. The production function is described in Harrison *et al.* (2011), and in Appendix 1 below, and so will not be repeated here. The key point to note is that except for the sector-specific shocks, which we describe below, real marginal cost, μ, is common across all firms – ie, all firms in all the 12 sectors – producing non food and energy goods:

[6] NFE represents the CPI basket *excluding* food and energy. That is, a composite of the 12 other goods in our model. How this composite is made up is discussed later.

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 Generalised Taylor model, which can be thought of as 'duration' sectors superimposed on the CPI sectors within the NFE.

We set up each of the COICOP sectors constituting the NFE sector as in the GT model of Dixon and Kara (2010). Firms in each of the twelve NFE COICOP sectors are divided up into *K* 'duration' subsectors, where sub-subsector *k= 1, ... K,* denotes those firms whose prices change every *k* periods. We first note that the optimal flexible price in any sub-subsector will simply be a (time-varying) mark-up over marginal cost in that sub-subsector, where we assume that this mark-up is the same across the entire NFE sector and reflects monopolistic competition in that sector. Following, Rotemberg and Woodford (1998), we assume that the government imposes a lump-sum tax on NFE firms that fully offsets the welfare loss resulting from the monopoly power of firms in this sector.

We further 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, real marginal cost within a COICOP subsector will be given by μe^{ε_k} where ε_k is the *relative* productivity shock in COICOP subsector *k*. Given our empirical 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 productivity 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* productivity 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* productivity shock and then allowed for 12 sector-specific productivity shocks that added up to zero (in effect 11 independent shocks). These two approaches are of course linked: we can think of the shocks ε_k in terms of the mean productivity 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, the *NFE* as a whole will experience a technological improvement if the shocks across the COICOP sectors tend to be more positive than negative.

Denote the price set by a firm in GT duration subsector *k* of COICOP sector *z* that is able to reset its price in period *t* by $x_{z,k,t}$. As we show in Appendix 1, this price is defined implicitly by the equation:

$$q_t x_{z,k,t}^{-\eta} (\eta - 1)\left(x_{z,k,t} - \frac{\eta}{\eta - 1} \mu_t e^{\varepsilon_{z,t}} \right) + E_t \sum_{i=1}^{k-1} \prod_{j=1}^{i} \frac{1}{1 + i_{t+j-1}} q_{t+i} x_{z,k,t}^{-\eta} (\eta - 1)\left(x_{z,k,t} - \frac{\eta}{\eta - 1} \mu_{t+i} e^{\varepsilon_{z,t+i}} \prod_{j=1}^{i} \left(1 + \pi_{t+j}\right)\right) = 0 \qquad \textbf{(5)}$$

Where π denotes the inflation rate in the NFE sector and $\eta/\eta-1$ denotes the steady-state mark-up in the NFE sector. The real reset price, $x_{z,k}$ will be eroded by inflation (since it is the nominal price that is kept constant). This is captured by the inflation terms in equation **(5)**: higher expected future inflation will raise the real reset price. 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.

Note that the sectoral shock $\varepsilon_{z,t}$ 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 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 **(5)** need to be considerably larger in terms of variance in order to be consistent with the shocks we observe in the inflation data.

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

$$p_{z,k,t} = \left(\frac{1}{k} \left(x_{z,k,t}^{1-\eta} + \sum_{j=1}^{k-1} \frac{1}{\prod_{i=0}^{j-1} (1+\pi_{t-i})} x_{z,k,t-j}^{1-\eta} \right) \right)^{\frac{1}{1-\eta}} \qquad \textbf{(6)}$$

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

$$p_{z,t} = \left(\sum_{k=1}^{K} \gamma_{z,k} p_{z,k,t}^{1-\eta} \right)^{\frac{1}{1-\eta}} \qquad \textbf{(7)}$$

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

$$1 = \left(\sum_{z=1}^{12} \gamma_z p_{z,t}^{1-\eta} \right)^{\frac{1}{1-\eta}} \qquad \textbf{(8)}$$

Whilst we have used the GT framework to allow for us to model different levels of nominal rigidity across the COICOP 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 Other firms

As we said earlier, producers of NFE goods combine intermediate imports, petrol, utilities, labour and capital to produce their output. Following Harrison et al. (2011), we first assume that 'Value-added' producers use labour, *h*, and capital, *k*, to produce value-added, *V*:

$$V_t = e^{\varepsilon_{a,t}}\left(\alpha_v\left(k_{t-1}z_t\right)^{1-\frac{1}{\sigma_v}} + \left(1-\alpha_v\right)\left(h_t\right)^{1-\frac{1}{\sigma_v}}\right)^{\frac{\sigma_v}{\sigma_v-1}} \quad \textbf{(9)}$$

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

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

$$q_p = \min\left(\frac{I_o}{1-\psi_{qp}}, \frac{V_p}{\psi_{qp}}\right) \quad \textbf{(10)}$$

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 also assumed to be monopolistically competitive and subject to nominal rigidities in their price-setting. We again follow Rotemberg and Woodford (1998) and assume that firms in this sector are subject to a lump-sum tax that perfectly offsets the distortion arising from their monopoly power and following Calvo (1983), we assume that firms in this sector are able to optimally change their price in any given quarter with probability 1-χ_p. The resulting New Keynesian Phillips Curve (NKPC) is:

$$\pi_{p,t} = \beta \mathrm{E}_t \pi_{p,t+1} + \frac{\left(1-\chi_p\right)\left(1-\beta\chi_p\right)}{\chi_p}\hat{\mu}_{p,t} \quad \textbf{(11)}$$

where π_p represents the inflation rate for petrol prices and $\hat{\mu}_p$ denotes the log-deviation from steady state of real marginal cost in this sector.

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

$$q_u = \min\left(\frac{I_g}{1-\psi_u}, \frac{V_u}{\psi_u}\right) \quad \textbf{(12)}$$

Firms in this sector are again assumed to be monopolistically competitive and subject to nominal rigidities in their price-setting. And again we follow Rotemberg and Woodford (1998) and assume that firms in this sector are subject to a lump-sum tax that perfectly offsets the distortion arising from their monopoly power. We assume that firms in this sector are able to optimally change their price in any given quarter with probability 1-χ_u. The resulting NKPC is:

$$\pi_{u,t} = \beta E_t \pi_{u,t+1} + \frac{(1-\chi_u)(1-\beta\chi_u)}{\chi_u}\hat{\mu}_{u,t} \quad \textbf{(13)}$$

where π_u represents the inflation rate for utility prices and $\hat{\mu}_u$ denotes the log-deviation from steady state of real marginal cost in this sector.

3.4 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, defined as what value-added would be in an economy identical to the one we consider except that prices were completely flexible.

The fiscal authority is assumed to buy only NFE and to have the same preferences across these goods and services as consumers. It collects lump-sum taxes from each of the firms in order to eliminate the welfare distortions resulting from monopolistic competition. Any remaining budget shortfall is met via lump-sum taxes on consumers (or budget surplus returned to consumers via lump-sum transfers). When the government's budget constraint is combined with the households' budget constraint and the definition of firms' profits, we obtain the market clearing condition for NFE output:

$$q_t = c_{n,t} + k_t - (1-\delta)k_{t-1} + e^{\varepsilon_{g,t}} + x_{n,t} \quad \textbf{(14)}$$

where q is output of NFE goods, e^{ε_g} denotes government spending with ε_g being a government spending shock, and x_n denotes exports of NFE.

3.5 Foreign sector

We assume that the United Kingdom is a small open economy. Following Harrison *et al.* (2011), we assume that there is an infinitely elastic supply of oil and gas on world markets available at exogenous world prices. The domestic prices of oil and gas are determined by the law of one price. Net trade in oil and gas will be determined as the difference between the demands for oil and gas and the United Kingdom's exogenous endowments of each of these goods. UK NFE exporters are assumed to face a downward-sloping demand curve for their goods, subject to an exogenous shock to world demand of NFE goods.

UK food and non food and energy import prices, on the other hand, take time to adjust to purchasing power parity.[7] This results in the NKPCs for food prices and for import prices ex food and energy:

$$\pi_{f,t} = \frac{\iota_{pf}}{1+\beta\iota_{pf}}\pi_{f,t-1} + \frac{\beta}{1+\beta\iota_{pf}}E_t\pi_{f,t+1} + \frac{(1-\xi_{pf})(1-\beta\xi_{pf})}{(1+\beta\iota_{pm})\xi_{pf}}\left(\varepsilon_{p_f} - \hat{s}_t - \hat{p}_{f,t}\right) \quad \textbf{(15)}$$

$$\pi_{m,t} = \frac{\iota_{pm}}{1+\beta\iota_{pm}}\pi_{m,t-1} + \frac{\beta}{1+\beta\iota_{pm}}E_t\pi_{m,t+1} + \frac{(1-\xi_{pm})(1-\beta\xi_{pm})}{(1+\beta\iota_{pm})\xi_{pm}}\left(\varepsilon_{p_{mf}} - \hat{s}_t - \hat{p}_{m,t}\right) \quad \textbf{(16)}$$

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, s denotes the real exchange rate, p_m denotes 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, and 'hats' denote log-deviations from trend.

4 Calibration

In this section, we discuss how we calibrate our model. The idea is to calibrate the model so that it matches UK data in enough detail to allow us to provide quantitative answers to the question of to what extent, if at all, should monetary policy makers respond to movements in sectoral inflation rates. We start by discussing the parameters within our model that are standard and for which we already have good estimates for the United Kingdom. We then move on to discuss how we match up the size of our sectors within the model – that is their shares in consumption and production – to their UK analogues before discussing how we calibrate the driving processes within our model. Finally, we discuss how we construct the GT weights for each sector so as to match the distributions of price stickiness across firms in each of our 12 NFE COICOP sectors.

4.1 Standard parameters

When calibrating those parameters within our model that can be found in most standard macroeconomic models, we almost always followed the values used in Harrison *et al.* (2011) and so refer the interested reader to that paper for a complete discussion of where these values come from. The only exceptions to this approach, were the parameters governing the Taylor rule. Here we used the Harrison *et al.* value for the interest rate smoothing term and the original values in Taylor (1993) for the responses to inflation and output deviations:

$$i_t - \left(\frac{1}{\beta} - 1\right) = 0.8\left(i_{t-1} - \left(\frac{1}{\beta} - 1\right)\right) + 0.2\left(1.5\pi_{c,t} + 0.125\hat{y}_{FP,t}\right) + \varepsilon_{i,t} \quad \textbf{(17)}$$

We also needed to estimate the process for food price inflation, since the Harrison *et al.* (2011) model had no role for food prices. We estimated equation **(17)** and obtained the following results:

$$\pi_{f,t} = 0.9925E_t\pi_{f,t+1} + 0.50375\left(\varepsilon_{p_f} - \hat{s}_t - \hat{p}_{f,t}\right) \quad \textbf{(18)}$$

[7] The underlying assumption here is that UK importers of food and imported intermediate goods excluding food, oil and gas are monopolistically competitive and face 'Calvo' frictions in their ability to set prices. Again, we follow Rotemberg and Woodford (1998) and assume that the government imposes a lump-sum tax on importers that fully offsets the distortion arising from their monopoly power.

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 (those applied in 2012 based on expenditure shares in 2011) – as shown in Table E – to give us the weights of each of our sectors in consumption.

Table E: 2012 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 need the weights of gas in utilities output and oil in petrol output. From the 2008 *Supply and Use Tables* (SUTs), we can note that inputs of ‘oil and gas extraction’ into ‘electricity production and distribution and gas distribution’ were worth £24,987 million and into ‘coke ovens, refined petroleum and nuclear fuel’ were worth £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.

We also need the weight of energy in NFE output. We define ‘food’ as sectors 1, 3 and 8 through 17 in the SUTs.[8] 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 NFE sector of £1,708,506 million.

[8] 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 NFE 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 NFE of £19,115 million and of petrol into NFE 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 NFE imports in NFE 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 NFE were £380,907 million. So the share of NFE imports in NFE 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 NFE. Hence, the share of government spending in NFE is equal to 18.38%. Given these shares, we can then set our remaining parameters so that the model generates these shares in steady state.[9] Doing so results in the parameter values shown in Table F.

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

Parameter	Value	Description	Comment
κ_x	0.1245	Exports of non-energy	Normalises the exchange rate, s, to equal unity in steady state
κ_c	1.4105	Scale parameter on consumption aggregator	Normalises the relative price of consumption, p_c, to equal unity in steady state
κ_h	0.6677	Relative utility of leisure	Normalises total hours, h, to equal unity in steady state
α_b	0.2239	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	0.0002	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	0.0051	Parameter governing share of energy in consumption	Ensures that the steady-state share of energy in consumption spending is 8.7%.
ψ_n	0.4482	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	0.0072	Parameter governing share of petrol in consumption	Ensures that the steady-state share of petrol in consumption spending is 4.3%.
ψ_{qp}	0.5148	Parameter governing share of oil in petrol production	Ensures that the steady-state share of oil in petrol production is 0.7592.
ψ_u	0.8852	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%.
$\overline{O}$	0.0046	Economy's endowment of oil	Ensures that the steady-state share of oil in GDP is 1.3%.
$\overline{G}$	0.0050	Economy's endowment of gas	Ensures that the steady-state share of gas in GDP is 1.4%.
c_g	0.0837	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%.

[9] The equations governing the steady state of the model are laid out in Appendix 2.

4.3 Shock processes

In order to use the model to analyse how monetary policy should respond to movements in sectoral inflation rates, we need the model to match the stylised facts on sectoral inflation presented in Section 2, as well as stylised facts about aggregate inflation and output. In order to do this, we need to calibrate the processes driving the 19 exogenous shocks in our model: aggregate productivity, monetary policy, government spending, the world prices of oil, gas, food, and intermediate imports 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. Now, as we said earlier, the sectoral shocks of our model are not the same as the sectoral shocks estimated in section 2. So, in calibrating the standard deviations of these shocks, we need to multiply up the standard deviations of the estimated sectoral inflation shocks coming from Equation **(1)** by scaling factors for each sector that depend on their relative stickiness. The calculation of these scaling factors is described in Appendix 3. Our calibrated standard deviations for the sectoral shocks are shown in Table G.

Table G: Standard deviations of sectoral shocks (per cent)

Non-Alcoholic Beverages	3.20
Alcoholic Beverages and Tobacco	1.30
Clothing and Footwear	1.44
Housing and Water	3.92
Furniture, household equipment and maintenance	0.81
Health	1.52
Transport (ex Fuel and Lubricants)	3.54
Communication	2.07
Recreation and Culture	0.83
Education	17.24
Restaurants and hotels	1.00
Misc Goods and Services	1.32

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:

$$\varepsilon_{p_f,t} = 0.70\varepsilon_{p_f,t-1} + \nu_{p_f,t}, \sigma_{p_f} = 0.0366 \quad \textbf{(19)}$$

$$\varepsilon_{p_g,t} = 0.60\varepsilon_{p_g,t-1} + \nu_{p_g,t}, \sigma_{p_g} = 0.2426 \quad \textbf{(20)}$$

$$\varepsilon_{p_o,t} = 0.75\varepsilon_{p_o,t-1} + \nu_{p_o,t}, \sigma_{p_o} = 0.1479 \quad \textbf{(21)}$$

$$\varepsilon_{p_{mf},t} = 0.78\varepsilon_{p_{mf},t-1} + \nu_{p_{mf},t}, \sigma_{p_{mf}} = 0.0168 \quad \textbf{(22)}$$

For the monetary policy shock we assumed that the shock was white noise. 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 **(18)**. 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.[10] Specifically, we used a version of equation **(10)** in which capacity utilisation was always at its steady state together with the calibration in Table E to obtain:

$$\varepsilon_{a,t} = \hat{V}_t - 0.75\left(\frac{V}{h}\right)\hat{h}_t - 0.25\left(\frac{V}{h}\right)\hat{k}_{t-1} \qquad \textbf{(23)}$$

In the steady state of our calibrated model $\frac{V}{h} = 1.1585$ and $\frac{V}{k} = 0.5245$. Given these values, and HP-filtered GDP, total hours worked and capital, we constructed ε_a and estimated the AR(1) process:

$$\varepsilon_{a,t} = 0.77\varepsilon_{a,t-1} + \nu_{a,t}, \sigma_a = 0.0063 \qquad \textbf{(24)}$$

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:

$$\varepsilon_{g,t} = 0.54\varepsilon_{g,t-1} + \nu_{g,t}, \sigma_g = 0.0079 \qquad \textbf{(25)}$$

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

The data for the sectoral GT weights is taken from Dixon and Tian (2012), adjusted for the splitting off of *Fuel and lubricants* from *Transport, Utilities* from *Housing and water* and *Food* from *Food and Non-alcoholic beverages*. The sectoral GT weights are 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 using the approach outlined in Appendix 4 and UK data from 1996 to 2006 representing the 'Great Moderation' period. The ONS micro price data we use is described by Bunn and Ellis (2012). The derivation of the 12x12 matrix of sectoral duration coefficients γ_{ji} (shown in Table H) is based on the steady-state identities derived in Dixon (2012). By averaging out over the ten 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 four-quarter spells equal to 1 and the rest to zero.[11] The modal duration is highlighted in yellow, the median duration is underlined

[10] For a description of how the capital services series we used was constructed see Oulton and Srinivasan (2003).
[11] 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, the steady-state assumption is a good approximation in terms of how the model behaves.

and the arithmetic mean is in the bottom row.[12] 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 mean duration across the entire CPI would be lower; second, the distribution is truncated at 12 quarters which reduces the mean. Overall, the mean estimated by Dixon and Tian (2012) across all sectors excluding education is 10.9 months.

Table H: The Sectoral GT weights in NFE

Duration	Non-Alcoholic beverages	Alcoholic beverages	Clothing and Footwear	Housing and Water	Furniture	Health
1	0.1330	0.3797	0.3996	0.0763	0.4460	0.1355
2	0.1314	0.2792	0.2608	0.1117	0.2014	0.1482
3	0.1353	0.2217	0.1155	0.1201	0.0983	0.1662
4	0.1657	0.0395	0.0862	0.1223	0.0769	0.1778
5	0.0699	0.0240	0.0423	0.0635	0.0493	0.0912
6	0.0608	0.0133	0.0316	0.0760	0.0345	0.0809
7	0.0721	0.0071	0.0180	0.0692	0.0217	0.0424
8	0.0541	0.0054	0.0158	0.0650	0.0197	0.0290
9	0.0450	0.0051	0.0091	0.0407	0.0139	0.0249
10	0.0161	0.0044	0.0077	0.0391	0.0110	0.0237
11	0.0383	0.0091	0.0031	0.0471	0.0065	0.0071
12	0.0783	0.0114	0.0104	0.1691	0.0209	0.0731
Mean	5.04	2.38	2.58	6.23	2.77	4.53
Duration	**Transport**	**Communications**	**Education**	**Recreation and Culture**	**Restaurants and Hotels**	**Miscellaneous**
1	0.0624	0.3551	0.0000	0.3427	0.1232	0.2287
2	0.1119	0.3062	0.0000	0.2053	0.1757	0.2017
3	0.1260	0.1112	0.0000	0.1361	0.2065	0.1513
4	0.1567	0.0730	1.0000	0.1114	0.1811	0.1468
5	0.0609	0.0584	0.0000	0.0505	0.1004	0.0668
6	0.0817	0.0848	0.0000	0.0462	0.0584	0.0521
7	0.0794	0.0075	0.0000	0.0298	0.0486	0.0441
8	0.0742	0.0039	0.0000	0.0157	0.0331	0.0299
9	0.0307	0.0000	0.0000	0.0147	0.0223	0.0199
10	0.0432	0.0000	0.0000	0.0121	0.0183	0.0181
11	0.0414	0.0000	0.0000	0.0074	0.0120	0.0059
12	0.1316	0.0000	0.0000	0.0281	0.0204	0.0345
Mean	5.98	2.48	4.00	3.14	4.04	3.71

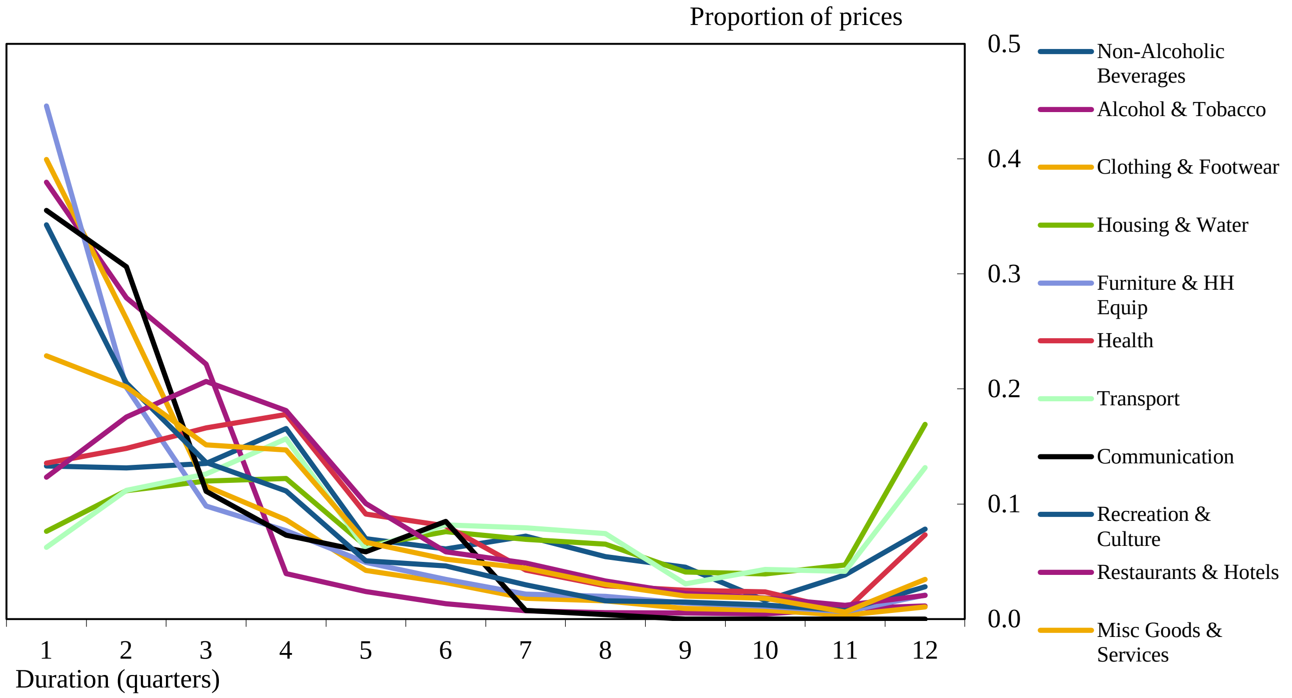
As we can see, if we look across the first row, the share of 'flexible' prices in each sector can be quite large. These prices will respond immediately to any shock in that sector. However, in most sectors with the exceptions of *Communications* and *Education*, there is a long tail of prices which have a duration beyond two years. Note that we have 'split off' flexible parts of the CPI from NFE: *Food* from *Alcohol*, *Fuels and lubricants* 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

[12] 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.

heterogeneity across sectors. The NFE sectors 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 three quarters, and *Housing and Water* which peaks at 12 quarters. The arithmetic mean durations vary quite a lot as well: the longest are *Housing and Water* and *Transport*, both with means of about six quarters and the lowest are *Alcoholic Beverages* (2.4 quarters) and *Communications* (2.5 quarters). This heterogeneity is of course common in CPI data. (See, for example, Bills *et al.* (2012).) Medians and modes are usually consecutive or coincide, except for *Housing and Water* and *Miscellaneous*.

The sectional distributions are depicted in Chart 3. 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 four quarters dominates too much. Note that there is a local maximum at 12 quarters for most categories. This is because all durations longer than 12 quarters are included in this (recall, we estimated up to 48 months).

Chart 3: Sectoral hazard rate distributions



5 Model validation

In this section, we 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.[13] We consider this as an exercise in 'validation'; that is, in order to use our model to analyse how monetary policy should respond to movements in sectoral and aggregate inflation, we need to be convinced that it is successfully capturing the drivers of such movements and the overall behaviour of aggregate and sectoral inflation.

We first consider the implications of our model for the relative volatility of quarterly sectoral and aggregate inflation. Recall that in the data, aggregate inflation was less volatile than inflation in all of our 15 sectors. Table I reports the asymptotic standard deviations of aggregate and sectoral inflation given our model calibration. As can be seen the model matches the stylised fact that aggregate inflation is less volatile than inflation in all of our 15 sectors. The volatility of aggregate inflation is almost exactly the same as in the data, whereas the average volatility of sectoral inflation rates is a little high relative to the data. This result is driven by the excessively high volatilities in the model for *Fuel and Lubricants* and *Food*, both functions of the rapid pass-through from world prices that we assume.

Table I: Standard deviations (per cent)

	Model	Data
Headline CPI	**0.48**	**0.52**
Sector average	**1.38**	**1.16**
Fuel and Lubricants	7.08	3.42
Electricity, Gas and Other Fuels	1.55	2.69
Communication	1.35	1.25
Education	1.58	1.10
Clothing and Footwear	1.11	1.06
Non-Alcoholic Beverages	0.86	1.02
Alcoholic Beverages and Tobacco	1.03	1.02
Food	1.61	0.99
Housing and Water	0.69	0.91
Health	0.55	0.89
Transport (ex Fuel and Lubricants)	0.59	0.71
Furniture, household equipment and maintenance	0.86	0.65
Restaurants and hotels	0.48	0.62
Recreation and Culture	0.72	0.59
Misc Goods and Services	0.70	0.52

Table J 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 little persistence in this model. This is a result of the fact the model generates basically no persistence in sectoral volatilities – though this is not too far out of line with the data – as a result of the fact that sectoral inflation rates are mainly determined by the white noise sectoral shocks. The model is clearly failing to capture the effect of some persistent macroeconomic shocks on sectoral inflation rates. Since the model treats all NFE sectors as similar except for nominal rigidity, it may miss the possibility that some sectors are

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

more directly affected by macroeconomic variables than others. That said, the model does match the key result that aggregate inflation is much more persistent than sectoral inflation.

Table J: Inflation persistence		
	Model	**Data**
Headline CPI	**0.22**	**0.65**
Sector average	**-0.00**	**0.45**
Non-Alcoholic Beverages	-0.21	0.57
Electricity, Gas and Other Fuels	0.34	0.59
Clothing and Footwear	-0.22	0.63
Recreation and Culture	-0.03	0.69
Communication	-0.26	0.44
Transport (ex Fuel and Lubricants)	-0.03	0.47
Restaurants and hotels	0.28	0.61
Education	0.04	0.31
Food	0.28	0.46
Fuel and Lubricants	0.17	0.16
Health	0.07	0.26
Alcoholic Beverages and Tobacco	-0.16	0.24
Housing and Water	-0.14	0.30
Furniture, household equipment and maintenance	-0.11	0.53
Misc Goods and Services	-0.05	0.43

Table K shows the proportion of variance in sectoral inflation rates that results from aggregate shocks – which, importantly, include shocks to the world prices of *oil*, *gas* and *food* as well as *imported intermediates* – and compares this with the proportion of UK sectoral inflation rates explained by the 'common factors' we found in the UK data (shown in Table C). Leaving aside *food*, *petrol* and *utilities*, which are explained entirely by aggregate shocks to the world prices of food, oil and gas, respectively, Table K suggests that sectoral shocks are important in explaining inflation in all sectors. On average, they explain about 40% of variation in sectoral inflation, compared with about 60% in the data. Almost all of the variance of aggregate inflation in the model results from aggregate shocks as opposed to only about 75% in the data. These results suggest that the sectoral shocks are not having as large an impact on either sectoral or aggregate inflation, relative to the aggregate shocks, as we might have expected.

Table K: Proportion of variance explained by aggregate shocks		
	Model	**Data**
Headline CPI	**0.93**	**0.76**
Sector average (ex petrol, food and utilities)	**0.39**	**0.39**
Fuel and Lubricants	1.00	0.64
Food	1.00	0.56
Transport (ex Fuel and Lubricants)	0.27	0.54
Non-Alcoholic Beverages	0.18	0.50
Electricity, Gas and Other Fuels	1.00	0.49
Furniture, household equipment and maintenance	0.59	0.48
Clothing and Footwear	0.34	0.45
Housing and Water	0.20	0.43
Restaurants and hotels	0.74	0.41
Alcoholic Beverages and Tobacco	0.41	0.36
Communication	0.22	0.29
Health	0.51	0.26
Recreation and Culture	0.64	0.21
Education	0.06	0.13
Misc Goods and Services	0.48	0.08

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.

The central bank's goal is to maximise the unconditional expectation of the present discounted value of the representative consumer's current and future streams of utility. This is equivalent to maximising the unconditional expectation of the representative consumer's period utility function:

$$U_t = \frac{c_t^{1-\frac{1}{\sigma_c}} - 1}{1-\frac{1}{\sigma_c}} - \frac{\kappa_h}{1+\frac{1}{\sigma_h}} h_t^{1+\frac{1}{\sigma_h}} \quad \textbf{(26)}$$

Given that we have followed Rotemberg and Woodford (1998) and assumed that firms are subject to lump-sum taxes that perfectly offset the distortions arising from their monopoly power in the various markets, we can note that the Pareto Optimal period welfare function is given by:

$$\tilde{U}_t = \frac{\tilde{c}_t^{1-\frac{1}{\sigma_c}} - 1}{1-\frac{1}{\sigma_c}} - \frac{\kappa_h}{1+\frac{1}{\sigma_h}} \tilde{h}_t^{1+\frac{1}{\sigma_h}} \quad \textbf{(27)}$$

Where $\tilde{c}$ and $\tilde{h}$ are the levels of consumption and hours, respectively, that would result in an economy identical to the one we consider except that prices were completely flexible and there were no mark-up shocks.

So, we can use a second-order expansion of the two welfare functions around the (non-stochastic) steady state in order to analyse deviations of the policymaker's period welfare from the Pareto Optimum. This will be given by:

$$U_t - \tilde{U}_t = \frac{1}{2}\frac{\sigma_c - 1}{\sigma_c}\bar{c}^{1-\frac{1}{\sigma_c}}\left(\hat{c}_t - \tilde{c}_t\right)^2 - \frac{\kappa_h}{2}\frac{\sigma_h + 1}{\sigma_h}\left(\hat{h}_t - \tilde{h}_t\right)^2 \quad \textbf{(28)}$$

where $\bar{c}$ is the steady-state level of consumption and the steady-state level of hours has been normalised to unity.

For this section of the paper, we shall use numerical methods to analyse different monetary policy rules in terms of which is optimal, ie, minimises the unconditional expectation of the deviations of utility from its Pareto optimum, given by equation **(28)**, subject to the log-linearised equations that characterise our model.

Given our calibration this results in the loss function:

$$\frac{E\left(U_t-\overline{U}\right)}{\overline{U}_c\overline{c}}=\frac{E\left(U_t-\overline{U}\right)}{\overline{c}^{1-\frac{1}{\sigma_c}}}=-0.2576Var\left(\hat{c}-\tilde{c}\right)-0.5363Var\left(\hat{h}-\tilde{h}\right) \quad \textbf{(29)}$$

Where $\overline{U}_c$ is the steady-state marginal utility of consumption and we have followed Erceg *et al.* (2000) by scaling the welfare deviation by $\overline{U}_c\overline{c}$ so as to express these welfare losses as a fraction of Pareto-optimal consumption.

We consider the following simple policy rules:

$$i_t-i=\theta_\pi\pi_{c,t}+\theta_y\hat{y}_t \quad \textbf{(30)}$$

$$i_t-i=\theta_\pi\pi_{c,t}+\sum_{j=1}^{15}\theta_j\pi_{j,t}+\theta_y\hat{y}_t \quad \textbf{(31)}$$

$$i_t-i=\theta_\pi\pi_t+\theta_y\hat{y}_t \quad \textbf{(32)}$$

$$i_t-i=\theta_\pi\pi_{vc,t}+\theta_y\hat{y}_t \quad \textbf{(33)}$$

Equation **(30)** represents a standard Taylor rule, in which the central bank responds to aggregate CPI inflation and the deviation of value-added output from trend. Equation **(31)** is similar, except that we allow the central bank to respond separately to inflation in each of our 15 COICOP sectors. Equation **(32)** considers a Taylor rule in which the central bank responds to NFE inflation.[14] Equation **(33)** 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). Optimisation was carried out numerically using the 'OSR' *Dynare* module. Our results are shown in Table L.

The rule in which the central bank responds differently to inflation rates in the different sectors outperforms the other rules (as it must). Although it improves on the performance of the Taylor rule by about 40%, the difference in welfare space is not large: a standard Taylor rule results in a welfare loss equivalent to only 0.0015% of Pareto optimal consumption relative to the more general sectoral rule. These results are in line with both Eusepi *et al.* (2011) and Kara (2010). Our results also suggest that a rule based on DGI outperforms a rule based on NFE inflation by about 5%, which itself outperforms the standard Taylor rule by about 5%. The good performance of the DGI rule – in line with Aoki (2001) – results from the reduction in consumption volatility it implies. But again the differences between these rules in welfare space are all extremely small: using a standard Taylor rule results in a welfare loss equivalent to only 0.0004% of steady-state consumption relative to the rule based on DGI. Interestingly, if we had applied a 'standard' loss function based on output and inflation volatility, the DGI-based rule would be the worst performing rule as it results in much more inflation volatility than the other rules. This is because such a rule ignores the large direct effect of import

[14] 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 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).

prices on CPI. So, in terms of monetary policy conceived of in terms of inflation stabilization the DGI rule is not attractive.

If we compare the rules, we can see that there is a significant reduction in the volatility of consumption, inflation and value-added using the sectoral rule as compared with the other three rules, whilst the volatility of hours is similar across all rules. The sectoral rule also works by having a low weight on output whilst the other three have a significant negative weight on output (10-20 times larger than the sectoral rule).

Table L: Optimal simple rules

	Standard Taylor rule	Policy responding to sectoral inflation rates	Policy responding to NFE inflation	Policy responding to DGI
θ_{π}	1.7176	1.5190	1.8046	2.3127
θ_{y}	-0.8273	-0.0721	-0.8746	-1.5066
$\theta_{\text{Non alcoholic beverages}}$	-	0.0251	-	-
$\theta_{\text{Alcohol and tobacco}}$	-	0.0296	-	-
$\theta_{\text{Clothing and footwear}}$	-	0.0279	-	-
$\theta_{\text{Housing and water}}$	-	0.0213	-	-
$\theta_{\text{Household goods}}$	-	0.0286	-	-
θ_{Health}	-	0.0267	-	-
$\theta_{\text{Transport (ex petrol)}}$	-	0.0221	-	-
$\theta_{\text{Communication}}$	-	0.0290	-	-
$\theta_{\text{Recreation and culture}}$	-	0.0278	-	-
$\theta_{\text{Restaurants and hotels}}$	-	0.0279	-	-
$\theta_{\text{Miscellaneous}}$	-	0.0272	-	-
$\theta_{\text{Education}}$	-	0.0267	-	-
θ_{Petrol}	-	-0.0862	-	-
$\theta_{\text{Utilities}}$	-	0.0242	-	-
θ_{Food}	-	0.0026	-	-
Standard deviations (per cent)				
Consumption	1.14	0.85	1.12	1.07
Total hours	0.25	0.25	0.23	0.24
Value-added output	1.16	0.88	1.17	1.17
CPI inflation	0.72	0.43	0.77	1.02
Loss	$3.6830*10^{-5}$	$2.1963*10^{-5}$	$3.5150*10^{-5}$	$3.2582*10^{-5}$
Improvement relative to Taylor rule benchmark	-	40.37%	4.56%	11.53%

In order to understand the significance of the numbers in the first three optimal policy rules, we can express them in terms of the implied weights on each sector. In the case of the standard Taylor rule, the implied weight on each sector is simply the Taylor coefficient on inflation (1.718) times the CPI weight of that sector from Table E. All of the implied sectoral weights are blown up by the same proportion: since the CPI weights themselves add up to 1, the implied weights add up to 1.718. These implied weights are reported in the first column of Table M. The second gives the corresponding implied weights for the optimal sectoral rule. These are the sum of two things: the coefficient on aggregate CPI (1.52) times the sectoral weights, added to the coefficient on the sectoral inflation rate. If we turn to NFE inflation, this is obtained putting zero weight on the three sectors (*food*, *petrol* and *utilities*). This leaves out 19% of the CPI weight. The CPI weights of the remaining sectors are then adjusted so that they add up to one: they will still have the same relative values as in the simple Taylor rule. The coefficient on the Taylor rule for NFE inflation is 1.80: the implied sectoral coefficients on the sectors included in the NFE sector are 30% higher than the simple Taylor rule (most of this comes from the reweighting, as the coefficient on aggregate inflation is only slightly higher). These coefficients are in the third column of the table.

Table M: Sectoral and aggregate effects.

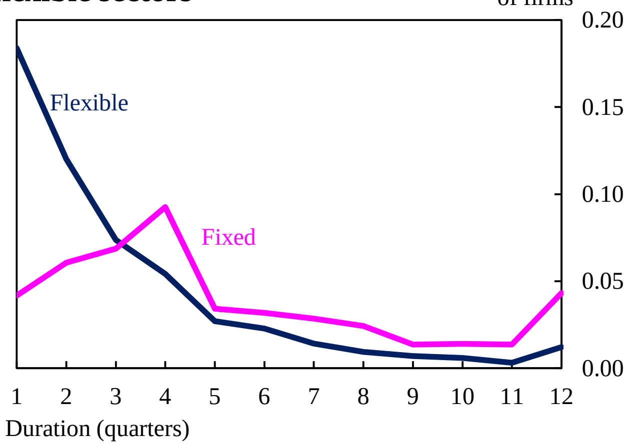
	CPI	Sectoral	NFE	%(2-1)/1	%Δsectoral	Mean	Mode
Non-alcoholic beverages	0.0258	0.0479	0.0334	85.9	110.2	5.04	4
Alcohol and tobacco	0.0721	0.0934	0.0936	29.5	46.4	2.38	1
Clothing and footwear	0.1048	0.1206	0.1359	15.1	30.1	2.58	1
Housing and water	0.1460	0.1504	0.1894	3.0	16.5	6.23	4
Furniture, household equipment and maintenance	0.1048	0.1213	0.1359	15.7	30.9	2.77	1
Health	0.0412	0.0632	0.0535	53.2	73.2	4.53	4
Transport excluding fuels and lubricants	0.1992	0.1983	0.2584	-0.5	12.5	5.98	4
Communication	0.0447	0.0685	0.0579	53.4	73.4	2.48	1
Recreation and culture	0.2525	0.2511	0.3275	-0.6	12.5	3.14	1
Education	0.0309	0.0540	0.0401	74.8	97.7	4.00	4
Restaurants and hotels	0.2061	0.2102	0.2673	2.0	15.3	4.04	3
Miscellaneous goods and services	0.1632	0.1715	0.2117	5.1	18.8	3.71	1
Food	0.1769	0.1807	0	2.1	15.5		
Electricity, gas and other fuels (utilities)	0.0756	0.0995	0	31.7	48.9		
Fuels and lubricants (petrol)	0.0739	-0.0209	0	-128.3	-132.0		

In the fourth column of Table M, we express the percentage deviation of the coefficients for the optimal sectoral rule from the implied coefficients for the simple Taylor rule. We also report the percentage deviation of the sectoral weight from the weight implied by the coefficient on aggregate CPI (1.52): in effect, in percentage terms, how much do the sectoral coefficients in Column 2 of Table L contribute to the overall sectoral coefficients in column 2 of Table M.

If we look at Table M, comparing the first two columns, we can note that the sectoral rule implies putting more weight on all sectors except for petrol, for which there is a massive reduction which takes it below zero. Indeed, if we add up the sectoral weights, the sectoral rule implies a more aggressive response to inflation with coefficient of two. However, for six sectors there is little change (*Housing and Water*, *Transport*, *Recreation and culture*, *Restaurants and hotels*, *Food*, *Miscellaneous*) for the rest there is either a significant increase (*Alcohol and Tobacco*, *Clothing and Footwear*, *Furniture, utilities*) or a large increase (*Non Alcoholic Beverages, Health, Communication, Education*). Recall that the only difference between the NFE COICOP sectors is the distribution of durations. We can see that the sectors with the large percentage increases in column three are all *small* sectors: even after significant increases over the first column, the second column is still less than 0.1. On the other hand, the sectors with the largest CPI share (eg, *Recreation and Culture*) show a small increase.

To make sense of the overall changes, we divide the CPI sectors into two groups: flexible price sectors (mode one and mean less than four) with a combined CPI share of 53% of the NFE total, and fix-price (mean over four and a mode at least three). In fact *Miscellaneous* is the only slightly ambiguous category: it has a mode of one quarter and a mean of 3.71. The other flex price categories have mean durations of around three quarters. So, if we group the COICOP sectors in this way, we see that there is in fact very little difference between the two sectors. In fact both the flex and the fix price groups see a 26% rise in their weight as we move from column one to column two of Table M. Hence the variety of changes in weights for the NFE sectors in Table M probably reflects a flat objective function around the optimum. Contrary to the results of Eusepi *et al.* (2011), there is no evidence that the optimal sectoral rule is trying to target sectors with more fixed prices and put less weight on those with flexible prices. The reason for this is possibly that whilst the proportions of price-durations in the one to three quarter range are much larger in the flexible sector, there is still a fat tail of long durations. This can be seen from Chart 3, and is even more evident if we aggregate the sectors into fixed and flexible as in Chart 4. This illustrates the importance of modelling the entire distribution of price stickiness in each sector rather than using a single measure of price stickiness for each sector as in Eusepi *et al.*

Chart 4: Distributions for fixed and flexible sectors



Hence, we believe that the differences between the simple Taylor rule, the NFE-based rule and the sectoral rule have mainly to do with the two sectors: *utilities* and *petrol*, which account for 8.7% of the CPI weight. The sectoral optimum involves putting much less weight on Petrol (indeed, slightly negative), and quite a lot more on utilities as compared to the simple rule. *Food* is little changed from the simple Taylor rule: this is in contrast to most of the NFE sectors and utilities. However, note that Food has a large CPI share, so the small increase is in line with other large sectors.

If we compare *Utilities* and *Petrol*, they both have similar production functions combining value added with gas and oil respectively, which are both prices determined internationally. The key difference between the sectors is the degree of price-flexibility in the calibration: the quarterly probability of changing price in *Petrol* is 67%, whilst in *Utilities* it is half that. Hence, in effect eliminating the weight put on *Petrol* in the sectoral rule means reducing the weight on the CPI component that most directly represents the direct and immediate effect of the exchange rate. Hence the optimal sectoral rule reduces reactions to immediate and short lived changes in the exchange rate.

Food prices are assumed to react sluggishly to world prices (a probability 0.5 of prices changing per quarter), as are non-food and energy imports (probability 0.4). Hence, like *Utilities, Food* captures more persistent exchange rate effects. It is these more persistent effects that will show up in *NFE*, since *NFE* combines value added with imports and energy. The reason that a rule based on NFE inflation does worse is that it does not allow the information available in the behaviour of *Food* and *Utilities* to be used: whilst they do react to the foreign prices, the reaction is muted but nevertheless allows the monetary authorities to react to persistent exchange rate changes that will show through in NFE sector inflation. The increase in weight of the two sectors combined is 12% from 0.25 under CPI targeting to 0.29 with sectoral weights.

7 Conclusions

In this paper, we have developed an open-economy model which allows us to sensibly explore the question of how sectoral shocks fit into the inflation story for the United Kingdom 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.

We first examined the data on sectoral inflation rates and found that the sectoral rates have much bigger variances than aggregate CPI inflation, which can be seen as a pooled variance. When we broke down the raw sectoral inflation shocks into sector-specific and aggregate components, we found that the persistence we observe in aggregate inflation comes mainly from the effect of the aggregate factors with sectoral shocks being white noise.

Using our model, we analysed optimal simple monetary policy rules, where the central bank could respond to aggregate inflation, sectoral inflation rates, NFE inflation (CPI excluding the volatile elements of food and energy) and DGI. We found that the optimal rule in which interest rates respond to sectoral inflation rates only leads to a small – in terms of consumption – improvement over a rule in which interest rates only respond to aggregate inflation. This gain comes from partially looking through movements in aggregate inflation driven by movements in petrol price inflation, which is volatile and tends not to reflect underlying inflationary pressure. This fact implied that the rules based on NFE inflation and DGI also performed slightly better than a rule based on aggregate CPI inflation. Although these results were basically in line with those of the previous literature – specifically Aoki (2001) and Eusepi *et al.* (2011) – our paper added to this literature by showing that those results went through in a more realistic – and so useful for actual policy makers – setting, something that was not guaranteed ahead of time. In addition, this added realism enabled us to show that the relative weights on different NFE sectors were not necessarily tied to the mean duration of prices in those sectors – as in Eusepi *et al.* – but reflected the entire distribution of price stickiness across firms in those sectors.

References

Aoki, K (2001), 'Optimal monetary policy responses to relative price changes', *Journal of Monetary Economics*, Vol. 48, pages 55-80.

Bank of England (2011), *Inflation Report*, February.

Bernanke, B, Boivin, J and Eliasz, P S (2005), 'Measuring the effects of monetary policy: a factor-augmented vector autoregressive (FAVAR) approach', *Quarterly Journal of Economics*, Vol. 120, pages 387-422.

Bils, M, Klenow, P J and Malin, B A (2012), 'Reset price inflation and the impact of monetary policy shocks', *American Economic Review*, Vol. 102, pages 2,798-825.

Boivin, J, Giannoni, M P and Mihov, I (2009), 'Sticky prices and monetary policy: Evidence from disaggregated US data', *American Economic Review*, Vol. 99, pages 350-84.

Bunn, P and Ellis C, (2012), 'Examining the behaviour of individual UK consumer prices', *Economic Journal*, Vol. 122, pages F35–55.

Calvo, G A (1983), 'Staggered prices in a utility-maximizing framework', *Journal of Monetary Economics*, Vol. 12, pages 383-98.

Catao, L A V and Chang, R (2010), 'World food prices and monetary policy', National Bureau of Economic Research *Working Paper* No. 16,563.

Dale, S (2011), 'MPC in the dock', speech given at the National Asset-Liability Management Global Conference, London, 24 March, 2011; available at http://www.bankofengland.co.uk/publications/Documents/speeches/2011/speech485.pdf.

De Graeve, F and Walentin I (2011), 'Stylized (arte) facts on sectoral inflation', Sveriges Riksbank *Working Paper* No. 254.

Dixon, H (2012), 'A unified framework for using micro-data to compare dynamic wage and price setting models', CESifo *Working Paper* No. 3,093.

Dixon, H and Kara, E (2010), 'Can we explain inflation persistence in a way that is consistent with the microevidence on nominal rigidity?,' *Journal of Money, Credit and Banking*, Vol. 42, pages 151-70.

Dixon, H and Le Bihan, H (2012), 'Generalized Taylor and generalised Calvo price and wage-setting: Micro evidence with macro implications', *Economic Journal*, Vol. 122, pages 532-44.

Dixon, H and Tian, X (2012), 'What we can learn about the behaviour of firms from the average monthly frequency of price changes: An application to the UK CPI data', Cardiff University *mimeo*.

Ellis, C, Mumtaz, H and Zabczyk, P (2009), 'What lies beneath: what can disaggregated data tell us about the behaviour of prices?', Bank of England *Working Paper* No. 364.

Erceg, C J, Henderson, D W and Levin, A T (2000), 'Optimal monetary policy with staggered wage and price contracts', *Journal of Monetary Economics*, Vol. 46, pages 281-313.

Eusepi, S, Hobijn, B and Tambalotti, A (2011), 'CONDI: A cost-of-nominal-distortions index', *American Economic Journal: Macroeconomics*, Vol. 3, pages 53-91.

Gábriel, P and Reiff, A (2010), 'Price setting in Hungary-a store-level analysis', *Managerial and Decision Economics*, Vol. 31, pages 161-76.

Harrison, R, Thomas, R and de Weymarn, I (2011), 'The impact of permanent energy price shocks on the UK economy', Bank of England *Working Paper* No. 433.

Kara, E (2010), 'Optimal monetary policy in the generalized Taylor economy', *Journal of Economic Dynamics and Control*, Vol. 34, pages 2,023-37.

Mackowiak, B, Moench, E, and Wiederholt, M (2009), 'Sectoral price data and models of price setting', *Journal of Monetary Economics*, Vol. 56, pages 578-99.

Mankikar, A and Paisley, J (2002), 'What do measures of core inflation really tell us?', Bank of England *Quarterly Bulletin*, Vol. 42, pages 373-83.

Millard, S P (2011), 'An estimated DSGE model of energy, costs and inflation in the United Kingdom', Bank of England *Working Paper* No. 432.

Oulton, N and Srinivasan, S (2003), 'Capital stocks, capital services and depreciation: An integrated framework', Bank of England *Working Paper* No. 192.

Rotemberg, J J and Woodford, M (1998), 'An optimization-based econometric framework for the evaluation of monetary policy', National Bureau of Economic Research *Technical Working Paper* No. 233.

Taylor, J B (1993), 'Discretion versus policy rules in practice', *Carnegie-Rochester Conference Series on Public Policy*, Vol. 39, pages 195-214.

Taylor, J B and Williams, J C (2011), 'Simple and robust rules for monetary policy', *Handbook of Monetary Economics*, Vol. 3B, pages 829-59.

Appendix 1: Derivation of the model and complete equation listing

In this appendix we derive and list all the equations of the model.

Households

The representative household consumes four final goods and supplies labour to the firms. It is 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 representative household's problem is then to maximise utility subject to their budget constraint. Mathematically:

Maximise $E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{c_t^{1-\sigma_c}}{1-\sigma_c} + \frac{\kappa_h}{1+\sigma_h} h_t^{1+\sigma_h} \right)$

Subject to

$$b_t + \frac{b_{f,t}}{s_t} + k_{j,t} = \frac{1+i_{t-1}}{1+\pi_t} b_{t-1} + \frac{1+i_{f,t-1}}{1+\pi_t}\frac{b_{f,t-1}}{s_t} + \left(1-\delta-\frac{\chi_z}{1+\phi_z}\left(z_t^{1+\phi_z}-1\right)\right)k_{j,t-1}$$
$$-\frac{\chi_k}{2k_{t-1}}\left(k_{j,t}-\left(\frac{k_{t-1}}{k_{t-2}}\right)^{\varepsilon_k} k_{j,t-1}\right)^2 + w_t h_h + w_{k,t} z_t k_{t-1} - p_t c_t - \frac{\chi_{bf}}{2}\left(\frac{b_{f,t}}{s_t}\right)^2$$
$$+ p_{o,t}\overline{O} + p_{g,t}\overline{G} + \Pi_t + T_t$$

Where *c* denotes consumption, *h* denotes total hours worked, *b* denotes (end-of-period) holdings of domestic government bonds (expressed in units of NFE goods, which we use as the numeraire), b_f denotes (end-of-period) holdings of foreign government bonds (expressed in units of NFE goods), k_j denotes the representative household's (end-of-period) capital stock, and *k* is the economy-wide capital stock (in equilibrium, equal to k_j), *i* is the domestic nominal interest rate, π is the rate of inflation of NFE goods, i_f is the foreign nominal interest rate, *z* is capital utilisation (whose steady-state value is normalised to unity), *w* is the real wage (in units of NFE), w_k is the real rental paid on capital, *p* is the consumer price index (price of aggregate consumption relative to the price of NFE), p_o is the relative (to NFE) price of oil, p_g is the relative (to NFE) price of gas, $\overline{O}$ is the economy's fixed endowment of oil, $\overline{G}$ is the economy's fixed endowment of gas, Π is total corporate sector profits (returned to the households lump sum) and *T* is a lump sum transfer from the government to the household sector.

The first order conditions determine the household's choice of aggregate consumption, labour supply, capital accumulation and utilisation:

$$c_t^{-\sigma_c} = \beta(1+i_t)E_t \frac{c_{t+1}^{-\sigma_c}}{(1+\pi_{c,t+1})} \quad \textbf{(A1)}$$

$$w_t = \kappa_h c_t^{\sigma_c} h_t^{\sigma_h} \quad \textbf{(A2)}$$

$$E_t \frac{1+i_t}{1+\pi_{t+1}}\left(1+\chi_k\left(\frac{k_t}{k_{t-1}}-\left(\frac{k_{t-1}}{k_{t-2}}\right)^{\varepsilon_k}\right)\right) = 1-\delta-\frac{\chi_z}{1+\phi_z}\left(z_t^{1+\phi_z}-1\right)+\chi_k\left(\frac{k_{t+1}}{k_t}-\left(\frac{k_t}{k_{t-1}}\right)^{\varepsilon_k}\right)\left(\frac{k_t}{k_{t-1}}\right)^{\varepsilon_k} + w_{k,t+1}z_{t+1} \quad \textbf{(A3)}$$

$$\chi_z z_t^{\phi_z} = w_{k,t} \quad \textbf{(A4)}$$

Finally, we also obtain the modified uncovered interest parity condition:

$$E\frac{1}{s_t}+\frac{\chi_{bf}b_{f,t}}{s_t^2}=\frac{1+i_{f,t}}{1+i_t}E_t\frac{1}{s_{t+1}} \quad \textbf{(A5)}$$

The portfolio adjustment cost term, $\frac{\chi_{bf}b_{f,t}}{s_t^2}$, ensures that the net foreign asset position of the economy is pinned down, thus closing the open-economy model by ensuring that the model has a steady-state solution (in this case with zero net foreign assets). Further, 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 the lump-sum transfer, *T*, on consumers.

Aggregate consumption 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. The consumption aggregator is given by:

$$c_t=\kappa_c\left(\psi_f c_{f,t}^{1-\frac{1}{\sigma_e}}+\psi_n c_{n,t}^{1-\frac{1}{\sigma_e}}+\left(1-\psi_f-\psi_n\right)c_{e,t}^{1-\frac{1}{\sigma_e}}\right)^{\frac{\sigma_e}{\sigma_e-1}} \quad \textbf{(A6)}$$

,t

Where c_e denotes consumption of 'energy':

$$c_{e,t}=\kappa_e\left(\psi_p c_{p,t}^{1-\frac{1}{\sigma_p}}+\left(1-\psi_p\right)c_{u,t}^{1-\frac{1}{\sigma_p}}\right)^{\frac{\sigma_p}{\sigma_p-1}} \quad \textbf{(A7)}$$

The numeraire is NFE. We define the consumer price index as the minimum level of expenditure required to obtain one unit of the consumption good. That is, we solve the problem:

Minimise $\quad p_t c_t = c_{n,t}+p_{p,t}c_{p,t}+p_{u,t}c_{u,t}+p_{f,t}c_{f,t}$ **(A8)**

Subject to equations **(A6)** and **(A7)**.

The first-order conditions for this problem imply the following inverse demand functions for food, utilities and petrol:

$$\frac{\kappa_c^{\frac{1-\sigma_c}{\sigma_c}}}{\psi_f}\left(\frac{c_t}{c_{f,t}}\right)^{-\frac{1}{\sigma_e}}=\frac{p_{c,t}}{p_{f,t}} \quad \textbf{(A9)}$$

$$\frac{\kappa_c^{\frac{1-\sigma_c}{\sigma_c}}}{1-\psi_f-\psi_n}\left(\frac{c_t}{c_{e,t}}\right)^{-\frac{1}{\sigma_e}}\frac{\kappa_e^{\frac{1-\sigma_c}{\sigma_c}}}{1-\psi_p}\left(\frac{c_{e,t}}{c_{u,t}}\right)^{-\frac{1}{\sigma_p}}=\frac{p_{c,t}}{p_{u,t}} \quad \textbf{(A10)}$$

and

$$\frac{1-\psi_p}{\psi_p}\left(\frac{c_{u,t}}{c_{p,t}}\right)^{-\frac{1}{\sigma_p}} = \frac{p_{u,t}}{p_{p,t}} \quad \textbf{(A11)}$$

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

Non food and energy producing firms

The representative NFE producing firm, firm *j*, say, is assumed to have the following production function for output *q*:

$$q_{j,t} = \kappa_q\left(\left((1-\alpha_q)(1-\phi_q)B_{j,t}\right)^{\frac{\sigma_q-1}{\sigma_q}} + \alpha_q\left(\phi_q e_{j,t}\right)^{\frac{\sigma_q-1}{\sigma_q}}\right)^{\frac{\sigma_q}{\sigma_q-1}} \quad \textbf{(A12)}$$

Firm *j*'s output is produced from two intermediates: energy e_j and a bundle of intermediate output, B_j, produced from value-added V_j, and intermediate imported goods, M_j according to the simple Cobb-Douglas function:

$$B_{j,t} = V_{j,t}^{1-\alpha_B} M_{j,t}^{\alpha_B} \quad \textbf{(A13)}$$

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

$$e_{j,t} = \min\left(\frac{I_{j,p,t}}{\psi_n}, \frac{I_{j,u,t}}{1-\psi_n}\right) \quad \textbf{(A14)}$$

where $I_{j,p}$ is the input of petrol and $I_{j,u}$ is input of utilities.

On the assumption that prices are flexible, the cost minimisation problem for the representative NFE firm, firm *j*, will be:

Minimise $\quad p_{vc,t}V_{j,t} + p_{m,t}M_{j,t} + p_{p,t}I_{j,p,t} + p_{u,t}I_{j,u,t}$

Subject to $\quad q_{j,t} = \kappa_q e^{-\varepsilon_{j,t}}\left(\left((1-\alpha_q)(1-\phi_q)V_{j,t}^{1-\alpha_B}M_{j,t}^{\alpha_B}\right)^{\frac{\sigma_q-1}{\sigma_q}} + \alpha_q\left(\phi_q \min\left(\frac{I_{j,p,t}}{\psi_n}, \frac{I_{j,u,t}}{1-\psi_n}\right)\right)^{\frac{\sigma_q-1}{\sigma_q}}\right)^{\frac{\sigma_q}{\sigma_q-1}}$

Solving this problem, and integrating over all NFE firms, implies the following demand curves for value-added, imports and energy:

$$p_{vc,t} = \mu_t(1-\alpha_q)(1-\alpha_B)\left((1-\phi_q)\kappa_q\right)^{\frac{\sigma_q-1}{\sigma_q}}\left(\frac{q_t}{B_t}\right)^{\frac{1}{\sigma_q}}\frac{B_t}{V_{n,t}} \quad \textbf{(A15)}$$

$$p_{m,t} = \mu_t (1-\alpha_q) \alpha_B ((1-\phi_q)\kappa_q)^{\frac{\sigma_q - 1}{\sigma_q}} \left(\frac{q_t}{B_t} \right)^{\frac{1}{\sigma_q}} \frac{B_t}{M_{n,t}} \qquad \textbf{(A16)}$$

$$\psi_n p_{p,t} + (1-\psi_n) p_{u,t} = \mu_t \alpha_q (\phi_q \kappa_q)^{\frac{\sigma_q - 1}{\sigma_q}} \left(\frac{q_t}{e_t} \right)^{\frac{1}{\sigma_q}} \qquad \textbf{(A17)}$$

where μ is real marginal cost, p_{vc} is the 'competitive' price of value-added (ie, the marginal cost of producing it) and p_m is the price of imported intermediates. Notice that since the production of NFE has constant returns to scale, average and marginal cost are equal.

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 model, which can be thought of as 'duration' sectors superimposed on the CPI sectors within the NFE.

As stated in the main text, we set up each of the COICOP sectors constituting the NFE sector as in the GT model of Dixon and Kara (2010). Firms in each of the twelve NFE COICOP sectors are divided up into K 'duration' subsectors, where sub-subsector $k= 1, \dots K,$ denotes those firms whose prices change every k periods. We first note that the optimal flexible price in any sub-subsector will simply be a mark-up over marginal cost in that sub-subsector, where we assume that this mark-up is the same across the entire NFE sector and reflects monopolistic competition in that sector. Following, Rotemberg and Woodford (1998), we assume that the government imposes a lump-sum tax on NFE firms that fully offsets the welfare loss resulting from the monopoly power of firms in this sector.

We further 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 $\mu_t e^{\varepsilon_k}$ where ε_k is the *relative* productivity shock in COICOP subsector k. Given our empirical 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 productivity 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* productivity 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* productivity shock and then allowed for 12 sector-specific productivity shocks that added up to zero (in effect 11 independent shocks). These two approaches are of course linked: we can think of the shocks ε_k in terms of the mean productivity 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, the *NFE* as a whole will experience a technological improvement if the shocks across the COICOP sectors tend to be more positive than negative.

So, consider the profit maximisation problem for a firm that can reset its price in GTE subsector k of COICOP sector z. We can write this problem as:

Maximise $q_{z,k,t}\left(x_{z,k,t}-\mu_t e^{\varepsilon_{z,t}}\right)+E_t\sum_{i=1}^{k-1}\frac{1}{\prod_{j=1}^{i}\left(1+i_{t+j-1}\right)}q_{z,k,t+i}\left(\frac{x_{z,k,t}}{\prod_{j=1}^{i}1+\pi_{t+j}}-\mu_{t+i}e^{\varepsilon_{z,t+i}}\right)$

Subject to $q_{z,k,t+i}=x_{z,k,t}^{-\eta}q_{t+i}$ for $i=0\ldots k-1$

Where $x_{z,k}$ is the firm's reset price relative to the aggregate price of NFE. Once set, the firm's price stays fixed for *k* periods (by definition) and so its price relative to the aggregate NFE price will be falling by the rate of NFE inflation, π.

The first-order condition for this problem implies:

$$q_t x_{z,k,t}^{-\eta}(\eta-1)\left(x_{z,k,t}-\frac{\eta}{\eta-1}\mu_t e^{\varepsilon_{z,t}}\right)$$
$$+E_t\sum_{i=1}^{k-1}\prod_{j=1}^{i}\frac{1}{1+i_{t+j-1}}q_{t+i}x_{z,k,t}^{-\eta}(\eta-1)\left(x_{z,k,t}-\frac{\eta}{\eta-1}\mu_{t+i}e^{\varepsilon_{z,t+i}}\prod_{j=1}^{i}\left(1+\pi_{t+j}\right)\right)=0 \quad \textbf{(A18)}$$

This equation implicitly defines the optimal reset price at time *t*. The optimal reset price equates the expected net present values of marginal cost with marginal revenue over the duration of the contract. The last term in brackets is the period *t+i* marginal revenue and marginal cost measured in period *t* prices. The weights vary with period specific outputs and elasticity; if these were constant, you could divide through the sum and they would drop out.

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

$$p_{z,k,t}=\left(\frac{1}{k}\left(x_{z,k,t}^{1-\eta}+\sum_{j=1}^{k-1}\frac{1}{\prod_{i=0}^{j-1}\left(1+\pi_{t-i}\right)}x_{z,k,t-j}^{1-\eta}\right)\right)^{\frac{1}{1-\eta}} \quad \textbf{(A19)}$$

And the average price prevailing across sector *z* will be given by:

$$p_{z,t}=\left(\sum_{k=1}^{K}\gamma_{z,k}p_{z,k,t}^{1-\eta}\right)^{\frac{1}{1-\eta}} \quad \textbf{(A20)}$$

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

$$1=\left(\sum_{z=1}^{12}\gamma_z p_{z,t}^{1-\eta}\right)^{\frac{1}{1-\eta}} \quad \textbf{(A21)}$$

Value-added sector

Perfectly-competitive 'value-added' producers use labour and capital to produce value-added, V, according to the production function:

$$V_t = e^{\varepsilon_{a,t}} \left((1-\alpha_v) h_t^{\frac{\sigma_v - 1}{\sigma_v}} + \alpha_v (z_t k_{t-1})^{\frac{\sigma_v - 1}{\sigma_v}} \right)^{\frac{\sigma_v}{\sigma_v - 1}} \quad \textbf{(A22)}$$

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; recall that capital utilisation is decided by the consumers so firms can only choose the total capital input, zk_{-1}. The representative firm's problem is to choose capital and labour input so as to maximise its profit subject to this production function, where its profit will be given by:

$$p_{vc,t} V_t - w_t h_t - w_{k,t} z_t k_{t-1}$$

The first-order conditions for this problem imply the following demand curves for capital and labour:

$$\frac{w_t}{p_{vc,t}} = e^{\left(1-\frac{1}{\sigma_v}\right)\varepsilon_{a,t}} \left(\frac{V_t}{h_t} \right)^{\frac{1}{\sigma_v}} \quad \textbf{(A23)}$$

$$\frac{w_{k,t}}{p_{vc,t}} = e^{\left(1-\frac{1}{\sigma_v}\right)\varepsilon_{a,t}} \left(\frac{V_t}{z_t k_{t-1}} \right)^{\frac{1}{\sigma_v}} \quad \textbf{(A24)}$$

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:

$$q_{p,t} = \min\left(\frac{I_{o,t}}{1-\psi_{qp}}, \frac{V_{p,t}}{\psi_{qp}} \right)$$

Cost minimisation implies:

$$I_{o,t} = (1-\psi_{qp}) q_{p,t} \quad \textbf{(A25)}$$

$$V_{p,t} = \psi_{qp} q_{p,t} \quad \textbf{(A26)}$$

$$\mu_{p,t} = \frac{\psi_{qp} p_{vc,t} + (1-\psi_{qp}) p_{o,t}}{p_{p,t}} \quad \textbf{(A27)}$$

Where p_o denotes the price of oil (relative to NFE) and μ_p denotes real marginal cost in this sector.

Petrol producers are assumed to operate in a monopolistically competitive market and face price rigidities a la Calvo (1983). Specifically, they are able to optimally change their price in any given quarter with probability 1-χ_p. Now, each period those producers that can change their price will set it so as to maximise their expected profit subject to their demand curves and the fact that they may not be able to change their price for a long while. The expected profit for a firm (say firm *j*) that can set its price in period *t* will be given by:

$$E_t \sum_{s=0}^{\infty} \left(\beta \chi_p\right)^s \left(\frac{p_{p,j,t}}{p_{p,t+s}} - \mu_{p,t+s} \right) y_{t+s} \left(\frac{p_{p,j,t}}{p_{p,t+s}} \right)^{-\eta} - \tau_{p,t}$$

Where $p_{p,j}$ is the price (relative to the numeraire, NFE) set by petrol producer *j* and τ_p denotes a lump-sum tax paid to the government (which offsets the distortion caused by monopolistic competition).

We assume the demand for petrol from producer *j*, $q_{p,j}$, is given by:

$$q_{p,j,t} = \left(\frac{p_{p,j,t}}{p_{p,t}} \right)^{-\eta} q_{p,t}$$

So, the first-order condition for a price-changing firm (in this case, firm *j*) will be given by:

$$E_t \sum_{s=0}^{\infty} (\beta \xi)^s \left(1 - \eta \left(1 - \mu_{t+s} \frac{P_{t+s}}{P_{j,t}} \right) \right) \frac{y_{t+s}}{P_{t+s}} \left(\frac{P_{j,t}}{P_{t+s}} \right)^{-\eta} = 0$$

The aggregate petrol price will be given by

$$p_{p,t} = p_{p,t-1}^{\chi_p} p_{p,j,t}^{1-\chi_p}$$

Taking a first-order Taylor series expansion of these two equations around a zero steady-state inflation rate gives the New Keynesian Phillips curve (NKPC) for this sector:

$$\pi_{p,t} = \beta E_t \pi_{p,t+1} + \frac{\left(1-\chi_p\right)\left(1-\beta\chi_p\right)}{\chi_p} \hat{\mu}_{p,t} \qquad \textbf{(A28)}$$

where π_p represents the inflation rate for petrol prices.

Utilities producers

Utilities producers are exactly analogous to petrol 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:

$$q_u = \min\left(I_g, V_u\right)$$

Cost minimisation implies:

$$I_{g,t} = (1-\psi_u)q_{u,t} \tag{A29}$$

$$V_{u,t} = \psi_u q_{u,t} \tag{A30}$$

$$\mu_{u,t} = \frac{\psi_u p_{vc,t} + (1-\psi_u)p_{g,t}}{p_{u,t}} \tag{A31}$$

Where p_g denotes the price of wholesale gas (relative to NFE) and μ_u denotes real marginal cost in this sector.

Firms in this sector are again assumed to be monopolistically competitive and subject to nominal rigidities in their price-setting: they are able to optimally change their price in any given quarter with probability $1-\chi_u$. Going through an analogous argument to that shown for the petrol sector, we can derive the NKPC for this sector as:

$$\pi_{u,t} = \beta E_t \pi_{u,t+1} + \frac{(1-\chi_u)(1-\beta\chi_u)}{\chi_u}\hat{\mu}_{u,t} \tag{A32}$$

where π_u represents the inflation rate for utility prices and $\hat{\mu}_u$ denotes the log-deviation from steady state of real marginal cost in this sector.

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}:

$$i_t - \left(\frac{1}{\beta}-1\right) = \theta_{rg}\left(i_{t-1} - \left(\frac{1}{\beta}-1\right)\right) + (1-\theta_{rg})(\theta_{pdot}\pi_{c,t} + \theta_y \hat{y}_{FP,t}) + \varepsilon_{i,t} \tag{A33}$$

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.

The government is assumed to buy only NFE goods and to have the same preferences across these goods as consumers. It collects lump-sum taxes from each of the firms in order to eliminate the welfare distortions resulting from monopolistic competition. Any remaining budget shortfall is met via lump-sum taxes on consumers or budget surplus returned to consumers via lump-sum transfers. We can write its budget constraint as:

$$b_t = \frac{1+i_{t-1}}{1+\pi_t}b_{t-1} + c_g e^{\varepsilon_{g,t}} + T_t - \tau_{NFE,t} - \tau_{p,t} - \tau_{u,t} - \tau_{f,t} - \tau_{m,t}$$

Where τ_{NFE}, τ_p, τ_u, τ_f, and τ_m denote lump-sum taxes levied on the NFE, petrol and utilities producers, and on the importers of food and intermediate goods, respectively, which offset the distortions caused by monopolistic competition in those sectors.

When the government's budget constraint is combined with the households' budget constraint and the definition of firms' profits, we obtain the market clearing condition for NFE output:

$$q_t = c_{n,t} + k_t - (1-\delta)k_{t-1} + \chi_z z_t + c_g e^{\varepsilon_{g,t}} + x_{n,t} \qquad \textbf{(A34)}$$

Where c_g denotes steady-state government spending, $\varepsilon_{g,t}$ is a government spending shock and x_n denotes exports of NFE goods. (We assume that the economy does not export food, petrol or utilities.)

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:

$$p_{o,t} = \frac{e^{\varepsilon_{p_o,t}}}{s_t} \qquad \textbf{(A35)}$$

$$p_{g,t} = \frac{e^{\varepsilon_{p_g,t}}}{s_t} \qquad \textbf{(A36)}$$

where ε_{p_o} is a shock to world oil prices and ε_{p_g} is a shock to world gas prices and we have normalised the steady-state world prices of oil and gas to unity.

UK food and non food and energy import prices, on the other hand, take time to adjust to purchasing power parity.[15] We assume the following NKPCs for food prices and for import prices ex food and energy:

$$\pi_{f,t} = \frac{\iota_{pf}}{1+\beta\iota_{pf}}\pi_{f,t-1} + \frac{\beta}{1+\beta\iota_{pf}}E_t\pi_{f,t+1} + \frac{(1-\xi_{pf})(1-\beta\xi_{pf})}{(1+\beta\iota_{pm})\xi_{pf}}\left(\varepsilon_{p_f} - \hat{s}_t - \hat{p}_{f,t}\right) \qquad \textbf{(A37)}$$

$$\pi_{m,t} = \frac{\iota_{pm}}{1+\beta\iota_{pm}}\pi_{m,t-1} + \frac{\beta}{1+\beta\iota_{pm}}E_t\pi_{m,t+1} + \frac{(1-\xi_{pm})(1-\beta\xi_{pm})}{(1+\beta\iota_{pm})\xi_{pm}}\left(\varepsilon_{p_{mf}} - \hat{s}_t - \hat{p}_{m,t}\right) \qquad \textbf{(A38)}$$

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.

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

$$x_{n,t} = \kappa_x x_{n,t-1}^{\psi_z}\left(s_t^{-\eta_x}\bar{x}\right)^{1-\psi_z} \qquad \textbf{(A39)}$$

Where ψ_z is captures the idea that foreign preferences exhibit a form of 'habit formation' and $\bar{x}$ denotes 'world demand' (assumed to be exogenous and constant).

[15] The underlying assumption here is that UK importers of food and imported intermediate goods excluding food, oil and gas are monopolistically competitive and face 'Calvo' frictions in their ability to set prices. Again, we follow Rotemberg and Woodford (1998) and assume that the government imposes a lump-sum tax on importers that fully offsets the distortion arising from their monopoly power.

Market clearing

We close the model with the following market-clearing conditions (in addition to equations **(A8)** and **(A34)**):

$$V_t = V_{n,t} + V_{u,t} + V_{p,t} \tag{A40}$$

$$q_{p,t} = c_{p,t} + I_{p,t} \tag{A41}$$

$$q_{u,t} = c_{u,t} + I_{u,t} \tag{A42}$$

$$\overline{O} = I_{o,t} + X_{o,t} \tag{A43}$$

$$\overline{G} = I_{g,t} + X_{g,t} \tag{A44}$$

$$\frac{b_{f,t}}{s_t} = \frac{1+i_{f,t-1}}{1+\pi_t}\frac{b_{f,t-1}}{s_t} + x_{n,t} + p_{g,t}X_{g,t} + p_{o,t}X_{o,t} - p_{m,t}M_{n,t} - p_{f,t}c_{f,t} \tag{A45}$$

Where X_O denotes exports of oil, X_G denotes exports of natural gas.

These equations complete the description of the model.

Appendix 2: The steady state

In order to calibrate the model so that it matches 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 Appendix 1:

$$1=\beta(1+i)=\beta(1+i_F) \quad \textbf{(A1), (A5)}$$

$$w=\kappa_h^{-\frac{1}{\sigma_h}}c^{\frac{1}{\sigma_c}} \quad \textbf{(A2)}$$

$$1=\beta(1-\delta+\chi_z) \quad \textbf{(A3), (A4)}$$

$$c=\kappa_c\left((1-\psi_e-\psi_f)c_n^{1-\frac{1}{\sigma_e}}+\psi_e c_e^{1-\frac{1}{\sigma_e}}+\psi_f c_f^{1-\frac{1}{\sigma_e}}\right)^{\frac{\sigma_e}{\sigma_e-1}} \quad \textbf{(A6)}$$

$$c_e=\kappa_e\left((1-\psi_p)c_u^{1-\frac{1}{\sigma_p}}+\psi_p c_p^{1-\frac{1}{\sigma_p}}\right)^{\frac{\sigma_p}{\sigma_p-1}} \quad \textbf{(A7)}$$

$$c=c_n+c_f+p_u c_u+p_p c_p \quad \textbf{(A8)}$$

$$1=\kappa_c^{\frac{\sigma_e-1}{\sigma_e}}\psi_f\left(\frac{c_f}{c}\right)^{-\frac{1}{\sigma_e}} \quad \textbf{(A9)}$$

$$p_u=\frac{\kappa_e^{\frac{\sigma_p-1}{\sigma_p}}(1-\psi_p)\left(\frac{c_u}{c_e}\right)^{-\frac{1}{\sigma_p}}}{\kappa_c^{\frac{\sigma_e-1}{\sigma_e}}\psi_e\left(\frac{c_e}{c}\right)^{-\frac{1}{\sigma_e}}} \quad \textbf{(A10)}$$

$$\frac{p_u}{p_p}=\frac{\psi_p}{(1-\psi_p)}\left(\frac{c_u}{c_p}\right)^{-\frac{1}{\sigma_p}} \quad \textbf{(A11)}$$

$$q=\kappa_q\left((1-\alpha_q)((1-\phi_q)B)^{1-\frac{1}{\sigma_q}}+\alpha_q(\phi_q e)^{1-\frac{1}{\sigma_q}}\right)^{\frac{\sigma_q}{\sigma_q-1}} \quad \textbf{(A12)}$$

$$B=V_n^{1-\alpha_B}M_n^{\alpha_B} \quad \textbf{(A13)}$$

$$e=\frac{I_p}{\psi_n}=\frac{I_u}{1-\psi_n} \quad \textbf{(A14)}$$

$$p_{vc}V_n=\mu\kappa_q^{1-\frac{1}{\sigma_q}}(1-\alpha_q)(1-\alpha_B)(1-\phi_q)^{1-\frac{1}{\sigma_q}}q^{\frac{1}{\sigma_q}}B^{1-\frac{1}{\sigma_q}} \quad \textbf{(A15)}$$

$$M_n=\mu\kappa_q^{1-\frac{1}{\sigma_q}}(1-\alpha_q)\alpha_B(1-\phi_q)^{1-\frac{1}{\sigma_q}}q^{\frac{1}{\sigma_q}}B^{1-\frac{1}{\sigma_q}} \quad \textbf{(A16)}$$

$$(\psi_n p_p+(1-\psi_n)p_u)=\mu\kappa_q^{1-\frac{1}{\sigma_q}}\alpha_q\phi_q^{1-\frac{1}{\sigma_q}}\left(\frac{q}{e}\right)^{\frac{1}{\sigma_q}} \quad \textbf{(A17)}$$

$$\mu = \frac{\eta - 1}{\eta} \quad \textbf{(A18)}$$

$$V = \left(1 - \alpha_V + \alpha_V k^{1 - \frac{1}{\sigma_v}}\right)^{\frac{\sigma_v}{\sigma_v - 1}} \quad \textbf{(A22)}$$

$$\frac{w}{p_{vc}} = (1 - \alpha_v) V^{\frac{1}{\sigma_v}} \quad \textbf{(A23)}$$

$$\frac{\chi_z}{p_{vc}} = \alpha_v \left(\frac{V}{k}\right)^{\frac{1}{\sigma_v}} \quad \textbf{(A24)}$$

$$q_p = \frac{I_o}{1 - \psi_{qp}} = \frac{V_p}{\psi_{qp}} \quad \textbf{(A25), (A26)}$$

$$(\psi_{qp} p_{vc} + 1 - \psi_{qp}) \frac{\eta_p}{\eta_p - 1} = p_p \quad \textbf{(A27), (A28)}$$

$$q_u = \frac{I_g}{1 - \psi_u} = \frac{V_u}{\psi_u} \quad \textbf{(A29), (A30)}$$

$$(\psi_u p_{vc} + 1 - \psi_u) \frac{\eta_u}{\eta_u - 1} = p_u \quad \textbf{(A31), (A32)}$$

$$q = c_n + \delta k + c_g + x_n \quad \textbf{(A34)}$$

$$x_n = \kappa_x \quad \textbf{(A39)}$$

$$V = V_n + V_u + V_p \quad \textbf{(A40)}$$

$$q_P = c_P + I_P \quad \textbf{(A41)}$$

$$q_u = c_u + I_u \quad \textbf{(A42)}$$

$$\overline{O} = I_O + X_O \quad \textbf{(A43)}$$

$$\overline{G} = I_G + X_G \quad \textbf{(A44)}$$

$$x_n + X_g + X_o = M_n + c_f \quad \textbf{(A45)}$$

Appendix 3: The relationship between the sectoral shocks of the model and the estimated sectoral inflation shocks

In section 2, we make an empirical estimate of the shocks to sectoral inflation under the assumption that the shocks are residuals once we have stripped out the macroeconomic factors. The underlying sectoral shocks give rise to these observed inflation shocks. However, the effect of the sectoral shocks on sectoral inflation will depend on the degree of nominal rigidity. If prices are perfectly flexible, the sectoral price level and hence inflation will reflect these shocks fully. If prices are completely fixed, then the sectoral shocks will not result in any inflation at all, as prices cannot vary.

With a generalised Taylor (GT) economy, there is a simple relationship between the sectoral shocks and the resultant sectoral inflation shocks. Let us consider sector *k*. Within sector *k* there are a proportion of firms γ_{k1} who have flexible prices: therefore from equation **(20)** the price they set at period *t* will fully reflect the sectoral shock $\varepsilon_{k,t}$. There is also a proportion γ_{k1} who set prices for two periods. Half of these will reset their price in period *t*. Since the expected shock in the next period is 0 ($E_t\, \varepsilon_{k,t+1}$ =0) it follows that (ignoring discounting) their current reset price will reflect only half of the sectoral shock. Similarly, for the proportion γ_{ki} who set their prices for *i* periods, only a proportion i^{-1} will reset their prices. Since they expect all future shocks to be zero, their reset price will only be affected by i^{-1} of the current sectoral shock $\varepsilon_{k,t}$. Hence the response of prices in sector *k* to the sectoral shock is given by:

$$\Delta P_k = \varepsilon_{k,t} \cdot \sum_{i=1}^{12} \frac{\gamma_{ki}}{i^2} \qquad \textbf{(A3.1)}$$

With discounting, the appropriate formula is:

$$\Delta P_k = \varepsilon_{k,t} \cdot \sum_{i=1}^{12} \frac{\gamma_{ki}}{i\left(\sum_{j=1}^{i} \beta^{j-1}\right)} \qquad \textbf{(A3.2)}$$

Since the quarterly discount rate is β =0.9925, discounting has little quantitative effect with the maximum price-spell of 12 quarters. Hence, we can see that the sectoral shocks will in general be much larger than the corresponding setoral inflation shocks. So given our estimates of the size of the inflation shocks, we will need to scale up the size of the sectoral shocks:

Using the GT coefficients for each sector, we obtain the appropriate scaling factor to two decimal places:

Non-Alc bev.	Alcohol	Cloth&F	H&W	Furn	Health	Transport	Comm	Rec&Cult	R&H	Misc	Average
5.00	2.09	2.05	7.39	1.94	4.74	8.05	2.20	2.37	4.77	3.21	4.25
5.01	2.09	2.06	7.42	1.94	4.75	8.08	2.21	2.38	4.78	3.21	

The figures in the first row are the scaling factors with discounting. The second row gives the figures without discounting: as we see, there is a very small quantitative effect if we approximate $\beta = 1$. The average scaling factor in NFE is 4.25 (using CPI weights). Education is missing from our data set. Given that we treat all price-spells as 4 quarters in *Education* this would indicate a scaling factor of 16, the value we use in our analysis.

Appendix 4: 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 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 12 quarters. In terms of the steady-state identities, not registering a price-change when the ONS stops looking at it means that implicitly the price-spell extends to 12 quarters. 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 $\tau = 1 \ldots 35$ $h(j,\tau)$ 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:

$$S(\tau) = \prod_{i=1}^{\tau-1}(1 - h(j,i)) \qquad \textbf{(A4.1)}$$

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

$$\gamma_{j\tau} = \tau . h(j,t) . S(\tau) . \bar{h} \qquad \textbf{(A4.2)}$$

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 $\gamma_j = (\gamma_{ji})_{i=1\ldots 12}$.

To illustrate the magnitude of the differences in the estimation method, we take as an example the estimated monthly weights for the COICOP categories *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*, whilst there is a short fat 'tail' sticking up at the end for the Classic method, the three methods otherwise 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.

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

Chart A4.1: Monthly hazard rates for Food and Non-Alcoholic Beverages

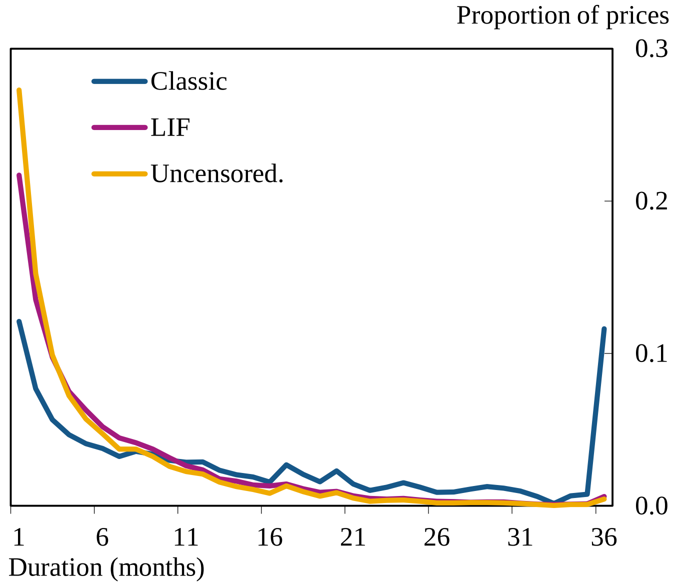


Chart A4.2: Monthly hazard rate distributions for Transport