The Impact of the 2008 Crisis on UK Prices: What We Can Learn from the CPI Microdata*

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Abstract

This paper takes the locally collected price quotes used to construct the CPI index in the UK for the period 1996–2013 and explores the impact of the Great Recession (2008-9) on the pricing behaviour of firms. We develop a time series framework which captures the link between macroeconomic variables and the behaviour of prices in terms of the frequency of price change, the dispersion of price levels and the size, dispersion and kurtosis of price-growth. We find strong evidence for inflation having an effect, but not output. The change in the behaviour of prices during the Great Recession is largely explained by the changes in inflation and VAT. Nevertheless, the magnitude of the inflation effect is sufficiently small that it need not influence monetary policy.

I. Introduction

The period 2008-2010 saw the biggest recession in terms of output loss in British postwar economic history:[1] it also witnessed 20% depreciations of sterling against both the Dollar and Euro along with inflation well above the levels seen in the preceding decade. There was also a temporary reduction in VAT (from December 2008, reversed in January 2010), plus a permanent increase (introduced in January 2011). We aim to assess how far these big macroeconomic events were reflected by changes in the behaviour of price setters. Specifically, we seek to document the impact of these events on the behaviour of prices as captured by the microdata on price quotes used to construct the UK Consumer Price Index (CPI). While the main determinants of individual prices are likely to be microeconomic

[1] However, note that the unemployment rate was higher in the 1980-1 recession despite a lower level of output loss.

shocks in the firm's immediate environment, nonetheless, macroeconomic factors affect all prices and can therefore have a significant impact on aggregate pricing behaviour which may be important for monetary policy design. We seek to analyse this using data that extend from the Great Moderation period until the postcrisis recovery period, spanning 1996–2013 with over 20 million price quotes covering a wide range of items across the CPI.

Our analytical approach proceeds in two stages. First, we describe the behaviour of aggregate prices using statistics built up from the price quote data used to construct the CPI index. The 'frequency' or *proportion of prices which change in a given month* (subdivided into changes up and down); measures of the *dispersion of price levels* for the same product; three dimensions of the distribution of the growth of prices (*absolute size, dispersion and kurtosis*). They are the main statistics about pricing behaviour that have been of interest in the recent literature.[2] This helps shed light on what happened to pricing during the Great Recession (GR) period. Second, we adopt a time series approach and scrutinize the relationship between these price statistics and the macroeconomic variables of output and inflation. We also examine the effects of the three VAT changes over the period 2008–11 and the GR. The VAT changes were common shocks across the range of items subject to VAT, while the crisis dummy captures the extent behaviour changed as a result the GR. Our study on UK data complements studies by Vavra (2014) and Nakamura *et al.* (2018) for the US and Berardi *et al.* (2015) for France. This also extends the many studies on precrisis pricing behaviour such as Dhyne *et al.* (2006), Baudry *et al.* (2007), Klenow and Kryvtsov (2008), Nakamura and Steinsson (2008), as surveyed in Klenow and Malin (2011).

Our main findings are clear. For all our statistics, inflation matters but output does not. The effect of output on pricing in theory is captured mainly via the link between output and marginal cost. While in some calibrations with a very low labour supply elasticity pricing can be highly responsive to output, in many calibrations output has little effect on marginal cost and pricing.[3] Our results support the calibrations where marginal cost responds little to output.

We find that inflation tends to increase the frequency of price changes, mainly by raising the frequency of price increases. Our estimates are that a 1% point increase in *annual inflation* causes an increase in the monthly frequency of about 0.5% points: thus for example an increase in inflation from 2% per annum to 5% might cause the monthly frequency to increase from 15% to 16.5%. Inflation reduces the dispersion of price levels,[4] and reduces the dispersion of price growth and increases its kurtosis. Changes in VAT have an important effect, as does seasonality.

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[2] For example, see Alvarez *et al.* (2016), Midrigan (2011), Klenow and Kryvtsov (2008), Nakamura and Steinsson (2008), Nakamura *et al.* (2018). Frequency is probably the most important statistic, as it reflects the flexibility of prices: a higher frequency is often interpreted as meaning prices are more flexible and hence monetary policy less effective. However, the other statistics have also been seen as important as shedding light on firm behaviour and consumer welfare.

[3] For a calibration where marginal cost is highly responsive to output, see Chari, Kehoe and McGrattan (2000). For one with low responsiveness see Coenen, Christofel and Levin (2007). Dixon and Kara (2011) discuss the various calibrations and the evidence for them. The unresponsiveness of marginal cost to output was called 'real rigidity' by Ball and Romer (1990).

[4] At least for our preferred measures of price dispersion.

The behaviour of these statistics during the GR is not much different from normal times.[5] Inflation was on average higher than usual during the GR, which explains most of what happened to our pricing statistics, along with the effect of the VAT changes. Our findings can be seen as complementing and contrasting with Costain and Nakov's (2011) more micro-oriented approach using The Nielsen Corporation scanner data for the US that concluded 'our estimates imply that state dependence is quite low', and also the findings of Berardi *et al.* (2015) for France using CPI data 'that during the Great Recession patterns of price adjustment were only slightly modified'.

The message of our findings for modelling monetary policy is that the magnitude of the effects of inflation is too small to be important in terms of the implied changes in our pricing statistics (e.g. frequency). The inflation targeting policy followed by many central banks over the last quarter century has led to low and stable inflation so that the feedback from macroeconomic variables to the pricing statistics is a minor second-order effect that will not normally be of importance for monetary policy. The effect of inflation is primarily found through *annual inflation*, in effect a 12-month moving summation of past monthly inflation. It takes time for monetary policy to influence annual inflation: a sustained change in monthly inflation is needed to feed through to annual inflation and hence to the frequency of price change and other statistics. In contrast, if monetary policy led to a long-term and significant increase in trend inflation, then our results imply that this would have a significant effect on aggregate pricing behaviour, which would need to be taken into account in monetary policy design.

The rest of the paper is organized as follows. In section II we describe the data and the behaviour of the pricing statistics: frequency of price change, price-level dispersion, and for price growth absolute size, dispersion and kurtosis. In section III we present the time series analysis of the relationship between the macroeconomic variables and the price statistics, with section IV concluding.

II.   The data and behaviour of prices

In this study we use a longitudinal micro data set of monthly price quotes published by the Office for National Statistics (ONS hereafter) and used to compute the national index of consumer prices. The sample spans the time period from 1996 to 2013 and includes over 20 million observations. The coverage and classification of the CPI indices are based on the international classification system for household consumption expenditures known as COICOP (classification of individual consumption by purpose). All the price-setting statistics we present are weighted across items using COICOP weights, with unweighted averages within the item.[6] In our study, we concentrate on 'regular prices': that is price quotes excluding sales and substitutions.[7] There was a change in the methodology of

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[5]This is true with our preferred estimation method of instrumental variables (IV).

[6]In US studies, such as Bils and Klenow (2004), Klenow and Kryvtsov (2008) and Nakamura and Steinsson (2008), all statistics are calculated in a similar way: 'the statistics at the ELI level are unweighted averages within the ELI'. (ELI meaning 'Entry Level Items', the US equivalent of ONS 'items'). See also Alvarez *et al.* (2016) who adopted a similar method with French CPI price quote data.

[7]We discuss this in more detail in the online appendix.

collecting data in January 2007: energy prices ceased to be collected locally and became collected centrally. In order to construct a consistent data set over the whole period 1996–2013, we removed all relevant energy prices from the data prior to 2007.[8]

The data we use are locally collected prices which are not usually online.[9] Over the period we are considering, there has been a significant increase in online shopping. In 2007 UK online shopping was about 5% of retail expenditure (Lünnemann and Wintr 2011) and in 2013 about 20%. Cavallo (2017) finds that 91% of online and offline prices are identical for the UK, the highest figure across all countries in his sample.[10] Since the increase in online shopping has been a relatively slow process, we would not expect it to affect much in our data except perhaps the trends in the period covered.

We divide up the data into three periods: precrisis (pre-2008), the Great Recession (January 2008 to December 2009) and the postcrisis period since January 2010. Our timing for the GR starts with the rapid decline in output growth. We could restrict ourselves to the NBER definition of a recession, in which case it starts later in 2008 and the end is a little earlier in 2009. However, since output was still below its 2007 level in 2013, the whole period since 2008 could be seen as part of the GR. We found that the exact specification made little difference to the one adopted in the paper of the two calendar years 2008–09.[11]

In Figure 1 we show the macroeconomic quarterly time series for annual CPI inflation and real GDP growth. We can see that in the period of the GR (2008–09) there was a precipitous fall in annual output growth from 3% at the beginning of 2008 to minus 6% by the first quarter of 2009 and a recovery to 2% by mid-2010. At the same time inflation was at high levels: the average over the two calendar years 2008–09 was almost 3% and is shown by the grey line. It peaked at almost 5% in the third quarter of 2008 and dropped to 1.4% in the third quarter of 2009, rising to over 3% by the first quarter of 2010. In the time series analysis we will use monthly data for inflation and output growth.

We now proceed to look at each of the statistics outlined above in turn and document how they behaved over the whole period.

The frequency of price changes

In Figure 2 we show the monthly frequency for all price changes and broken down into the frequencies of increases and decreases. We find that the mean monthly frequency over

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[8] In our data set, CPI component 'Energy goods' is a combination of 'Electricity, gas, and other fuels' within the COICOP division 'Housing and Utilities' and 'Fuels and lubricants' group within the division 'Transport'. The CPI weights for 'Energy goods' in the data dropped from 10.6 per cent pre-2007 to 0.4% post-2007. Leaving out energy goods largely affects the weight for division 'Transport', dropping from 15 per cent pre-2007 to 5% post-2007. However, the weight for division 'Housing and Utilities' changes little.

[9] Online prices are usually collected centrally as opposed to locally.

[10] See Cavallo (2017) Table 3 on page 291. The equivalent figure is 87% for the US and 48% for Japan.

[11] Our focus is more on the GR than the financial crisis or credit crunch. The start of the credit crunch in the UK is often associated with the bank run on Northern Rock in September 2007. Our reasoning would be that the emerging financial crisis would have had little effect on the great bulk of the sectors reflected in the CPI index. It is only in 2008 that the rate of GDP growth begins to fall. The collapse of Lehman Brothers in late 2008 is within the GR.
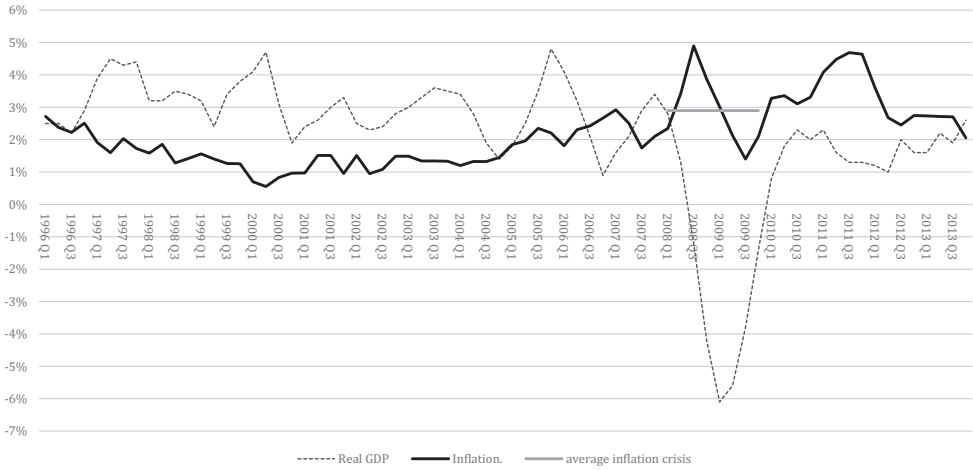
Figure 1. Quarterly inflation and output growth 1996–2013
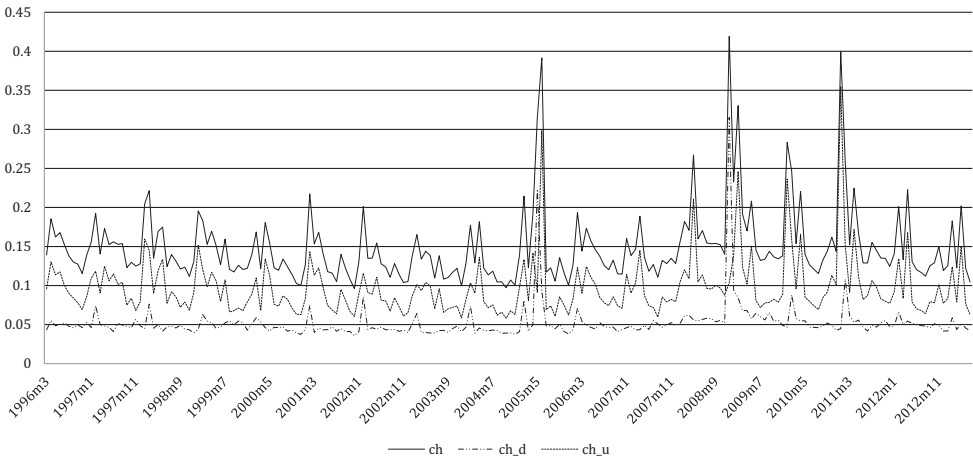
Figure 2. The time series of the frequency of price changes
Notes: "ch" denotes frequency of price change, "ch_d" the frequency of price cuts, and "ch_u" the frequency of price increases.

the whole precrisis period 1996:3 to 2007:12 is just 14.1%.[12] Indeed, if we consider the immediate precrisis period, January 2006 to December 2007, the mean is also about 14%. Looking at the crisis period, January 2008 to December 2009, the frequency is 17.2% *excluding* the VAT-induced peaks of December 2008 and January 2010. This represents a significant increase of 3.2% points (pp) in the frequency of price changes. The proportion of price increases rises from 9.1% in (2006:1 to 2007:12) to 11.1% during the crisis (2 pp): the frequency of price cuts rose by a smaller proportion from 4.8% to 6.0% (1.2 pp). This finding contrasts with the French study of Berardi *et al.* (2015), who found that

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[12] Note that this is smaller than reported in Bunn and Ellis (2009, 2012), since their data included energy prices which tend to change more often.

the recession had little effect on the frequency of price change. Overall, there is a slight downward trend over the whole sample if we exclude the VAT peaks.

Price-level dispersion

Price-level dispersion can be thought of as the dispersion of prices for the same item across different sellers.[13] The dispersion we observe in the ONS data set will thus partly reflect the choice of sellers by the ONS. We do not model this but simply take it as given: in the short run it will change little. However, in the longer run the choice of outlets and sellers will change to reflect the shopping habits of consumers. An alternative measure would be price dispersion for the same item across the same type of outlet. However, we choose the item level dispersion since this is what the consumer faces (and indeed has a choice of which type of outlet to frequent).

For price-level dispersion, we use two main measures of dispersion for each item. Firstly, the *median absolute deviation* divided by the median price (MADmed).[14] Our second measure is the interquartile range normalized by the median which we call the *standardized interquartile range* (SIQ). We need to divide both measures by the median to correct for the natural drift in absolute price dispersion that results from the background inflation over the period: in the 17 years covered by our data, the general price level measured by CPI increased by over one third. The SIQ simply looks at the range taken up by the 50% of prices 'in the middle' between the 25th and 75th quartile: it therefore ignores the 50% outside this range. While there is certainly an argument for ignoring outliers, we believe that the SIQ is too extreme: the price data we are using have already been filtered by the ONS in order to remove outliers, and we lose the information from half of the data. Finally and for completeness, we also add the coefficient of variation CV, which is the standard deviation divided by the mean. Like MADmed, this uses all prices, but puts a greater weight on outliers. All of these are measuring the same phenomenon of price-level dispersion, but differ in the weight they put on the more extreme values.

It is evident from Figure 3 that for MADmed there is a modest upward trend in price-level dispersion until 2001 after which it flattens out, albeit with variation. The crisis is associated with a very modest increase from 0.186 (2000–07) to 0.196 (2008–10), which falls back to 0.185 (2011–13). For SIQ there is little visual evidence of a crisis effect with an upward trend that was stronger prior to 2006. CV differs from the other measures in that it is increasing from 2006 to the end of the sample. The contrast between CV and the other measures of dispersion in the later years must indicate an increasing divergence of prices far from the mean and median price.

Distribution of price growth

Having looked at the frequency of price change and item-level price dispersion, we now go on to look at the distribution of price changes excluding prices that do not change (i.e. excluding the prices that have zero growth). Several studies have focussed on the

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[13] Note that an 'item' will include different brands and possibly levels of quality. However, this detail is not included in the published data, so we cannot be more specific.

[14] We also considered the *Mean* Absolute deviation divided by the mean price, but this is very highly correlated with MADmed, so we only report MADmed rather than both.
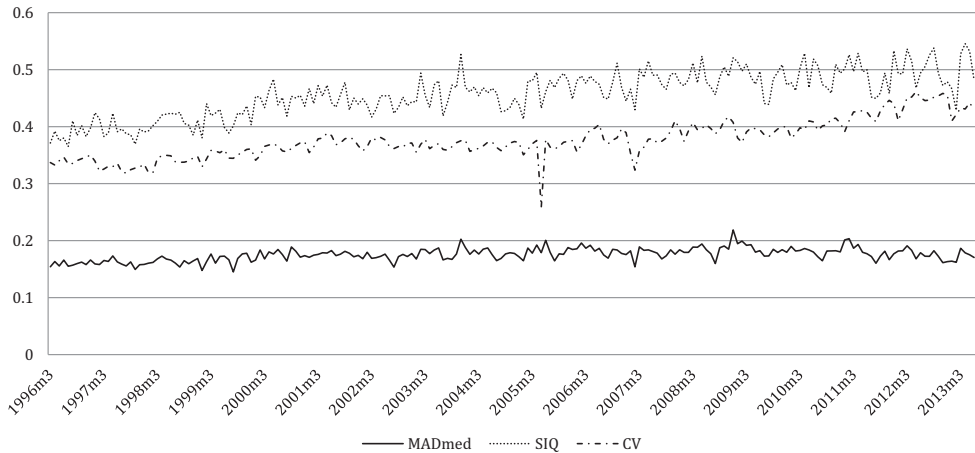
Figure 3. The time series of price-level dispersion measures MADmed, standardized interquartile range and coefficient of variation

size and dispersion of the growth in prices (see for example Midrigan, 2011; Vavra, 2014, Alvarez and Lippi, 2014; Berardi *et al.*, 2015; Alvarez *et al.*, 2016). We define the (proportional gross) price growth for price i at time t as $\Delta P_{it} = \log P_{it} - \log P_{it-1}$.

We look at this in a number of ways. First we look at the absolute proportionate size of price growth (absolute price growth, denoted SIZE). We will then go on to look at the distribution of price growth in terms of its dispersion and kurtosis. The raw data set for price quotes published by the ONS has passed a series of validity checks conducted by the ONS (see CPI Technical Manual for details). However, in this section we follow the method of existing authors: Eichenbaum *et al.* (2014) and Alvarez *et al.* (2016) both argue that the majority of both small and large changes are due to measurement error. In line with Alvarez *et al.* (2016), we therefore exclude price changes smaller than 0.1 per cent, or larger than $\ln(10/3) \simeq 1.203$ (both in absolute value). The share of outliers under this criterion in the total data set is less than 0.3 per cent.

Absolute size of price growth and its dispersion
The absolute size of price changes SIZE is calculated by taking the mean or median over all non-zero price changes in each month and both are shown in Figure 4a. Both are highly seasonal and the level increased in the early 2000s, but declined again in the period 2006–10, before increasing back to its 2005 value by 2011. The average absolute price change over the whole period is 16%, while the median is much lower at 8.5%. The median absolute price change is very similar to the figure calculated by Nakamura *et al.* (2018) for the US. The crisis period is associated with a lower absolute price change (mean 14.5%, median 7.5% from January 2008 to December 2009) than before or after, although the decline seems to have set in earlier than 2008. The decline in absolute price growth might be associated with small price cuts in the large UK supermarkets occurring in this period (Chakraborty *et al.*, 2015). The big February price spikes seen in the years prior to 2007 dissipated during 2007–12 only to reappear subsequently.

(a)

Mean Size of Price Changes -------- Median Size of Price Changes
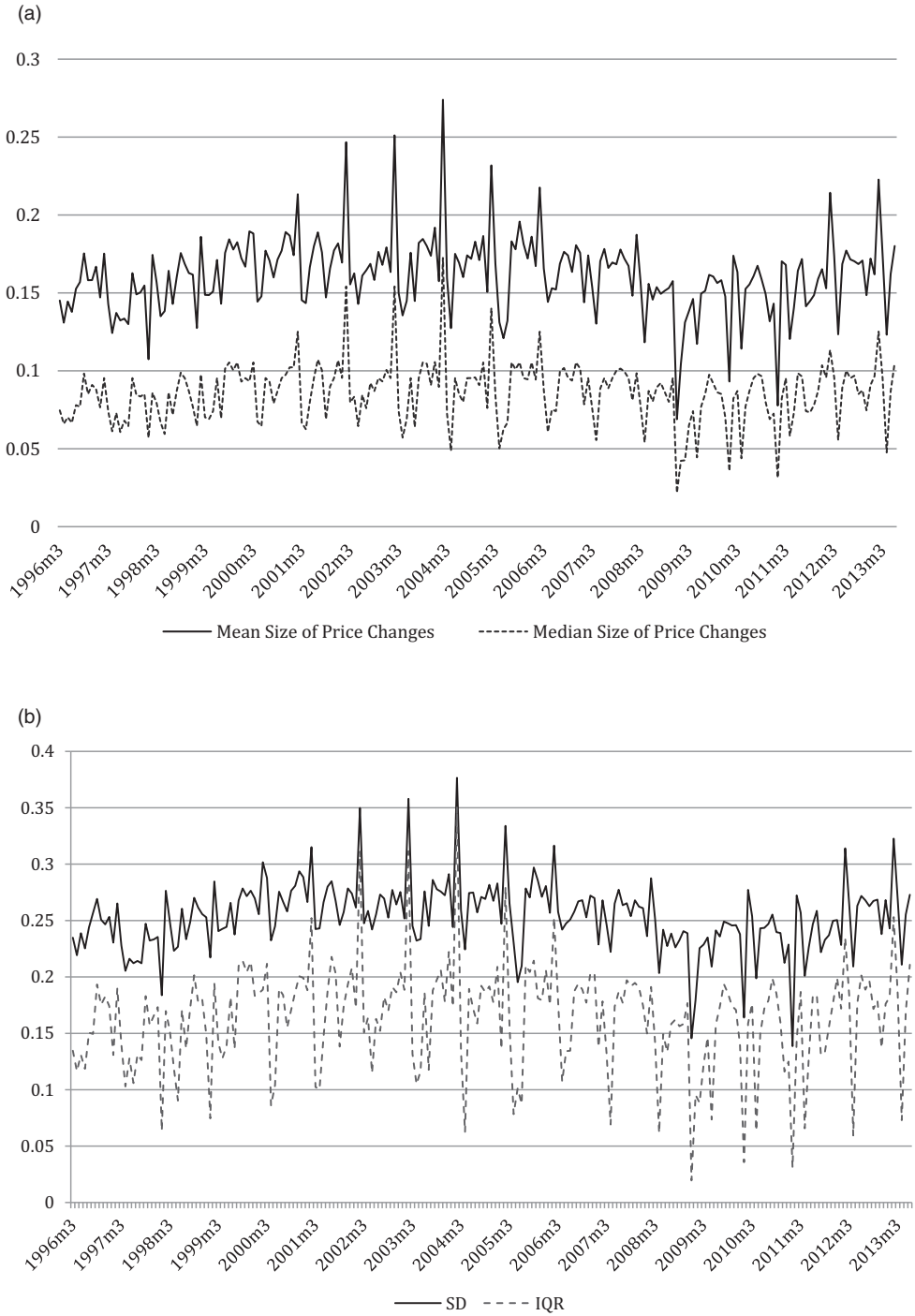
(b)

SD ---- IQR

Figure 4. (a) The time series of absolute size of price growth, (b) The time series of price-growth dispersion
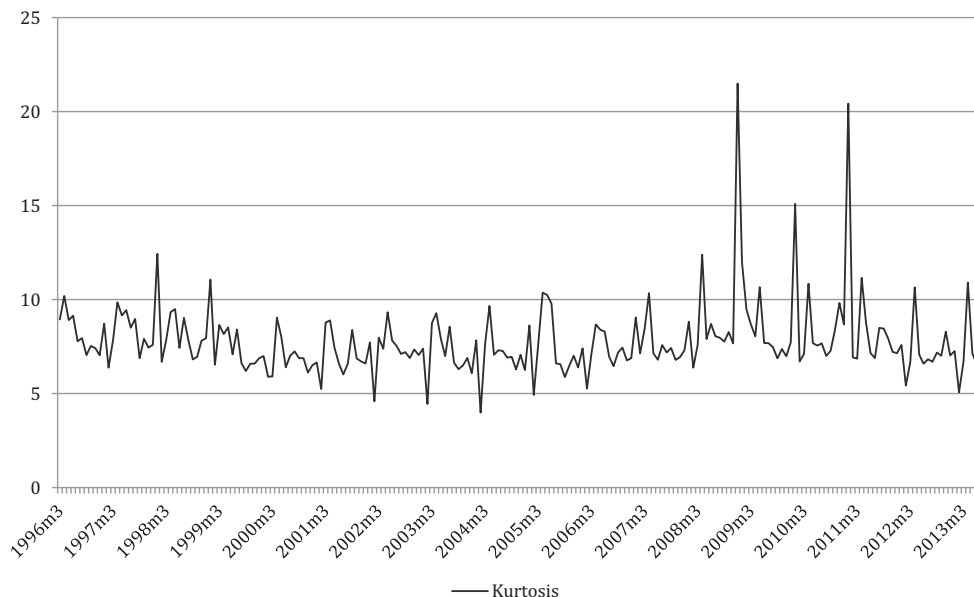
Figure 5. The time series of kurtosis

We measure the dispersion of price growth using the interquartile range (IQR). Since the growth rates are proportional they are invariant to the price level.[15] We can also measure the standard deviation of price growth, SD, which includes the extremes of the distribution outside the middle 50%. In Figure 4b, we depict the monthly time series for the regular price change data: we present two series, IQR and SD. As we can see, the two series are quite noisy and seasonal. For IQR there is an annual spike for February. The three lowest levels of price-growth dispersion occur at the times when VAT changes, when most firms are affected by the same 'shock' and so move together.

Kurtosis in the distribution of price growth
Midrigan (2011), Alvarez and Lippi (2014) and Alvarez *et al.* (2016) have stressed the importance of kurtosis of the price growth distribution.[16] As has been known since Midrigan (2011), confirmed by Alvarez *et al.* (2016) for French data and Alvarez and Lippi (2014) for US data, there is high kurtosis in the price-growth distribution: there are many small changes and a long tail of larger changes. These studies look at kurtosis taken across all time periods in the sample. For the UK, if we calculate kurtosis across all periods, the resultant kurtosis is 7.8. High kurtosis may well reflect the importance of flexible prices in the economy, since flexible prices will react even to small shocks.

Since we are interested in the *time series* properties of kurtosis, we construct a time series of monthly kurtosis calculated across all price changes in each month as shown in Figure 5. Without sales, the average monthly kurtosis is 8.00 across all products (with

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[15]Hence we do not need to divide IQR by the price level to take account of the general upward drift in prices, as we did when measuring price-level dispersion.

[16]Kurtosis is a measure of two aspects of a distribution: positive kurtosis reflects a high peak and heavy tails. The normal distribution has kurtosis of 3.

sales it is 5.70). The crisis has little effect, except for big spikes in the months affected by VAT changes, when kurtosis is much larger, as VAT changes cause a lot of prices to change together by a small amount. During the crisis there is an increase in kurtosis from 7.46 in calendar years 2006–07 to 8.90 in calendar years 2008–09. Kurtosis for 2008–09 is still higher than 2006–07 at 8.34 if we exclude the VAT change in December 2008. This increase persisted into 2010 and then fell back again.

III.   Time series estimates

Having described our basic macroeconomic pricing aggregates and their behaviour over the sample period, we now go on to analyse the relationship (if any) between price aggregates and the macroeconomic variables of inflation and output alongside other explanatory variables.

Frequency of price change

Early studies did not find significant time series evidence relating the frequency of price changes to inflation. Much of the attention has therefore focussed on cross-section evidence. For example, Bils and Klenow (2004), Dhyne *et al.* (2006), Golosov and Lucas (2007), Mackowiak and Smets (2008) and Klenow and Malin (2011) adopt an essentially cross-sectional approach looking at a range of economies, relating the average frequency of price setting to the average inflation rate (among other explanatory variables such as type of product, market structure etc.). More recently, papers by Vavra (2014) and Nakamura *et al.* (2018) have found that for the US data, inflation affects frequency positively.

It is essential to note the great heterogeneity in pricing behaviour across sectors: while some sectors have highly flexible prices, others have much more nominal rigidity. For example, in the UK 1996–2007, nearly 6% of UK prices (weighted by CPI) change price almost every month, while at the other end 20% of prices have a monthly frequency price change of below 10%. [17] For firms with menu costs, theory implies that higher inflation should be associated with a higher proportion of prices changing each month (Sheshinski and Weiss, 1977, Ball, Mankiw and Romer, 1988). However, flexible prices change often anyway and the level of inflation will have little or no effect on how often they change.[18] Likewise, with time-dependent pricing (Taylor or Calvo), inflation will also have no effect on the frequency of price change.[19] Hence the size of the relationship between inflation and frequency will depend partly on the relative shares of flexible or time-dependent prices relative to those with menu costs. Also, as Gagnon (2009) found with Mexican data, most of the effect of inflation is on raising the frequency of price increases and the effect on overall frequency may be insignificant if price cuts are decreased by inflation.

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[17] See Dixon and Tian (2017) for a breakdown by COICOP sectors.

[18] While competitive markets have flexible prices, imperfectly competitive sectors can also have flexible prices in the absence of menu costs.

[19] Empirical studies of pricing have found strong evidence of time dependency on pricing coexisting with state dependency. The probability of changing price at the firm level depends both on the time since the last price change and state variables such as cost and demand (see Leine, 2010 and Zhou and Dixon, 2018).

In this paper we adopt a time series approach which seeks to link variations in the monthly frequency to the key macroeconomic variables of inflation and output growth in the UK. The advantage of this methodology is that we can start to disentangle why the frequency of price change increased during the GR. We regress the overall frequency of price changes, and, separately, the frequency of price increases and price decreases on several explanatory variables. The list of our explanatory variables includes monthly and annual CPI inflation, monthly and annual growth in industrial output, a trend variable, and dummies for the decrease in VAT (Dec. 2008) and increases in VAT (Jan. 2010 and Jan. 2011). Calendar month dummies are added to capture the seasonality we observe in the data. We also include a crisis dummy (equal to one for Jan. 2008 through to Dec. 2009 and zero at other times) to test whether there was a special crisis effect needed to capture the behaviour of pricing in addition to the other explanatory variables during the Great Recession.

We have divided up inflation into two parts: the current monthly inflation rate (the month on month increase in the CPI price level) and the annual inflation rate (the increase in the CPI level over the last 12 months). We experimented with different lag structures on inflation. Annual inflation is a linear restriction on a general 12-month lag structure which imposes equal weights. If we estimate the general 12-month lag structure, the individual coefficients are not well determined because of collinearity. In effect, the annual inflation rate is a parsimonious way to capture the effects of lagged inflation on the frequency of price change. Adding the current monthly inflation allows for it to have a different coefficient capturing the immediate effect.

Over time, if a nominal price is fixed, it will drift away from the optimal flex price as inflation cumulates over time and is more likely to hit the critical (S,s) boundary and result in a price change. Annual inflation is a good measure, since 12 months is close to the cross-sectional mean of price spells in the UK, as estimated by Dixon and Tian (2017).[20] However, the key reason why we chose annual inflation rather than use a statistical criterion such as maximum likelihood to choose the optimal lag structure is *behavioural*. Annual inflation is how inflation is *perceived*: it is the annual inflation rate that is announced and talked about in the media and what people usually mean by 'inflation'.

Our choice of output variable for monthly data is the publicly available industrial output series.[21] We use output growth, which ensures stationarity. It may be thought that the *output gap* would be a better measure: we could de-trend the output series and interpret the residual as the output gap. However, we do not think that this makes much sense given the period considered. There exists no agreed upon measure of the output gap for UK output since 2008: output fell a lot in 2008, remained flat until 2012 and has grown modestly since then, but is still below its 2007 value at the end of our sample period. We feel that growth is an agnostic measure which is simple to understand and statistically appropriate. As with inflation, we adopt the parsimonious representation of current monthly growth and annual growth. We also include a lagged dependent variable for all equations.

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[20]Dixon and Tian (2017) used the same CPI data set over the period 1996–2007 to estimate the cross-sectional distribution of durations of price spells and examine how this relates to the average frequency of price changes.

[21]We also had access to the NIESR monthly GDP series, which is available to subscribers only. However, since the regression results were highly similar to the ones using industrial output, we chose to stick to the results using publicly available data. The results using the NIESR monthly GDP are available from the authors on request.

We adopt a single equation estimation methodology employing ordinary least squares (OLS) and instrumental variables (IV) estimates using lagged regressors as instruments. The main concerns about OLS regression are the issues of endogeneity bias and measurement errors. We employ the IV estimator which addresses these concerns. Specifically, we treat monthly and annual growth and inflation rates as endogenous covariates. The first- and second-order lags of each of these four regressors are used as instruments. The validity of these instruments is not rejected by Sargan tests. There was some evidence of residual serial correlation and heteroscedasticity which we address by computing Newey-West standard errors. OLS and IV results are largely similar, nonetheless, we attach more weight to IV estimates.

The results show that the frequency of price increases is significantly increased by annual inflation as are overall price changes (IV and OLS results) and price cuts (OLS only). Output growth is insignificant for both IV and OLS. The crisis dummy is insignificant under IV. All three VAT dummies are significant overall, except that the VAT increases in 2010 and 2011 are insignificant for price cuts as we would expect. The lagged dependent variable is significant overall and also for price cuts, but insignificant for price increases. Surprisingly, the VAT cut in 2008 is also positive and significant for price increases. The trend variable is significant and negative, showing a small decrease over time (as can be seen in Figure 2). The *P*-values of the Sargan tests do not reject the validity of the instruments in all cases at 5% or better.

Taken together, these results indicate that inflation has a clear effect on price increases, but not price cuts. Combining price cuts and increases we still find a smaller but significant positive effect. Output growth appears to play no role overall. Results appear robust across both estimators and the models show reasonable degrees of goodness of fit.

As we saw from Figure 1, there was an increase in average annual inflation over the crisis period: from a precrisis average of 2.3% (calendar years 2006–07) to crisis mean of 3.0% (calendar years 2008–09). Inflation increased by 0.7% points. Excluding VAT changes, the overall increase in average frequency from 2006–07 to 2008–09 was 0.32 pp. The coefficient on inflation in Table 1 is 0.57 (IV) for the frequency, so that on average the implied change in frequency would be 0.40 pp. However, the lagged dependent variable would dampen this effect of inflation in the short run. Furthermore the sharp rise, fall and recovery in inflation in the crisis period would lead to a lesser effect than a one-off step change (given the same mean inflation). The big drop in output growth during 2008 had no effect: while all of the coefficients are negative, they are all insignificant.

In Figure 6, we plot both the actual and predicted frequency implied by the IV estimates over the period 2006–13. Note that the exact fit for the VAT spikes are due to the VAT dummies. It is evident that the equation fits the data well and tracks the overall increase in the frequency over the crisis period as well as before and after the crisis.

Price-level dispersion

Standard New Keynesian models with time-dependent pricing predict a clear *positive* relationship between inflation and price-level dispersion: this is the main cause of welfare loss in these models (Gali, 2015). However, if inflation leads to increases in the frequency of price adjustment as we find in Table 1, inflation might lead to an increase or even a

TABLE 1

Regression results for frequency

Variables	OLS			IV		
	CH	CH_D	CH_U	CH	CH_D	CH_U
LDV	0.277***	0.184***	0.004	0.243**	0.137**	−0.069
	(0.099)	(0.034)	(0.048)	(0.118)	(0.058)	(0.078)
inflm	1.280	−0.450*	2.014**	6.673	−2.668	10.722
	(1.100)	(0.235)	(0.785)	(6.743)	(2.950)	(7.506)
infly	0.527***	0.156**	0.710***	0.574*	0.172	0.818***
	(0.199)	(0.072)	(0.137)	(0.305)	(0.143)	(0.262)
gqm	−0.037	−0.009	−0.090	−0.140	−0.698	0.609
	(0.164)	(0.064)	(0.130)	(0.862)	(0.590)	(0.768)
gqy	−0.045	−0.005	−0.061	−0.108	−0.063	−0.084
	(0.080)	(0.027)	(0.094)	(0.117)	(0.065)	(0.138)
crisisd	0.013*	0.005**	0.011	0.006	0.002	0.007
	(0.007)	(0.003)	(0.007)	(0.011)	(0.007)	(0.012)
dumvat08	0.288***	0.261***	0.027***	0.335***	0.235***	0.108*
	(0.009)	(0.003)	(0.007)	(0.059)	(0.029)	(0.065)
dumvat10	0.109***	−0.006**	0.111***	0.098***	0.008	0.082***
	(0.010)	(0.003)	(0.009)	(0.030)	(0.015)	(0.029)
dumvat11	0.234***	0.0004	0.235***	0.203***	0.021	0.176***
	(0.009)	(0.003)	(0.008)	(0.047)	(0.023)	(0.050)
R-squared	0.711	0.707	0.660	0.665	0.592	0.424
OIR	–	–	–	0.216	0.173	0.646

Notes: Newey-West standard errors are reported in parentheses. ***$P<0.01$, **$P<0.05$, *$P<0.1$. 'CH' stands for frequency of price change; 'CH_D' stands for frequency of price cuts; 'CH_U' stands for frequency of price increases. LDV is the one period lagged dependent variable; 'inflm' monthly inflation; 'infly' annual inflation; 'gqm' monthly industrial output growth; 'gqy' annual industrial output growth; 'crisisd' crisis dummy; 'dumvat08','dumvat10', and 'dumvat11' are VAT change dummies. A constant, time trend and monthly dummies are also included (estimates available on request). There are 207 observations for OLS and 206 for IV estimates. 1-2 lag periods of inflation and industrial outputs are used as instrumental variables. The row OIR reports the *P*-values of Sargan's test (of overidentifying restrictions) under the null that all instruments are valid, which are all Chi-Square (4) distributed.

decrease in price-level dispersion. As noted by Nakamura *et al.* (2018), 'This greatly limits the extent to which price-level dispersion rises with inflation in the menu cost model'. Furthermore, with flexible prices, an increase in inflation is likely to affect all prices more or less similarly (subject to idiosyncratic shocks altering relative prices) leaving the overall dispersion unaffected.

Results in Table 2 show that there is a significant *negative* relationship between annual inflation and price-level dispersion as measured by MADmed and SIQ, with no significant relationship for CV. The inflation parameter is less precise for SIQ. While some output parameters appear marginally significant for SIQ under OLS, there is no evidence of output influencing price-level dispersion for IV estimates. Likewise, while the crisis dummy is significant for OLS for MADmed, its coefficient is very small and becomes insignificant under IV for all measures. The VAT changes seem to have mixed effects: the 2008 cut increased MADmed and SIQ but not CV for both OLS and IV. The 2010 VAT reversal only
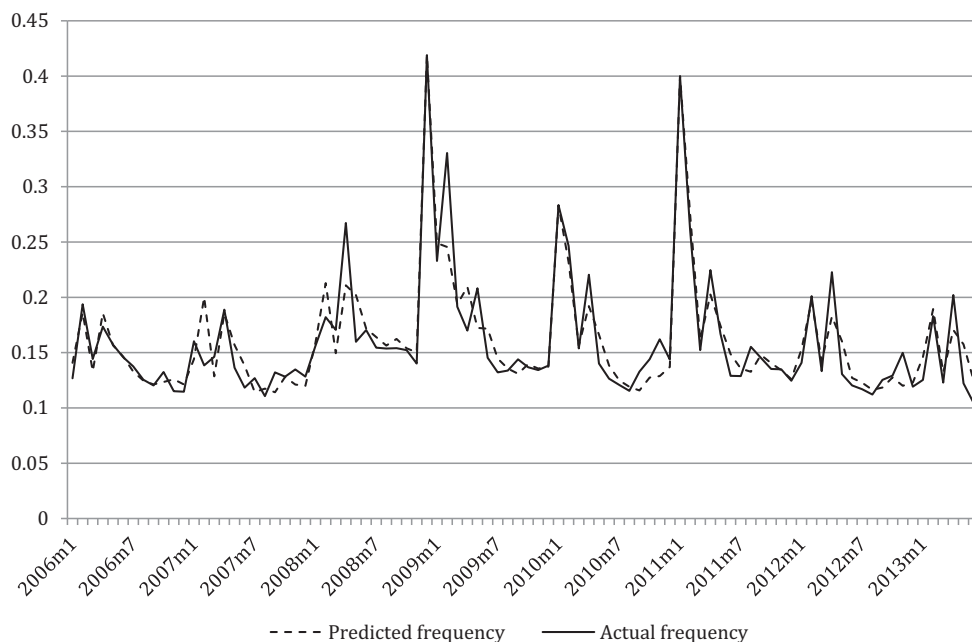
Figure 6. Actual and predicted frequency of price change 2006–13

affected SIQ under IV at marginal significance: the reversal was long pre-announced, unlike the 2008 cut. The VAT increase in 2011 increased MADmed under IV with significance only at the 10% level.[22]

If we step back, we can see that price-level dispersion has less clear overall links with macroeconomic variables than frequency. For CV, the measure is highly autocorrelated and no other variables are significant. [23] The other measures, MADmed and SIQ, tell a more consistent and largely similar story of a negative effect of inflation. However, when we look at output, the crisis and VAT dummies, there are differences between the measures and across the estimation methods. If, as seems sensible, we give priority to IV estimates, for all three measures output growth and the crisis dummy do not matter.

Price growth size, dispersion and kurtosis

Following the methodology of the previous sections, we now focus on the price-growth distribution and regress the monthly SD, IQR, SIZE and kurtosis on the macroeconomic variables and dummies, the results of which are shown in Table 3.[24]

The main result is that annual inflation has an effect which is statistically significant on all our price-growth dispersion statistics: negative on SD, IQR and SIZE, positive on kurtosis. Inflation is a common factor that potentially affects all prices: when inflation

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[22]The trend variable (not reported Table 2) shows a significant but small increases in price dispersion, as is evident in Figure 3.

[23]The trend and constant (unreported in Table 2) are significant.

[24]Note that we do not consider *skewness*. The absolute value of skewness in the UK data is small and does not represent any significant asymmetry by Bulmer's criterion (Bulmer, 1979).

TABLE 2

Regression results for price-level dispersion

Variables	OLS			IV		
	MADmed	CV	SIQ	MADmed	CV	SIQ
LDV	0.396***	0.913***	0.233***	0.385***	0.679***	0.263***
	(0.076)	(0.062)	(0.071)	(0.061)	(0.181)	(0.093)
inflm	0.129	0.194	0.209	0.766	1.087	7.472
	(0.272)	(0.280)	(0.877)	(1.831)	(2.212)	(5.516)
infly	−0.159***	0.068	−0.567***	−0.204***	0.104	−0.530*
	(0.058)	(0.064)	(0.206)	(0.064)	(0.119)	(0.321)
gqm	−0.089	0.030	−0.333**	−0.121	0.523	0.507
	(0.058)	(0.048)	(0.153)	(0.188)	(0.386)	(0.630)
gqy	0.033	0.018	0.132**	0.034	0.039	0.118
	(0.021)	(0.023)	(0.066)	(0.027)	(0.052)	(0.118)
crisisd	0.005**	0.001	0.008	0.004	0.001	0.005
	(0.002)	(0.003)	(0.006)	(0.003)	(0.006)	(0.012)
dumvat08	0.038***	−0.005	0.049***	0.043***	0.010	0.118**
	(0.003)	(0.003)	(0.011)	(0.017)	(0.021)	(0.051)
dumvat10	0.011***	−0.001	−0.010	0.010	−0.011	−0.036*
	(0.002)	(0.003)	(0.008)	(0.006)	(0.010)	(0.019)
dumvat11	0.025***	0.002	0.008	0.022*	−0.012	−0.044
	(0.003)	(0.003)	(0.009)	(0.012)	(0.016)	(0.036)
R-squared	0.618	0.901	0.725	0.605	0.837	0.554
OIR	–	–	–	0.698	0.927	0.794

Notes: Newey-West standard errors are reported in parentheses. ***$P < 0.01$, **$P < 0.05$, *$P < 0.1$. LDV is the one period lagged dependent variable; 'inflm' monthly inflation; 'infly' annual inflation; 'gqm' monthly industrial output growth; 'gqy' annual industrial output growth; 'crisisd' crisis dummy; 'dumvat08' ,'dumvat10', and 'dumvat11' are VAT change dummies. A constant, time trend and monthly dummies are also included (estimates available on request). There are 207 observations for OLS and 206 for IV estimates. 1-2 lag periods of inflation and industrial outputs are used as instrumental variables. The row OIR reports the P-values of Sargan's test (of overidentifying restrictions) under the null that all instruments are valid, which are all Chi-Square (4) distributed.

is higher prices tend to move together more which reduces dispersion. There is also a statistically significant effect of monthly inflation on IQR and Kurtosis, but only under OLS. Output has virtually no effect except for the marginal significance of monthly output growth on SD under IV. The crisis dummy is only significant with OLS estimates showing significant reductions in three of the four price-growth dispersion measures. The VAT dummies are all significant, with the sole exception of the VAT increase of 2011 for IQR under IV.

The effects of the VAT dummies are almost all significant at 1% and show consistent parameter signs. Again, VAT changes affect most prices, so that they *reduce* price-growth dispersion and SIZE (since the VAT changes were small). An increase in the proportion of small changes would also increase kurtosis. Alvarez *et al.* (2016) do not consider the time series properties of kurtosis. However, Vavra (2014) finds that in addition to a positive influence of inflation on kurtosis (as here), output has a significant positive effect which is absent here. Inflation has a strong positive effect on kurtosis. This reflects the fact that

TABLE 3

Regression results for price-growth dispersion, absolute size and kurtosis.

Variables	OLS				IV			
	SD	IQR	Size	Kurtosis	SD	IQR	Size	Kurtosis
LDV	0.319***	0.133**	0.301***	0.136***	0.270***	0.098	0.241***	0.123***
	(0.065)	(0.066)	(0.064)	(0.047)	(0.082)	(0.078)	(0.073)	(0.044)
inflm	−0.653	−3.542***	−0.928	82.813**	−1.046	−12.225	−3.129	−24.093
	(0.714)	(1.203)	(0.725)	(35.006)	(4.164)	(7.928)	(4.181)	(202.881)
infly	−0.735***	−0.757***	−0.658***	30.112***	−0.828***	−0.892***	−0.775***	29.300***
	(0.145)	(0.225)	(0.148)	(6.677)	(0.206)	(0.286)	(0.173)	(9.043)
gqm	0.046	0.146	−0.012	−2.042	0.848*	−0.000	0.526	−0.413
	(0.111)	(0.226)	(0.121)	(6.861)	(0.461)	(0.859)	(0.473)	(0.356)
gqy	0.009	0.044	0.027	−1.502	0.097	0.134	0.113	−0.076
	(0.060)	(0.113)	(0.064)	(3.353)	(0.090)	(0.161)	(0.093)	(0.064)
crisisd	−0.012***	−0.012*	−0.011**	0.479**	−0.004	−0.002	−0.003	0.181
	(0.004)	(0.007)	(0.005)	(0.213)	(0.007)	(0.015)	(0.008)	(0.379)
dumvat08	−0.102***	−0.177***	−0.111***	14.424***	−0.100***	−0.253***	−0.125***	13.323***
	(0.007)	(0.012)	(0.007)	(0.337)	(0.038)	(0.069)	(0.037)	(1.995)
dumvat10	−0.047***	−0.082***	−0.043***	5.646***	−0.057***	−0.062**	−0.046***	5.923***
	(0.005)	(0.011)	(0.006)	(0.405)	(0.014)	(0.029)	(0.014)	(1.057)
dumvat11	−0.077***	−0.088***	−0.065***	11.076***	−0.085***	−0.036	−0.060**	12.101***
	(0.007)	(0.013)	(0.007)	(0.449)	(0.026)	(0.051)	(0.026)	(1.722)
R-squared	0.716	0.608	0.702	0.807	0.644	0.485	0.650	0.794
OIR	—	—	—	—	0.191	0.291	0.105	0.199

Notes: Newey-West standard errors are reported in parentheses. ****P* < 0.01, ***P* < 0.05, **P* < 0.1. 'SD' stands for standard deviation of price changes; 'IQR' interquantile range of price changes; 'SIZE' mean size of price changes; 'KURTOSIS' kurtosis of distribution of price changes. LDV is the lagged dependent variable. 'infly' annual inflation; 'gqm' monthly industrial output growth; 'gqy' annual industrial output growth; 'crisisd' crisis dummy; 'dumvat08','dumvat10', and 'dumvat11' are VAT change dummies. A constant, time trend and monthly dummies are also included (estimates available on request). There are 207 observations for OLS and 206 for IV estimates. 1-2 lag periods of inflation and industrial output are used as instrumental variables. The row OIR reports the *P*-values of Sargan's test (of overidentifying restrictions) under the null that all instruments are valid, which are all Chi-Square (4) distributed.

inflation will tend to cause flexible prices to rise together by small amounts (at least when inflation is small as in our sample period).

Our results for a negative effect of inflation on price-growth dispersion are the *opposite* of what Vavra (2014) found with US data covering the similar but longer period 1988–2012: he found inflation has a *positive* effect on price-growth dispersion as measured by IQR. However, the empirical methodology of Vavra is somewhat different from the one we adopt in Table 3. In Online Appendix 2 we reproduce Vavra's methodology with the UK data. Our results are highly robust: we find that the seasonally adjusted and the filtered data both display negative correlations between price-growth dispersion. The difference is therefore between the behaviour of prices in the UK and the US, not the differences in estimation method.

While the empirical results for the UK are different to the US results of Vavra, they are quite consistent with the theoretical framework put forward by Vavra. Vavra adopts the (S,s) model found in Barro (1972), Sheshinski and Weiss (1977), Dixit (1991) and elsewhere, arguing that 'volatility shocks' will lead to increases in both the frequency of price adjustment and the standard deviation of price growth. The (S,s) model is of course very specific. It adopts the statistical framework of Brownian motion in assuming that the optimal price can be modelled as Brownian motion without drift: the 'volatility' is interpreted as the standard deviation of the Wiener process. However, as Vavra's own Proposition 2 shows, an aggregate shock can lead to exactly the behaviour we find in the data: an *increase* in the frequency of price changes coupled with a *decrease* in the standard deviation of price growth. It is essentially the same argument as for the VAT dummies: a change in tax causes prices to change (an increase in frequency) and many change by the same proportionate amount (a fall in the price-growth dispersion and rise in kurtosis).

The story for price-growth dispersion is largely the same as for frequency and price-level dispersion. Inflation matters, output growth does not. The crisis dummy is unimportant (at least for IV). What is different is the consistent and significant story told by the VAT dummies: they are exactly what we would expect since they generate similar small changes across a wide range of prices.

IV. Conclusion

In this paper we have focussed on the effect of macroeconomic variables on the pricing behaviour of firms as reflected in aggregate statistics such as the frequency of price change, the dispersion of price levels and the distribution of price growth (absolute size, dispersion and kurtosis). These statistics have all been the focus of interest in recent papers. Our main finding is that there is clear evidence of a link between *annual* inflation and these aggregate statistics. We believe this is a very robust result.[25]

How do our results help us to interpret what happened to pricing during the GR? Output growth fell dramatically and was negative for much of the GR, while inflation was on average high at 3%. The fall in output growth had little effect on pricing behaviour: the general increase in inflation over the crisis period dominated. Higher inflation led

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[25]This macroeconomic effect is quite consistent with the view that idiosyncratic shocks matter more at the firm level. This is a theme in the rational inattention literature of Mackowiak and Wiederholt (2009).

to a higher frequency of price changes, a reduction in the dispersion of price growth, a reduction in the absolute size of price changes and an increase in kurtosis, even allowing for the effects of the VAT changes. The behaviour of price-level dispersion during the GR is harder to explain: it increased a little during the recession when the increase in inflation would have led one to expect a decrease. However, the fact that the crisis dummy is insignificant indicates that the magnitude of the change is relatively small.[26]

Taken at face value, this implies that state-dependent pricing models are right: when the going gets tough, firms respond by changing their prices more. However, it remains to be seen whether the extent of state dependence of prices on macroeconomic variables is significant when we come to model monetary policy. For example, does the effect of inflation on the frequency of price change we have detected indicate that monetary policy will have a significant effect on pricing which we will need to take into account when modelling monetary policy, as has been argued by Petrella, Santoro and Simonson (2018)?

The effect of an increase in annual inflation on frequency is small: a 1% point increase in annual inflation will lead to a 0.6% point increase in the frequency. A small change in frequency will not lead to a large change in the behaviour of the economy. In the UK over the period of this study, annual inflation varied between 0% and 5%, but for the first decade prior to 2006 it was in the range 1%–3%. The effect of inflation on frequency would have been at most 3% points, while in the more normal ranges prior to 2006 the effect would have been at most 1.2% points. In any reasonable calibration of a DGSE model such variations would be almost negligible.[27]

However, if we consider more extreme forms of monetary policy, then the inflation effect might well become significant. For example, if the government raised the inflation target to 10% then we would expect to see a more significant increase in the average frequency of 6% points and the economy would see a clear reduction in nominal rigidity making monetary policy less effective in stabilizing output. However, sustained high inflation rates have not been observed in OECD countries in the last quarter century and are more likely to be a feature of emerging economies.

While we find that inflation influences pricing statistics, we believe that this does not mean monetary policy needs to take this effect into account: indeed, time-dependent models will remain a good approximation unless there is a significant and prolonged increase in trend inflation.

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[26] There is little evidence of a need for an 'uncertainty' variable which some authors have argued was an important factor in the crisis period (for the US see Vavra, 2014).

[27] In an earlier draft of the paper (CESifo working paper 4226) we calibrated a simple dynamic macromodel with Calvo pricing in which the Calvo parameter was influenced by inflation according to our estimates. The resultant impulse responses were almost identical except for the small variation in the frequency.

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