



BANK OF ENGLAND

Working Paper No. 457

What do sticky and flexible prices tell us?

Stephen Millard and Tom O'Grady

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What do sticky and flexible prices tell us?

Stephen Millard⁽¹⁾ and Tom O'Grady⁽²⁾

Abstract

In this paper, we investigate the information content of prices in relatively sticky-price sectors versus relatively flexible-price sectors. We first present some empirical evidence that relatively flexible prices react more to deviations of output from trend than stickier prices and that sticky prices can tell us about firms' inflation expectations. We then develop a simple DSGE model with a sticky-price sector and a flexible-price sector and use this model to show that these empirical results are exactly what you would actually expect to see, given standard economic theory. Taken together, the results of this paper suggest that calculations of 'flexible-price' inflation could, potentially, be used to provide monetary policy makers with a steer on the output gap, which is notoriously hard to measure, and that calculations of 'sticky-price' inflation could, potentially, be used to provide monetary policy makers with a steer on the medium-term inflation expectations of price-setters.

Key words: Flexible-price inflation, sticky-price inflation, heterogeneous price-setting.

JEL classification: E3, D4.

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Contents

Summary	3
1 Introduction and motivation	4
2 Previous literature	5
2.1 Models of pricing, inflation persistence and the Phillips curve	5
2.2 The results of incorporating heterogeneity into macro models	5
2.3 Theoretical approaches to price heterogeneity and inflation persistence	7
3 An empirical investigation	8
4 The model	13
4.1 Consumers and demand	14
4.2 Labour market and wage-setting	15
4.3 Firms and price-setting	16
4.4 Calibration	20
5 Results	22
6 Conclusions	25
References	26

Summary

Much recent research has looked at the microdata that make up price indices such as the UK consumer price index (CPI). This work reaches three key conclusions. First, the microdata do support the underlying premise of the New Keynesian project, namely that there is a substantial amount of price stickiness. But second, underlying the headline inflation measures – which appear to be smooth and relatively autocorrelated (that is, current inflation is correlated with its own lags) – are inflation rates at the sub-component level that are much more volatile, and differ in terms of persistence. Third, and most importantly, the degree of price stickiness varies substantially across sectors. These results could potentially help us think about how inflation persistence arises. Inflation persistence may occur because the prices of different components of the CPI basket change at different speeds; some firms react to a shock immediately, whereas others take time to respond.

If that is the case, then prices that change at different speeds may also give us differing signals about the state of the economy. For example, relatively flexible prices may react more to the output gap than stickier prices: prices that change very frequently may be set on the basis of the current state of the economy. In contrast, relatively stickier prices may be more forward looking. If a firm knows that its price will last for a long time, it may think more about the future state of the economy when setting it. One implication is that sticky prices could tell us about firms' inflation expectations. Another is that we might want to look to flexible prices to see the impact of the output gap on inflation. And finally, the sticky component of inflation might be more useful than the aggregate for forecasting medium-run inflation, given that it drives persistence. This paper assesses these three claims against empirical evidence, and looks at how they hold up in the context of a formal model.

The paper first presents some empirical evidence that relatively flexible prices react more to deviations of output from trend than stickier prices, suggesting that prices that change very frequently are set on the basis of the current state of the economy. Some further evidence suggests that sticky prices contain information about firms' inflation expectations and that sticky-price inflation may be useful in forecasting aggregate inflation two years out. These empirical results are then investigated further in the context of a dynamic stochastic general equilibrium model (which takes into account interactions between forward-looking optimising agents' choices in an economy subject to random shocks) containing a sticky-price sector and a flexible-price sector. Results generated by this model suggest that you would expect flexible-price inflation to be more strongly related to the current output gap and sticky-price inflation to medium-term inflation and inflation expectations, given standard economic theory.

Taken together, the results of this paper suggest that calculations of 'flexible-price' inflation could, potentially, be used to provide monetary policy makers with a steer on the current state of the economy, in particular, the current output gap, which is notoriously hard to measure. In addition, calculations of 'sticky-price' inflation could, potentially, be used to provide monetary policy makers with a steer on the medium-term inflation expectations of price-setters within the economy, again something about which it is hard to obtain any direct evidence.

1 Introduction and motivation

Much recent research has looked at the microdata that make up price indices such as the UK CPI. This work reaches three key conclusions. First, the microdata do support the underlying premise of the New Keynesian project, namely that there is a substantial amount of price stickiness. But second, underlying the headline inflation measures – which appear to be smooth and relatively autocorrelated – are inflation rates at the sub-component level that are much more volatile, and differ in terms of persistence. Third, and most importantly, the degree of price stickiness varies substantially across sectors. For instance, Greenslade and Parker (2010) found that although the median UK firm reviews its price twice a year, there are notable differences between sectors. In particular the distribution of responses was bimodal, with many firms changing their prices at least monthly on average, while many other firms changed their price only once a year. This marked heterogeneity also appears in the ONS data underlying the construction of the producer and consumer price indices. (See Bunn and Ellis (2010) and (2011).)

These results could potentially help us think about how inflation persistence arises. Standard New Keynesian Phillips Curves cannot account for inflation persistence without relatively *ad hoc* adjustments, such as introducing lags of inflation. In reality, inflation persistence may occur because the prices of different components of the CPI basket change at different speeds; some firms react to a shock immediately, whereas others take time to respond.

Importantly, as argued in Bryan and Meyer (2010), prices that change at different speeds may also give us differing signals about the state of the economy. For example, relatively flexible prices may react more to the output gap than stickier prices: prices that change very frequently may be set on the basis of the current state of the economy. On the other hand, stickier prices may be more forward looking. If a firm knows that its price will last for a long time, it may think more about the future state of the economy when setting it. One implication is that sticky prices could tell us about firms' inflation expectations. Another is that we might want to look to flexible prices to see the impact of the output gap on inflation. And finally, as argued by Bryan and Meyer, the sticky component of inflation might be more useful than the aggregate for forecasting medium-run inflation, given that it drives persistence.

The contribution of this paper is to assess these three claims against empirical evidence, and to look at how they hold up in the context of a formal model. Previous papers, such as Kara (2009) and Dixon and Kara (2007), have shown that incorporating findings from micro price data into macroeconomic models has important theoretical implications for monetary policy. Here, we extend this work by demonstrating how these models can be used in a practical way to inform policymaking.

The structure of the paper is as follows. In the next section, we review the recent literature discussing heterogeneity in price-setting. Section 3 conducts a simple empirical investigation of the different properties of inflation in flexible-price sectors and sticky-price sectors, using UK data. Section 4 develops a formal two-sector model of the economy that we can use to analyse

whether theory would predict these different properties. Section 5 presents and discusses the results from our model and Section 6 concludes.

2 Previous literature

The key question for this paper is whether the fact that price stickiness differs across sectors within the economy matters, or not. The literature we discuss below attempts to get at this question. We begin by setting up the types of issues discussed in this literature. We go on to discuss two strands of this literature, starting with papers that look at embedding the results from the microdata in macroeconomic models, and finishing with papers that look in a more theoretical way at how persistent we might expect inflation to be once we incorporate these findings.

2.1 *Models of pricing, inflation persistence and the Phillips curve*

New Keynesian Phillips Curves (NKPCs) are typically based on Taylor (1980), where all firms have overlapping contracts of the same length, or Calvo (1983), where all firms have an equal probability of changing price in a given period. While these modelling assumptions have proved useful, they are problematic for two reasons.

First, they lack microfoundations, given that the microdata show systematic differences across sectors in the frequency of price changes. It is important to ask whether the assumption of a ‘representative firm’ is innocuous, or whether it changes the conclusions of these models. And second, standard NKPCs generate much less inflation persistence than we observe in the data. One standard ‘fix’ for this issue is just to include lags of inflation in the NKPC, which is usually done by allowing firms that do not optimally reset their prices to index them to inflation. But as emphasised by Dixon and Kara (2010), this implies that all prices change in *every* period, which is entirely inconsistent with the microdata.

So can we do better? And what are the implications of models with more realistic microfoundations?

2.2 *The results of incorporating heterogeneity into macro models*

Dixon and Kara (2007) develop the ‘Generalised Taylor Economy’ (GTE), in which there are sector-specific contract lengths. Within each sector defined by a contract length, contracts overlap. They use a small macro model to generate impulse responses, and show that the GTE exhibits markedly stronger persistence in inflation than the standard set-ups, for a given degree of average price stickiness. This result is found too by Carvalho and Schwartzman (2008) in a continuous time context, and by Sheedy (2010), who shows that such a model is very similar to one that contains lagged inflation terms. Dixon (2010) also develops the idea of a ‘Generalised Calvo Model’ (GC), where the probability of resetting the price is dependent on the age of the price, and the ‘Multiple Calvo Model’ (MC), which has sector-specific reset probabilities.

Both the GC and MC models can be calibrated to micro price data. Typically this data consists of a *hazard function* (the probability of a price change as a function of time) and/or data on the proportion of firms changing prices per month. It is clear how one could calibrate a GC model from this data. But Dixon also demonstrates formally how to derive the distribution of price durations from this data, so that the same data can be used to calibrate a GTE. In which case, it is clear that the GTE and GC are just two sides of the same coin: any steady state distribution of price spells corresponds to exactly one GTE and one GC. So what are the implications of these models?

Dixon (2010) concludes that the choice of microfoundation does indeed matter. Based on the UK data from Bunn and Ellis (2011), he generates impulse responses in the GTE, GC and MC set-ups to a one-off shock in the money supply. The GTE has a bigger output response and a smaller but more persistent inflation response, especially if the shock is auto-correlated. The GTE is also the only set-up where the response of inflation has a hump shape, which is what we typically observe in the macrodata. Dixon and Le Bihan (2010) go further by embedding versions of the GTE and GC set-ups for both prices and wages – calibrated on French micro price and wage data – into the standard macro model of Smets and Wouters (2003). They obtain the same result, *viz.* the GTE set-up implies a hump-shaped response of inflation to a monetary policy shock whereas the GC set-up does not. Mash (2004) and Yao (2009) both report similar results using similar models.

Why is this? Dixon and Kara (2007) suggest that firms in the GTE reset their prices more slowly, so they are likely to be more ‘myopic’ in their price-setting behaviour. This is because they *know* how long their price spell is going to last. In the GC economy on the other hand, firms may need to be more forward looking in their price-setting behaviour, as they do not know how long the price may need to last for.

This is interesting, as it suggests that the choice of how we model price changes is intimately linked to the behaviour of firms: how forward looking do we think they are? Some recent work from the Atlanta and Cleveland Feds – Bryan and Meyer (2010) – suggests that firms in some sectors are more forward looking than others. Taking as given the results of Bilal and Klenow (2004) – that some firms change their prices frequently whereas others change them only infrequently – they use the same US micro price data to show that inflation persistence may well be driven by ‘sticky-price’ firms, who change prices infrequently and must therefore take more account of the future state of the economy when setting their prices. The price is going to last a long time, so they might place a higher premium on thinking about the future. Note that this is a little different to the Dixon (2010) argument, where companies changing prices *more* often may be more forward looking. But both papers suggest ways in which the micro price data might also help us think about the links between inflation and firms’ inflation expectations.

The bottom line is that if you are going to microfound macro models then you must take seriously heterogeneity across firms. And it *is* possible to produce models which are microfounded in line with the price microdata, which fit the macrodata better than models with more *ad hoc* assumptions on pricing, generating inflation persistence, and which might help us to think about inflation expectations.

2.3 *Theoretical approaches to price heterogeneity and inflation persistence*

Some papers, rather than going as far as embedding the microdata in an explicit pricing model, look in a more general (and often more explicitly theoretical) way at how persistent we might expect inflation to be when we incorporate heterogeneity. These papers do not always reach the same conclusions as Dixon and Kara (2007), and differences are often due to exactly how the microfoundations are incorporated into the models.

One key paper in this strand is Sheedy (2007), which argues that heterogeneity in price stickiness leads to *negative* intrinsic persistence in inflation and so, when combined with persistent shocks, *reduces* the persistence in the response of inflation to such shocks. The logic is that those firms responding to shocks are precisely those who reset their prices most frequently and so can reverse their responses most quickly once the shock has gone.

But this theory is inconsistent with the evidence shown in Altissimo *et al* (2009), who estimated a dynamic factor model for 404 sub-indices of euro-area CPI, decomposing the dynamics of these sub-indices into a common ('macroeconomic') shock and sector-specific idiosyncratic shocks. They found that one common factor explained about one third of the variance of the disaggregate indices and was also the key driver of aggregate dynamics. Crucially, the speed of propagation of this common shock varied across sectors, with some very quick, and others (especially services) rather slow. The authors then showed that this heterogeneous propagation is what accounts for the smoothness and persistence of aggregate inflation, with sectors where the propagation of shocks is slow driving persistence. Along similar lines, Boivin *et al* (2009) and Mackowiak *et al* (2009) find that within a particular sector, prices respond much faster to sector-specific shocks compared with macro shocks, and that prices in more 'flexible' sectors respond more quickly to macro shocks. So the weight of evidence suggests that it *is* macro shocks that drive the persistence of aggregate inflation.

Perhaps more promisingly, Sheedy (2010) presents a model in which 'newer' prices – ie, the prices of those goods whose price was reset relatively recently – are stickier than 'older prices', and shows that this gives intrinsic inflation persistence. In this case, once a shock has dissipated, firms with stickier prices will still be adjusting to the shock, while others will already have done so. Carvalho (2006) suggests the same thing: those sectors with more sticky prices are the main drivers of movements in aggregate inflation. A key thing to take from both papers is that intrinsic persistence is linked to the probability that those prices set a long time ago are likely to change soon relative to the probability that those prices set recently are likely to change soon, ie, the shape of the hazard function. But there is, in fact, considerable debate over the shape of the hazard function. In which case, the 'macro' results that one obtains may well depend on what the 'micro' story actually is.

Another paper that attempts to reconcile the high degree of inflation persistence at the macro level with the low degree of persistence at the micro level is Cagliarini *et al* (2010). As is the case in Dixon (2010), Cagliarini *et al* consider a model in which different sectors have different production functions and different degrees of price stickiness. In addition, they have

‘roundabout’ production: each intermediate producer uses intermediate goods produced by all the other intermediate producers. What is interesting is that they find the responses of output and inflation to preference, technology and monetary policy shocks to be more or less identical between their microfounded model and the standard Calvo (1983) model plus indexation.

In light of their result, it is worth noting briefly that even if correctly microfounded models have the same aggregate implications as models founded on Calvo pricing with indexation, monetary policy makers may still want to consider using fully microfounded models. Kara (2009) shows that policies that are optimal from the perspective of standard models that are inconsistent with the microdata – such as the Calvo model with indexation (as laid out in, eg, Christiano *et al* (2005)) or the sticky information model of Mankiw and Reis (2002) – can lead to large welfare losses in an economy with staggered pricing and heterogeneity in the duration of price spells, such as laid out in Dixon and Kara (2010). And this is the case despite the fact that there may be no material difference between the predictions of models for inflation persistence. In other words, Kara finds that policy conclusions are significantly affected by whether inflation persistence arises in a manner consistent with the microdata or not. The intuition for Kara’s result is that firms that set prices less regularly will tend to make larger, discrete changes in prices. These larger price jumps require larger movements in the output gap to dampen them, so that a monetary policy that strongly reacts against inflation may be more costly than in a world where prices adjust smoothly and quickly.

3 An empirical investigation

In this section, we develop measures of sticky and flexible prices for the United Kingdom, and demonstrate the information that these can convey for monetary policy making.

Bryan and Meyer (2010) conclude that ‘some prices are more forward looking than others’. In particular, they propose that firms who change their prices less frequently are likely to be more forward looking, so that the price-setting behaviour of such firms could tell us something about their inflation expectations. The idea is that retailers who change their prices monthly or even weekly may be worried only about the *current* state of the economy when they set their prices, such as prevailing demand conditions, given that their prices could last as little as a few weeks.¹ But firms who set their prices for many months or even a year ahead might take more account of the *future* state of the economy when setting prices. The best price to set will depend on the range of price and demand conditions that are expected during the period in which prices are expected to remain unchanged. Hence we might expect firms whose prices are reset infrequently to raise prices now, if they believe prices will rise in the future, since otherwise their future price could be sub-optimally low. We now investigate these propositions using UK data, and use our results to motivate the theoretical model we develop in Section 4.

We first used the aggregate inflation rates for the classification of individual consumption by purpose (COICOP) divisions for the UK CPI to construct series for ‘sticky-price’ inflation and

¹ This is consistent with a standard microfounded New Keynesian Phillips Curve, where it can easily be shown that firms with a higher Calvo probability of changing prices would have a larger coefficient on their real marginal cost variable.

‘flexible-price’ inflation. To do this, we used the results from Ellis and Bunn (2011) on the frequency of price changes in the CPI for each COICOP division, and used the median frequency of change as the dividing line telling us which COICOP sectors to place in which constructed inflation series. On average, prices in the ‘flexible’ series change once every four months, whereas prices in the ‘sticky’ series change every ten months, with the ‘flexible’ series accounting for 45% of the full CPI basket.² The variance of the twelve-month rate of inflation of the flexible-price series since 1997 is two and a half times greater than the variance of the sticky-price series.

Bryan and Meyer (2010) suggests two hypotheses that we can apply to the United Kingdom. First, prices that change frequently should exhibit a strong correlation with current economic conditions. And second, if sticky prices are set with regard to the expected future state of the economy, then we might expect them to be an indicator of firms’ medium-term inflation expectations. This could be particularly useful, since data on firms’ inflation expectations are sparse, even though it is likely that firms’ expectations matter a lot in their pricing decisions, and hence in the inflation process.

To investigate the first hypothesis, we looked at correlations between aggregate, economy-wide, output relative to trend and our two series for flexible and sticky-price inflation.³ Our measure of output relative to trend is simply the percentage difference between actual real GDP at basic prices (*ABMM*), and trend GDP as measured using a Hodrick-Prescott (HP) filter.⁴ We should note that this is *not a measure of the output gap*, defined as the difference between actual output and what output would be in a (counterfactual) world in which all prices are flexible. We make this difference clear later when we present our model and assess its ability to match the data shown here.

The correlations between output relative to trend and our inflation measures are shown in Table A and in Charts 1 and 2. Correlations are displayed separately for the periods 1997-2007 and 2008-10, since macroeconomic volatility differs greatly between these two periods.⁵ For the period from 1997-2007, although the correlation is – unsurprisingly – far from perfect, there is some evidence of a positive correlation between output relative to trend and flexible-price inflation whereas output relative to trend is uncorrelated with sticky-price inflation. During the recession and its aftermath, output seems to have been highly correlated with sticky-price inflation, a result that directly contradicts the Bryan and Meyer (2010) hypothesis. However, it is possible that this result comes from the fact that the sticky-price sector includes ‘electricity, gas and other fuels’ (henceforth referred to as ‘utilities’), whose prices have been extremely volatile since 2007. The prices of utilities are highly unusual among CPI categories since they

² The flexible series comprises food, alcohol, tobacco, petrol, clothing & footwear, furniture, transport and communication. The sticky series contains all of the rest of the basket

³ We seasonally adjust both our series in order to make them comparable to GDP, which has already been seasonally adjusted.

⁴ The HP filter suffers from a well-known ‘end-point’ problem, whereby trend GDP may be underestimated if the end point of the sample falls during an economic downturn. This means that the difference between output and trend output presented here may be overstated before the financial crisis that began in 2007, and understated after the crisis. However, we have verified that our results are not particularly sensitive to alternatives, such as growing trend GDP from 2008 at its pre-2008 average, although there must be a question mark over the HP estimates given the possibility that output is substantially below the true unobserved trend for an extended period at the end of the sample.

⁵ The variance of annual CPI inflation was almost three times as great from 2008-10 relative to 1997-2007

change infrequently (almost on a *quasi*-seasonal basis), but can change by large amounts when they do. Utility prices may be set more on the basis of electricity and gas futures curves, which are themselves highly flexible and volatile, and which can reflect current output as well as exogenous factors unrelated to the current state of the UK economy. If we remove utilities from the sticky-price basket, then the correlation between sticky-price inflation and output since 2008 is much lower (though it remains higher than that between flexible-price inflation and output over the same period). And, of course, we should not put too much emphasis on results from such a short time period anyway as they may well not be robust.

Table A: Correlations of flexible and sticky-price inflation with output relative to trend

	<i>Flexible-price</i>	<i>Sticky-price</i>	<i>Sticky-price ex utilities</i>
1997-2007	0.24	-0.09	0.02
2008-2010	0.12	0.76	0.30

Chart 1: Scatter plot of sticky-price inflation against HP-filtered output, 1997-2010

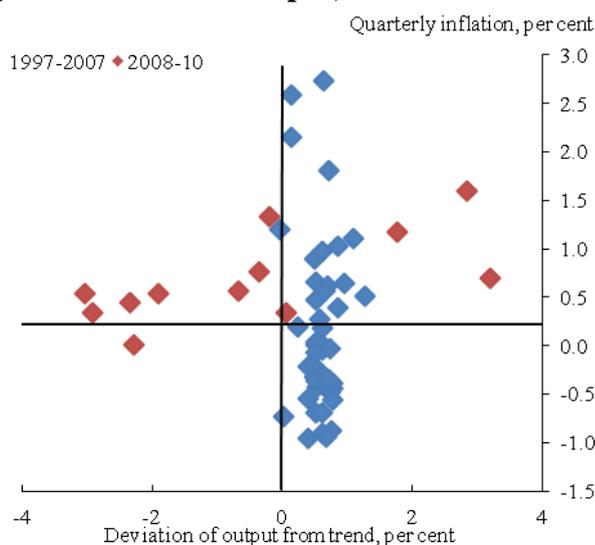
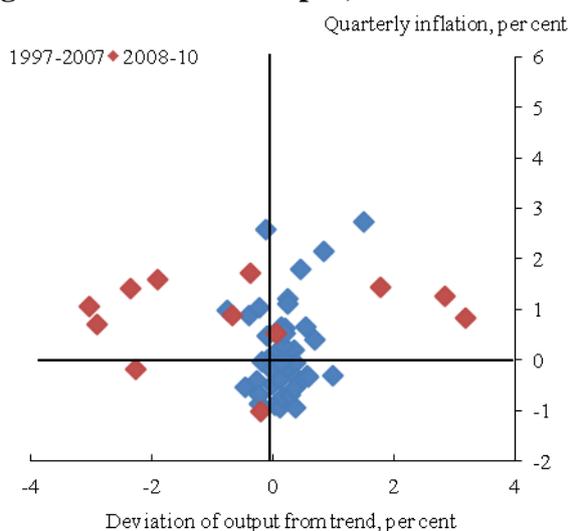
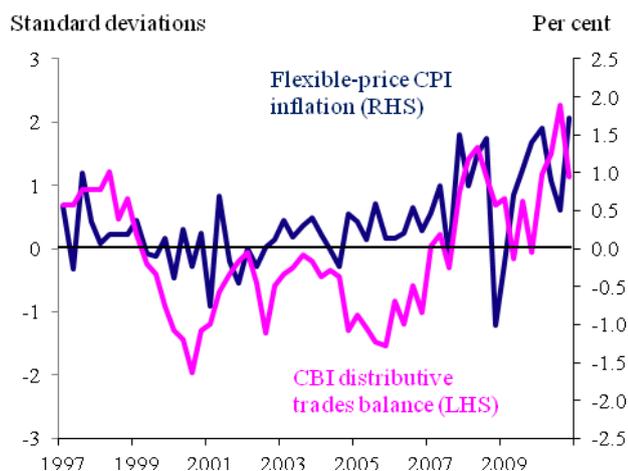


Chart 2: Scatter plot of flexible-price inflation against HP-filtered output, 1997-2010



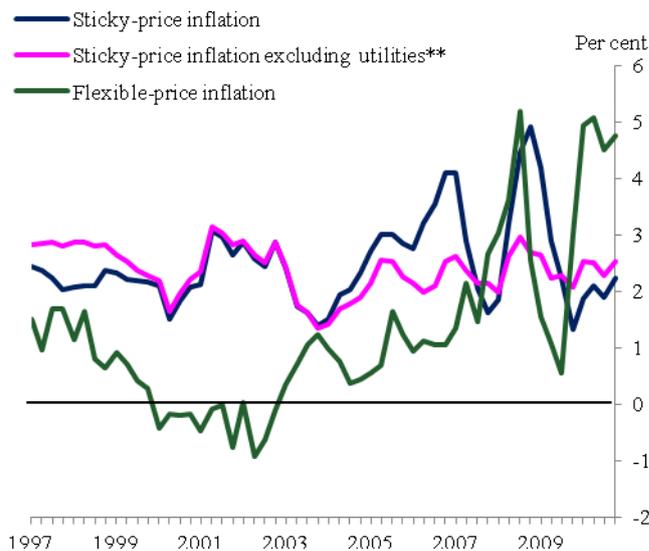
A further piece of evidence on the link between flexible-price inflation and the current state of the economy is provided by Chart 3, which shows our series for (unadjusted) flexible-price CPI inflation alongside the normalised percentage of firms expecting price rises one month ahead in the *CBI Distributive Trades Survey*. This suggests that there is a good correlation – the correlation coefficient is equal to 0.45 – between the two measures, implying that flexible prices may not be very forward looking. Indeed, the *CBI Distributive Trades Survey* mostly covers firms producing ‘flexible-price’ goods, such as food and clothing.

Chart 3: Quarterly flexible-price inflation and CBI Distributive Trades Survey one month ahead retail price expectations*



*CBI Distributive Trades measure shows per cent of firms expecting price rises over the next month, normalised so that the units display the number of standard deviations from average.

Chart 4: Annual inflation rates



**Utilities, here, refers to 'electricity, gas and other fuels'.

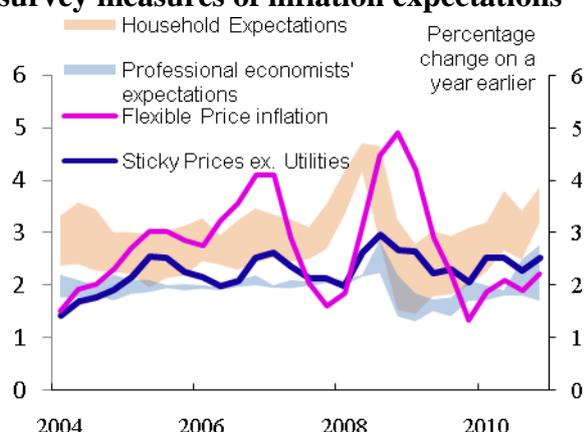
It is not easy to determine whether or not sticky prices reflect firms' medium-term (meaning, in this case, more than one year ahead) inflation expectations: there is no available survey measure of firms' expectations for retail prices at that horizon. But Chart 4 shows that sticky-price inflation typically stays closer to the 2% inflation target than flexible-price inflation, though it is highly volatile since 2007, when volatility in utilities prices increased. Chart 4 shows that, excluding this part of the basket, sticky-price inflation has stayed remarkably close to target throughout the recession, which may be consistent with some anchoring of medium-term expectations.

The sticky-price measure clearly does not provide a perfect reading of firms' beliefs about the future. This is not least because these prices are affected by shocks, just like any other prices. For example, they are likely to be affected by the exchange rate. Though even here, Chart 4 suggests that following the 1996 appreciation of sterling, sticky-price inflation fell by considerably less than flexible-price inflation. This may be because the sticky-price series is less import-intensive than the flexible-price series, which may in turn be consistent with the fact that the sticky part of the CPI basket contains more services. One further caveat is that sticky prices may not convey as much information about medium-term inflation expectations as we would actually like, since many prices in the 'sticky' basket still change more often than once a year. But we do think that the basic point – that sticky prices tell you something about expectations – probably holds.

There are two further cross-checks we can do to determine how helpful sticky-price inflation might be in assessing firms' inflation expectations. One is to see whether the message it gives is consistent with the message from standard survey measures of households' and professional forecasters' inflation expectations. And the second is to determine whether or not sticky-price inflation is helpful for forecasting overall inflation.

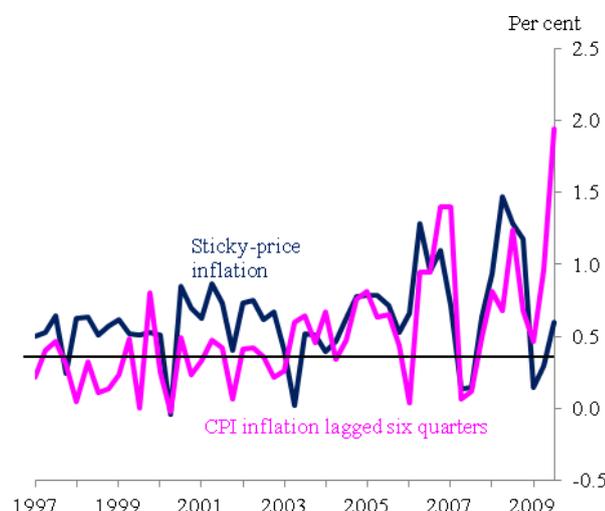
Starting with the first of these checks, inflation for sticky prices excluding utilities has been much closer than that of flexible prices to the one to two year ahead inflation expectations of professional forecasters (Chart 5). However, household expectations appear somewhat closer to flexible-price inflation, at least prior to 2010. This may be because households, in part, form their expectations based on items that they commonly purchase, such as food and petrol, which are included in the flexible-price series.⁶ Professional forecasters, on the other hand, may be better at recognising the temporary nature of some of the forces affecting flexible prices. Overall then, the message on inflation expectations from sticky-price inflation could be consistent with the message given by survey data.

Chart 5: Sticky and flexible-price inflation, and survey measures of inflation expectations



Notes: Swathe of household inflation expectations measures includes Bank of England/GfK NOP and Barclays Basix one year and two year ahead measures, and Citigroup one year ahead measure. The Professional economists' swathe includes Bank of England and HMT surveys of professional forecasters for one year and two years ahead.

Chart 6: Quarterly sticky-price and future aggregate inflation



On the second of these, Chart 6 suggests that sticky-price inflation looks quite correlated with aggregate CPI inflation six quarters on and so might be useful for forecasting. This is confirmed in Table B, which shows the correlations of sticky and flexible-price inflation with aggregate CPI inflation contemporaneously and at various leads.

Table B: Correlations of sticky and flexible-price inflation with current and future aggregate CPI inflation

<i>Correlation with aggregate CPI inflation at time:</i>	<i>Flexible-price inflation at time t</i>	<i>Sticky-price inflation at time t</i>
<i>t</i>	0.89	0.59
<i>t+1</i>	0.44	0.16
<i>t+4</i>	0.21	-0.19
<i>t+6</i>	0.38	0.45

⁶ However, survey evidence shows that households also take into account factors beyond recent trends in inflation in forming their expectations (Barnett, Oomen and Bell (2009)).

Bryan and Meyer (2010) assess the ability of their sticky and flexible-price inflation series to forecast aggregate inflation using a simple Phillips curve set-up where inflation is modelled as a function of lagged deviations of output from trend and inflation terms. They find that their forecasts are considerably more accurate using sticky prices than using flexible prices. We carried out a similar exercise, using UK data for CPI and HP-filtered GDP from 1996 to 2011. We estimated twelve separate models: four for each measure of inflation (aggregate, sticky price and flexible price) assuming a one, two, four and eight-quarter information lag. In each case, the model was estimated up to 2007 Q4, and then forecasts were computed for one, two, four and eight quarters ahead. The model was then re-estimated for each subsequent quarter, with forecasts computed at each step. Table C displays the results of this exercise, showing root mean squared errors (RMSEs) for all our models.

Our results are broadly in line with both our intuition and the results of Bryan and Meyer (2010) for the United States. At short forecast horizons, that is one and two quarters ahead, a forecasting model based on lags of aggregate inflation outperforms models based on lags of sticky-price and flexible-price inflation. In fact, lags of sticky-price inflation are insignificant in such forecasting equations. At a forecast horizon of two years, this is reversed and a model incorporating lags of sticky-price inflation outperforms models based on lags of aggregate inflation or flexible-price inflation, which are simply insignificant at this horizon. This is a key result and suggests that sticky-price inflation contains information about future inflation and, hence, may give us a good guide to expectations of inflation two years out. The surprising result is that a forecasting model based on lags of flexible-price inflation outperforms models based on lags of sticky-price inflation and aggregate inflation at the horizon of one year. Less surprising is that the model based on lags of sticky-price inflation also outperforms the model based on lags of aggregate inflation.

Table C: Root mean squared errors (RMSEs) for different forecast models

<i>No. of quarters ahead</i>	<i>RMSEs</i>		
	<i>Aggregate CPI</i>	<i>Sticky-price CPI</i>	<i>Flexible-price CPI</i>
1	0.005347	0.005311*	0.005463
2	0.005562	0.005787*	0.005806
4	0.005584	0.005231	0.005171
8	0.006216* ⁺	0.005185	0.006216* ⁺

Notes: The out-of-sample forecast period is 2008 Q1 – 2011 Q1.

* Forecast equation includes no terms in lagged inflation.

⁺ These two forecasting equations are identical.

4 The model

In this section, we develop a simple New Keynesian DSGE model containing two sectors: one where prices are fully flexible and another where prices are sticky. Both the sticky and flexible-price sectors consist of intermediate goods and services producers with market power. The sticky-price sector is characterised by overlapping Taylor contracts where firms can reset their prices once every four quarters. In the flexible-price sector, prices can adjust instantly. Both

sets of firms sell to a final goods firm that bundles these intermediate goods into a final good, which is sold in a perfectly competitive market. Otherwise the model is standard.

4.1 Consumers and demand

The economy is populated by a unit continuum of households indexed by j . Their problem is to maximise the discounted value of their current and future expected streams of utility, which is positive in consumption and negative in hours worked. In addition, consumption exhibits ‘habit persistence’; that is, individual consumers like to ‘keep up’ with average consumption in the sense that they do not like consuming less than the ‘average’ consumer did last period.

We write the utility function as:

$$\text{Maximise } E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{(c_{j,t} - \psi c_{j,t-1})^{1-\sigma} - 1}{1-\sigma} - \frac{(h_{j,t})^{1+\phi}}{1+\phi} \right)$$

where c_j denotes consumption of consumer j , c denotes aggregate consumption, h_j denotes total hours worked, $1/\sigma$ will be the intertemporal elasticity of substitution, ψ represents the degree of habit persistence, and $1/\phi$ will be the Frisch elasticity of labour supply.

Consumers are assumed to hold two types of assets: government bonds (in zero supply in equilibrium) and physical capital. Hence, they make decisions about investment and also about the rate at which their capital is utilised. They face a standard budget constraint given by:

$$B_{j,t} = (1+i_{t-1})B_{j,t-1} + P_t r_{k,t} z_{j,t} k_{j,t-1} + W_{j,t} h_{j,t} + Div_{j,t} - P_t c_{j,t} - P_t I_{j,t} - P_t \frac{a_0}{1+\sigma_z} (z_{j,t}^{1+\sigma_z} - 1) k_{j,t-1}$$

where B_j denotes consumer j 's holdings of bonds, k_j denotes consumer j 's holdings of capital, i is the nominal interest rate, r_k denotes the rental rate paid on capital, W_j denotes the nominal wage paid to worker j , Div_j denotes the real profits of firms (which are transferred as lump-sum dividends from firms to consumers), I_j is investment by consumer j , z_j is the rate at which j utilises capital, and P is the aggregate price level. The final term represents costs incurred by overusing capital. If capital is being used at capacity, that is $z = 1$, these costs will be zero.

Consumer j 's capital evolves according to the capital accumulation condition:

$$k_{j,t} = (1-\delta)k_{j,t-1} + \left(1 - \frac{\kappa}{2} \left(\frac{I_{j,t}}{I_{j,t-1}} - 1 \right)^2 \right) I_{j,t} \quad (1)$$

where the final term captures the idea that adjustments to investment are costly, with $\kappa/2$ the cost of squared deviations from the previous period's level. Using these, we can derive the equations describing consumption and investment behaviour:

The first-order conditions for this problem imply:

$$\begin{aligned} (c_{j,t} - \psi c_{t-1})^{-\sigma} &= \beta(1+i_t)E_t \frac{(c_{j,t+1} - \psi c_{j,t+1})^{-\sigma}}{1 + \pi_{t+1}} \\ r_{k,t} &= a_0 z_{j,t}^{\sigma_z} \\ P_{k,t} &= \beta E_t \frac{(c_{j,t+1} - \psi c_{j,t+1})^{-\sigma}}{(c_{j,t} - \psi c_{j,t})^{-\sigma}} \left\{ r_{k,t+1} z_{j,t+1} - \frac{a_0}{1 + \sigma_z} (z_{j,t+1}^{1+\sigma_z} - 1) + (1 - \delta) P_{k,t+1} \right\} \\ p_{k,t} \left(1 - \frac{\kappa}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right) &= 1 + p_{k,t} \kappa \frac{I_t}{I_{t-1}} \left(\frac{I_t}{I_{t-1}} - 1 \right) - \beta E_t \frac{(c_{t+1} - \psi e_{t+1})^{-\sigma}}{(c_t - \psi e_t)^{-\sigma}} p_{k,t+1} \kappa \left(\frac{I_{t+1}}{I_t} \right)^2 \left(\frac{I_{t+1}}{I_t} - 1 \right) \end{aligned}$$

and the capital accumulation condition (equation (1)).

Log-linearising these equations gives:

$$\hat{c}_t = \frac{\psi}{1 + \psi} \hat{c}_{t-1} + \frac{1}{1 + \psi} E_t \hat{c}_{t+1} - \frac{1}{(1 + \psi)\sigma} \left(i_t - E_t (\hat{p}_{t+1} - \hat{p}_t) - \left(\frac{1}{\beta} - 1 \right) \right) \quad (2)$$

$$\hat{r}_{k,t} = \sigma_z \hat{z}_t \quad (3)$$

$$\hat{p}_{k,t} = E_t \left\{ (\hat{p}_{t+1} - \hat{p}_t) - i_t + \left(\frac{1}{\beta} - 1 \right) + (1 - \beta(1 - \delta)) \left(r_{k,t+1} - \left(\frac{1}{\beta} - 1 + \delta \right) \right) + \beta(1 - \delta) \hat{p}_{k,t+1} \right\} \quad (4)$$

$$\hat{I}_t = \frac{1}{1 + \beta} \hat{I}_{t-1} + \frac{\beta}{1 + \beta} E_t \hat{I}_{t+1} + \frac{1}{(1 + \beta)\kappa} \hat{p}_{k,t} \quad (5)$$

$$\hat{k}_t = (1 - \delta) \hat{k}_{t-1} + \delta \hat{I}_t \quad (6)$$

4.2 Labour market and wage-setting

We assume that households have some market power in wage-setting. That is, we assume that labour of type j is only partly substitutable for labour of type k , say. In particular, we assume that the demand for labour of type j is given by:

$$h_{j,t} = \left(\frac{W_{j,t}}{W_t} \right)^{\frac{1 + \lambda_w}{\lambda_w}} h_t$$

where W is the aggregate nominal wage, and h is aggregate total hours worked.

The labour market is characterised by wage stickiness. Wage-setting follows a simple Taylor (1980) structure where wages are fixed for one year in overlapping contracts. Specifically, households are divided into four groups, with each group eligible to reset their wages in a different quarter.

For a worker able to reset their wages, their problem is given by:

$$\text{Maximise } E_t \sum_{r=0}^3 \beta^r \left(\frac{U_{c,t+r}}{P_{t+r}} \tilde{W}_{j,t} h_{j,t+r} - \frac{(h_{j,t})^{1+\phi}}{1+\phi} \right)$$

where $r = \{0,1,2,3\}$ is the period over which the wage remains fixed and $\tilde{W}_{j,t}$ denotes the wage of workers who can reset their wage.

We assume that there is a common labour market. This means that, in equilibrium, the wages of all workers who reset their wage in the same period will be the same. Given that, the first-order conditions for workers who are able to reset their wages imply:

$$\tilde{W}_t = \frac{E_t \sum_{r=0}^3 \beta^r \frac{1+\lambda_w}{\lambda_w} \left(\left(\frac{W_t}{W_{t+r}} \right)^{\frac{1+\lambda_w}{\lambda_w}} h_{t+r} \right)^{1+\phi}}{E_t \sum_{r=0}^3 \beta^r \frac{U_{c,t+r}}{\lambda_w P_{t+r}} \left(\frac{W_t}{W_{t+r}} \right)^{\frac{1+\lambda_w}{\lambda_w}} h_{t+r}}$$

Finally, given that the wage-setting groups are of equal size, the aggregate wage at time t is simply:

$$W_t = 0.25 [\tilde{W}_t + \tilde{W}_{t-1} + \tilde{W}_{t-2} + \tilde{W}_{t-3}]$$

Log-linearising these equations gives:

$$\left(1 + \frac{1+\lambda_w}{\lambda_w} \phi \right) \hat{\tilde{W}}_t = \frac{1}{1+\beta+\beta^2+\beta^3} \sum_{r=0}^3 \beta^r \left(\phi \hat{h}_{t+r} + \frac{1+\lambda_w}{\lambda_w} \phi \hat{W}_{t+r} + \sigma \left(\frac{1}{1-\psi} \hat{c}_{t+r} - \frac{\psi}{1-\psi} \hat{c}_{t+r-1} \right) + \hat{P}_{t+r} \right) \quad (7)$$

$$\text{and } \hat{W}_t = 0.25 \left(\hat{\tilde{W}}_t + \hat{\tilde{W}}_{t-1} + \hat{\tilde{W}}_{t-2} + \hat{\tilde{W}}_{t-3} \right) \quad (8)$$

where we have used the fact that $\hat{U}_{c,t} = -\sigma \left(\frac{1}{1-\psi} \hat{c}_t - \frac{\psi}{1-\psi} \hat{c}_{t-1} \right)$.

4.3 Firms and price-setting

The economy is characterised by two sectors, one where firms have complete flexibility in price-setting ('flexible-price firms') and another where firms have overlapping Taylor contracts ('sticky-price firms'). Each sector produces its own output, denoted y_t^F and y_t^S respectively, and then these are combined into total output by a perfectly competitive retailer according to the production function $y_t = (y_t^F)^\tau (y_t^S)^{(1-\tau)}$, with τ and $(1-\tau)$ denoting sectoral shares in output. The retailer's problem is to maximise profits – given by $(Py - P^S y^S - P^F y^F)$ – subject to this production function.

The first-order conditions for this problem imply:

$$y_t = (y_t^F)^\tau (y_t^S)^{(1-\tau)}$$

$$\tau \left(\frac{y_t^F}{y_t^S} \right)^{\tau-1} = \frac{P^F}{P}$$

$$(1-\tau) \left(\frac{y_t^S}{y_t^F} \right)^{-\tau} = \frac{P^S}{P}$$

Log-linearising these gives:

$$\hat{y}_t = \tau \hat{y}_t^F + (1-\tau) \hat{y}_t^S \quad (9)$$

$$\hat{P}_t^F + (1-\tau)(\hat{y}_t^F - \hat{y}_t^S) = \hat{P}_t \quad (10)$$

$$\hat{P}_t^S + \tau(\hat{y}_t^S - \hat{y}_t^F) = \hat{P}_t \quad (11)$$

4.3.1 Flexible-price firms

Firms in this sector have complete flexibility to reset their prices, and so the price level is simply derived from profit maximisation. As is standard, we assume monopolistically competitive intermediate goods firms producing differentiated goods indexed by j , with their goods bundled into one ‘flexible-price’ good by firms that sell it on to the retailer in a perfectly competitive market. The problem for these firms is to maximise their profits subject to their demand curve (coming from the unreported profit maximisation problem of the bundlers) and their production function. Mathematically we can write their problem as:

$$\text{Maximise } \left\{ P_{j,t}^F y_{j,t}^F - W_{j,t} h_{j,t}^F - P_{k,t}^F r_{k,t} (z_t k_{j,t}^F) \right\}$$

$$\text{Subject to } y_{j,t}^F = \left(\frac{P_{j,t}^F}{P_t^F} \right)^{\frac{1+\lambda_p}{\lambda_p}} y_t^F$$

$$\text{and } y_{j,t}^F = A_t h_{j,t}^{1-\alpha} (z_t k_{j,t}^F)^\alpha \quad (12)$$

where A is a productivity shock that follows the process:

$$\ln A_t = \rho_A \ln A_{t-1} + \varepsilon_{A,t}$$

where ε_A is a mean-zero, white-noise shock with standard error σ_A .

The first-order conditions for this problem imply:

$$\frac{W_t}{P_t^F} = \frac{1-\alpha}{1+\lambda_p} \frac{y_t^F}{h_t^F}$$

$$r_{k,t} = \frac{\alpha}{1+\lambda_p} \frac{y_t^F}{z_t k_t^F}$$

and the production function (equation (12)).

Log-linearising these equations gives:

$$\hat{y}_t^F = \hat{A}_t + (1-\alpha)\hat{h}_t^F + \alpha(\hat{z}_t + \hat{k}_t^F) \quad (13)$$

$$\hat{W}_t - \hat{P}_t^F = \hat{y}_t^F - \hat{h}_t^F \quad (14)$$

$$\hat{r}_{k,t} = \hat{y}_t^F - \hat{z}_t - \hat{k}_t^F \quad (15)$$

4.3.2 Sticky-price firms

Here we make the assumption that there are four equally sized groups of firms setting prices for one year each, with each eligible to reset their price once per year. So the objective of firm j , say, that is able to reset its price will be to

$$\text{Maximise } E_t \sum_{r=0}^3 \beta^r \left[\tilde{P}_{j,t}^S y_{j,t+r}^S - W_{j,t} h_{j,t+r}^S - \tilde{P}_{t+r}^S r_{k,t+r} (z_{t+r} k_{j,t+r}^S) \right]$$

$$\text{Subject to } y_{j,t}^S = \left(\frac{P_{j,t}^S}{P_t^S} \right)^{\frac{1+\lambda_p}{\lambda_p}} y_t^S$$

$$\text{and } y_{j,t}^S = A_t h_{j,t}^S{}^{1-\alpha} (z_t k_{j,t}^S)^\alpha$$

where $\tilde{P}_{j,t}^S$ is the price set by those firms that are able to reset their prices. Cost minimisation implies:

$$\frac{W_t}{P_t^S} = \mu_t (1-\alpha) \frac{y_t^S}{h_t^S}$$

$$r_{k,t} = \alpha \mu_t \frac{y_t^S}{z_t k_t^S}$$

where μ is real marginal cost.

We can then re-write the objective function for a price-setting firm as:

$$\text{Maximise } E_t \sum_{r=0}^3 \beta^r \left[\tilde{P}_{j,t}^S - \mu_{j,t+r} P_{t+r}^S \right] \left(\frac{\tilde{P}_{j,t}^S}{P_{t+r}^S} \right)^{-\frac{1+\lambda_p}{\lambda_p}} y_{t+r}^S$$

The first-order condition for this problem is:

$$\sum_{r=0}^3 \beta^r \left\{ \left(\frac{\tilde{P}_{t+r}^S}{P_{t+r}^S} \right)^{-\frac{1+\lambda_p}{\lambda_p}} y_{t+r}^S \left(1 - \frac{1+\lambda_p}{\lambda_p} \left(1 - \mu_{t+r} \frac{P_{t+r}^S}{\tilde{P}_{t+r}^S} \right) \right) \right\} = 0$$

And finally, we can write the aggregate price level P_t^S as:

$$P_t^S = 0.25 \left[\tilde{P}_t^S + \tilde{P}_{t-1}^S + \tilde{P}_{t-2}^S + \tilde{P}_{t-3}^S \right]$$

Collecting together equations and log-linearising gives:

$$\hat{y}_t^S = \hat{A}_t + (1-\alpha)\hat{h}_t^S + \alpha(\hat{z}_t + \hat{k}_t^S) \quad (16)$$

$$\hat{W}_t - \hat{P}_t^S = \hat{\mu}_t + \hat{y}_t^S - \hat{h}_t^S \quad (17)$$

$$\hat{r}_{k,t} = \hat{\mu}_t + \hat{y}_t^S - \hat{z}_t - \hat{k}_t^S \quad (18)$$

$$\sum_{r=0}^3 \beta^r \left\{ \hat{\mu}_{t+r} + \hat{P}_{t+r}^S - \hat{P}_t^S \right\} = 0 \quad (19)$$

$$\hat{P}_t^S = 0.25 \left[\tilde{\hat{P}}_t^S + \tilde{\hat{P}}_{t-1}^S + \tilde{\hat{P}}_{t-2}^S + \tilde{\hat{P}}_{t-3}^S \right] \quad (20)$$

4.3.3 Monetary policy and equilibrium

Monetary policy is described by a standard Taylor rule with interest rate smoothing:

$$i_t - \left(\frac{1}{\beta} - 1 \right) = \rho_i \left(i_{t-1} - \left(\frac{1}{\beta} - 1 \right) \right) + (1-\rho_i) \left[\gamma_\pi (\hat{P}_t - \hat{P}_{t-1}) + \gamma_y (\hat{y}_t - \hat{y}_{FP,t}) \right] + \varepsilon_{i,t} \quad (21)$$

where $\hat{y}_{FP,t}$ is the deviation from trend of output in a flexible price and wage economy subject to the same shocks as our model economy; this is the appropriate variable to use when calculating an output gap in these types of model. In addition, ε_i is a mean zero, white noise, monetary policy shock with standard error σ_i .

Finally, we note that the markets for labour, capital and goods must all clear:

$$h_t = h^F_t + h^S_t$$

$$k^F_t + k^S_t = k_{t-1}$$

$$y_t = c_t + I_t + \frac{a_0}{1 + \sigma_z} (z_t^{1+\sigma_z} - 1) k_{t-1} + g_t$$

where g is a government spending shock that follows the process:

$$\hat{g}_t = \rho_g \hat{g}_{t-1} + \varepsilon_{g,t}$$

where ε_g is a mean zero, white noise shock with standard error σ_g .

Log-linearising these equations gives:

$$\hat{h}_t = \tau \hat{h}^F_t + (1 - \tau) \hat{h}^S_t \quad (22)$$

$$\tau \hat{k}^F_t + (1 - \tau) \hat{k}^S_t = \hat{k}_{t-1} \quad (23)$$

$$\hat{y}_t = \left(1 - \frac{g}{y} - \frac{\alpha \delta}{\left(\frac{1}{\beta} - 1 + \delta \right) (1 + \lambda_p)} \right) \hat{c}_t + \frac{\alpha \delta}{\left(\frac{1}{\beta} - 1 + \delta \right) (1 + \lambda_p)} \hat{I}_t + \frac{\alpha}{1 + \lambda_p} \hat{z}_t + \frac{g}{y} \hat{g}_t \quad (24)$$

This completes the description of the model.

4.4 Calibration

The parameter values we use in simulating our model are given in Table D. In calibrating the model, we follow as closely as possible the values of the parameters in Harrison *et al* (2005). For the elasticity of investment costs and the wage mark-up, which do not correspond to any parameters discussed in Harrison *et al*, we used the values in Smets and Wouters (2003). For the relative sizes of the sticky and flexible-price sectors, we used the result in Bunn and Ellis (2011) that 27% of items they examined had an average time between price changes of less than three months.⁷

⁷ Of course, we should weight items by their share in total output. Bunn and Ellis (2011) argue that, although their sample weights are not quite the same as the weights of the products in CPI, this does not substantially affect their results, so we are happy to run with this calibration. Of course, all the items examined in this data set are ‘consumption’ goods, whereas output in our model also includes capital goods and goods purchased by government, which may have different degrees of price stickiness. We ignore this issue in our calibration.

Table D: Calibrated parameter values

Parameter	Description	Value	Source
ψ	Degree of habits in consumption	0.7	Harrison <i>et al</i> (2005)
σ	Degree of intertemporal substitution in consumption	5	Harrison <i>et al</i> (2005)
β	Discount factor	0.998	Harrison <i>et al</i> (2005)
σ_z	Inverse elasticity of capital utilisation costs	0.1	Harrison <i>et al</i> (2005)
δ	Capital depreciation rate	0.006	Harrison <i>et al</i> (2005)
κ	Elasticity of investment adjustment costs	6	Smets and Wouters (2003)
λ_w	Wage mark-up	0.5	Smets and Wouters (2003)
ϕ	Inverse of labour supply elasticity	10	Harrison <i>et al</i> (2005)
τ	Share of flexible-price firms in total output	0.27	Bunn and Ellis (2011)
α	Capital share	0.3344	Estimated production function
λ_p	Price mark-up	0.11	Harrison <i>et al</i> (2005)
g/y	Share of government spending in output	0.2961	Average of <i>NMRY/ABMM</i> over 1971 Q1 to 2010 Q4
ρ_i	Persistence in interest rates	0.65	Harrison <i>et al</i> (2005)
γ_π	Coefficient on inflation in the monetary policy rule	1.5	Harrison <i>et al</i> (2005)
γ_y	Coefficient on the output gap in the monetary policy rule	0.125	Harrison <i>et al</i> (2005)
ρ_A	Autocorrelation of productivity shock	0.7172	Estimated production function
σ_A	Standard deviation of productivity shock	0.0077	Estimated production function
ρ_g	Autocorrelation of government spending shock	0.3528	Based on HP-filtered real government consumption
σ_g	Standard deviation of government spending shock	0.0144	Based on HP-filtered real government consumption
σ_i	Standard deviation of monetary policy shock	0.0038	Standard deviation of HP-filtered interest rate

For the productivity shock, we used data on GDP growth, employment-in-hours growth (series *YBUS* in the Labour Force Survey) and capital services growth over the sample 1971 Q1 to 2010 Q4 to estimate the production function:⁸

$$\Delta \ln y = \Delta \ln TFP + \alpha \Delta \ln k + (1 - \alpha) \Delta \ln h \quad (25)$$

Armed with a value for α , we calculated total factor productivity, A , as $A = \frac{y}{k^\alpha h^{1-\alpha}}$. We then detrended TFP using the HP filter and calculated the productivity shock as $\varepsilon_{a,t} = \hat{A}_t - \rho_a \hat{A}_{t-1}$,

⁸ We used a measure of capital services calculated in house at the Bank of England. For full details on the calculations see Oulton and Srinivasan (2003).

where ρ_a was the estimated first-order correlation coefficient of our detrended productivity series. For the government spending shock, we first HP filtered government consumption (*NMRY*) to get a series for government spending, g , over the sample 1971 Q1 to 2010 Q4. We then calculated the shock as $\varepsilon_{g,t} = \hat{g}_t - \rho_a \hat{g}_{t-1}$, where ρ_g was the estimated first-order correlation coefficient of our detrended government spending series.

Finally, for the monetary policy shock we used the Taylor rule in Harrison *et al* (2005):

$$i_t - \left(\frac{1}{\beta} - 1\right) = 0.65 \left(i_{t-1} - \left(\frac{1}{\beta} - 1\right) \right) + 0.35 \left[1.5(\hat{P}_t - \hat{P}_{t-1}) + 0.125(\hat{y}_t - \hat{y}_{FP,t}) \right] + \varepsilon_{i,t} \quad (26)$$

and set the standard deviation of the monetary policy shock to 38 basis points, equal to the standard deviation of the HP-filtered quarterly Bank Rate (*AMIH*).⁹

5 Results

In this section we examine the implications of our model for inflation dynamics, including persistence, volatility, and correlation with the output gap and expected inflation, where expected inflation is simply the model-consistent expectation of inflation in period $t+1$ conditional on period t data. In particular, we are concerned with how the behaviour of inflation differs in the two sectors.

Our results are summarised in Table E, below. As a comparison, we compute equivalent statistics for the UK data for the period 1997-2007. The first thing to notice is that sticky-price inflation is less volatile than flexible-price inflation. This also implies that sticky-price inflation will tend to stay closer to the 2% inflation target (the assumed steady-state inflation rate in the model) than will flexible-price inflation, in line with Chart 4, above.

Now, recall that earlier we suggested several features that might be true of flexible versus sticky prices. First, sticky prices should be more persistent, given that they are changed less often, and this should drive the persistence of aggregate inflation. Second, we would expect flexible-price inflation to be more responsive to movements in the output gap, ie, the implied Phillips curve relationship between flexible-price inflation and the output gap is steeper than that between sticky-price inflation and the output gap. Third, we would expect sticky-price inflation to be more correlated with inflation expectations, and with future inflation. In fact, our model exhibits all of these features.

⁹ Of course, in setting up monetary policy in this way, we are unable to capture the effects of quantitative easing (QE). But, this should not matter for the results presented, so long as a QE increase has a similar effect to an interest rate cut on the output gap and inflation in the two sectors.

Table E: Volatilities, cyclicity and persistence

Variables		Aggregate inflation		Inflation in the sticky-price sector		Inflation in the flexible-price sector	
		Model	Data	Model	Data	Model	Data
Autocorrelation	1 lag	0.1796	0.0063	0.6964	0.3233	-0.1434	-0.1768
	2 lags	0.1594	0.1589	0.4003	0.0333	-0.0891	0.3660
	3 lags	0.1395	0.3628	0.1093	0.0315	-0.0435	0.2489
	4 lags	-0.1339	0.0532	-0.1769	-0.2131	-0.0586	0.1127
	5 lags	-0.1000	0.1537	-0.1467	-0.1746	-0.0350	0.1327
Standard deviation		0.0051	0.0023	0.0036	0.0025	0.0131	0.0039
Standard deviation relative to output		0.5258	0.2547	0.3711	0.2763	1.3505	0.4370
Correlation with inflation expected next period		0.4706	-	0.5958	-	0.2356	-
Correlation with actual inflation next period		0.1796	0.0063	0.2273	0.2047	0.0899	0.3274
Correlation with actual inflation six quarters on		-0.0741	0.4454	-0.0763	0.5842	-0.0502	0.2945
Correlation with output		0.0868	0.1110	-0.1074	-0.0911	0.2075	0.2445
Correlation with output gap		0.7762	-	0.8460	-	0.4916	-
Slope of Phillips curve (output)		0.0510	0.4361	-0.0399	-0.3296	0.2802	0.5594
Slope of Phillips curve (output gap)		0.5278	-	0.4061	-	0.8587	-

Chart 7: Autocorrelations of inflation

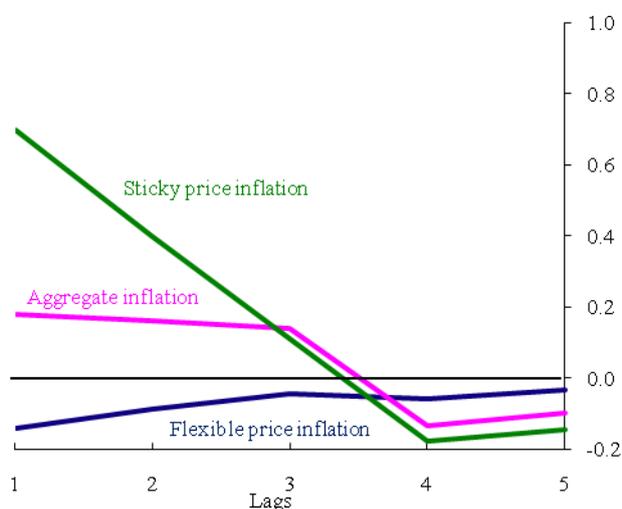
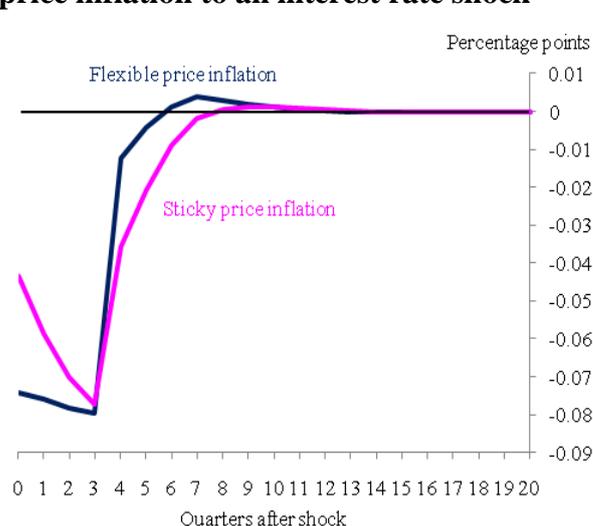


Chart 8: Response of sticky and flexible-price inflation to an interest rate shock



Looking at the autocorrelations, Chart 7 shows that the model implies that inflation is clearly more persistent in the sticky-price sector than in the flexible-price sector. Flexible prices exhibit no persistence from quarter to quarter, whereas sticky prices are significantly autocorrelated up to two quarters ahead. As we would expect, the persistence of aggregate inflation lies some way between the two. This, then, is evidence that sticky prices drive inflation persistence in the model. The data is more nuanced. Although sticky-price inflation exhibits some autocorrelation, it is much less than implied by the model. Neither aggregate inflation nor

flexible-price inflation exhibit any persistence in the data, more or less in line with the model. Chart 8 illustrates the persistence point in a different way. It displays impulse responses to a one standard deviation shock in interest rates in the two-sector model. In broad terms, the two sectors show similar results. But it is clear that sticky-price inflation is slower to respond: only falling by roughly half as much on impact as flexible-price inflation. It also persists at a lower rate of inflation for longer, taking two years to return to base rather than a year and half in the case of flexible-price inflation.

The differences in correlations with expected inflation and output, and the implied Phillips curve slopes are our key results. Table E shows that sticky-price inflation is more correlated with next period's expected inflation than flexible-price inflation, with aggregate inflation sitting between the two. These results are in line with our intuition and match up with the correlation between sticky-price inflation and professional forecasters' inflation expectations shown in Chart 5. In the data, both flexible-price inflation and sticky-price inflation are more correlated with next period's aggregate inflation than today's aggregate inflation, with flexible-price inflation being the best leading indicator. This goes against what happens in the model, where sticky-price inflation is a better indicator of next period's aggregate inflation and today's aggregate inflation is a better indicator of next quarter's inflation than today's flexible-price inflation. In the model, no inflation series provides any useful information about inflation six-periods ahead unlike in the data, where sticky-price inflation has forecasting power for aggregate inflation at that horizon (as shown in Chart 6). These results suggest that the speed with which movements in our disaggregate inflation measures feed into aggregate inflation is much faster in the model than it is in the data. For sticky-price inflation, shocks feed through in one quarter in the model versus six quarters in the data. For flexible-price inflation, all of the effects of shocks come through in the current quarter in the model versus this quarter and the next in the data.

Turning to the relationship between our disaggregated measures of inflation and output, it is comforting to see that all our measures of inflation are more highly correlated with the (flexible-price) output gap than with output itself, in line with standard theory. Table E also shows that the correlations of flexible-price inflation and sticky-price inflation are quite low, with flexible-price inflation being positively correlated with output and sticky-price inflation being negatively correlated with output. As shown in Table E, these results are in line with the UK data. In terms of the slopes of the implied Phillips curves, the model suggests that inflation is more responsive to movements in the output gap than output itself, as we would expect, and that flexible-price inflation is more responsive to movements in the output gap (and output) than is fixed-price inflation, with aggregate inflation in the middle. Again, this is in line with our intuition.

6 Conclusions

In this paper, we have investigated the information content of prices in relatively sticky-price sectors versus relatively flexible-price sectors, given the findings of Greenslade and Parker (2010) that, although the median UK firm reviews its price twice a year, the distribution of price changes seems to be bimodal, with retailers changing their prices every month on average, while consumer service providers changed their price only once a year. Following Bryan and Meyer (2010) we presented some empirical evidence that relatively flexible prices react more to deviations of output from trend than stickier prices, suggesting that prices that change very frequently are set on the basis of the current state of the economy. We also presented some tentative empirical evidence that sticky prices can tell us about firms' inflation expectations. We then developed a simple DSGE model with a sticky-price sector and a flexible-price sector and used this model to show that the empirical results were what you would actually expect to see, given standard economic theory.

Taken together, the results of this paper suggest that calculations of 'flexible-price' inflation could, potentially, be used to provide monetary policy makers with a steer on the current state of the economy, in particular, the current output gap, which is notoriously hard to measure. In addition, calculations of 'sticky-price' inflation could, potentially, be used to provide monetary policy makers with a steer on the medium-term inflation expectations of price-setters within the economy, again something about which it is hard to obtain any direct evidence.

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