The impact of the 2008 crisis on UK prices: what we can learn from the CPI microdata[*]

Huw David Dixon[†], Kul Luintel[‡], Kun Tian[§],
CPI@Cardiff, Cardiff Business School.

August 6, 2014

Abstract

This paper takes the locally collected price-quotes used to construct the CPI index in the UK for the period 1996-2013 to explore the impact of the crisis on the pricing behavior of firms. We develop a time-series framework which is able to capture the link between macroeconomic variables (inflation and output) and the behavior of prices in terms of the frequency of price change, the dispersion of price levels and the dispersion of price-growth. Whilst these effects are present, they are small and do not have significant effects for monetary policy.

JEL: E50.

Keywords: Price-spell, steady state, duration.

[*]We would like to thank Jeff Ralph and Ainslie Restiaux at the ONS for their help. This was presnted at the EMF meeting March 2014 and the Bank of England May 2014. We would like ot thank Matt Canzoneri, Dale Henderson, Herve Le Bihan, Patrick Minford, Greg Thwaites, Rupert de Vincent-Humphries and participants for their comnments. Faults remain our own.

[†]Cardiff Business School, Colum Drive, Cardiff. CF10 3EU, dixonh@cardiff.ac.uk (corresponding author).

[‡]luintelk@cardiff.ac.uk.

[§]Tiank1@cardiff.ac.uk

The period 2008-2010 saw the biggest recession in British post-war economic history: it also witnessed 20% devaluations of sterling against the Dollar and Euro along with inflation well above the levels seen in the preceding decade. In this paper, we seek to document the impact of these events on the behavior of prices as captured by the CPI microdata on price-quotes used to construct the Consumer Price Index. Our data extends from the Great Moderation period until the post-crisis recovery period, spanning 1996-2013 with over 20 million price-quotes covering a wide range of items. The fundamental issue is to see how far these big macroeconomic events were reflected by changes in the behavior of price-setters. We look at the behavior of prices from a number of perspectives: the "frequency" or proportion of prices which change in a given month (sub-divided into changes up and down); the dispersion of prices for the same product; the distribution of the growth of prices. There was also a temporary reduction in VAT (from December 2008, reversed in January 2010), plus a permanent increase (introduced in January 2011) which may also shed light on pricing.

How the behavior of prices has changed has important implications for how we should model the pricing behavior of firms. The first key relationship between the macroeconomy and pricing is inflation: we find that inflation has a significant effect on the frequency of price change, the distribution of prices and the distribution of price-growth. From a theoretical perspective, menu-cost models imply that higher inflation should be associated with a higher proportion of prices changing each month (Sheshinski and Weiss (1977), Ball et al. (1988)). This is indeed what we find: both the overall freqeuncy of price-change and the proportion of price hikes are increasing in the annual inflation rate. We find that this relationship holds across the whole period, including the Great Moderation (prior to 2008), something which has eluded previous studies (see Klenow and Malin (2011), fact 8). Our finding is that a 1% increase in annual inflation causes an increase in the monthly frequency of about 0.9%: thus for example an increase in inflation from 2% per annum to 5% might cause the monthly frequency to increase from 15% to 17.7%. Whilst there is a clear link between inflation and the frequency of price-change, it is important to note that in "normal" times when inflation is successfully stabilized, these effects will be very small. Indeed, monetary policy will not have much effect on the pricing behavior of firms unless it results in large sustained changes in inflation. This finding suggests that time-dependent models of pricing may well be a good approximation when we are looking at optimal monetary policy in low inflation economies.

The second key relationship in macroeconomic theory is between inflation and price-dispersion. Indeed, in the standard time-dependant New Keynesian DSGE model, the main source of welfare losses is price-dispersion which are generated by inflation. Some search theoretic models (e.g. Head and Kumar (2005)) suggest a negative relationship between inflation and price-dispersion (people search more when inflation is higher, leading to higher price-sensitivity). We focus on price-level dispersion for the same product measured by the coefficient of variation: aggregate price-dispersion is built up by aggregating from the product level. The relationship between inflation and price dispersion is harder to uncover, but we are able to find a positive relationship between inflation and dispersion.

The third key relationship is between aggregate output growth and price behavior. There is a problem here: our pricing data is monthly whilst the only reliable monthly output data is for industrial production which is only a small proportion of GDP. We therefore consider monthly data using industrial output, but also a quarterly model using GDP data. The quarterly data finds a significant negative effect of GDP growth on frequency whilst the monthly data is insignificant albeit with the same negative sign. This is similar to the result found in Vavra (2014) for US CPI data.

We take a structured empirical approach in estimating these relationships. In order to ensure comparability with the existing literature we employ single equation based estimators - the heteroscedasticity consistent OLS estimator or the instrumental variable (IV) estimator, the latter on grounds of possible endogeneity. We place greater emphasis on the more efficient OLS estimates when we find the explanatory variables to be weakly exogenous. However, any macroeconomic shock may impact on two or more of the four variables (frequency of price changes, price dispersion, price growth dispersion and kurtosis) generating contemporaneous correlations across the residuals (errors) of these equations. It is well-known that exploiting these contemporaneous error correlations improves the efficiency of the parameter estimates. Furthermore, frequency of price changes, the level of price dispersion and the dispersion of price growth could be simultaneously determined. To the best of our knowledge, these relationships have not been analyzed as a system which explicitly allows for cross equation contemporaneous error correlations and endogeneity. We bridge this gap by employing Three Stage Least Squares (3SLS) estimator. Given the importance of contemporaneous error correlations and endogeneity we attach most importance to our system based results. Broadly speaking, we find that the single equation OLS estimates and the system estimates are in agreement.

We summarize the empirical results of the paper in a series of "findings". These findings relate to "regular prices", that is after the price-quotes have been filtered to remove sales, substitutions and outliers as explained in detail below[1]. The detailed findings are given in the body of the paper: here we present simplified versions. Findings 1-10 relate to the single equation OLS estimates: Finding 11 the 4 equation 3SLS estimators.

Finding 1: The monthly frequency of price changes increased from pre-crisis level of 0.141 to crisis level of 0.186, and then dropped to post-crisis level of 0.157. The overall average frequency of price change across the whole sample is 0.149.

Finding 2: The frequency of price change is influenced positively by the annual inflation rate and is highly seasonal. However, for the single equation estimates there is a significant and positive "crisis effect" which increases the frequency by about 0.02, being 44% of the overall increase.

Finding 3: The monthly frequency of price hikes and price cuts are both increased by annual inflation: monthly inflation also has a less significant effect, increasing price hikes but reducing the frequency of price-cuts. VAT changes are mostly significant with expected signs. The crisis dummy has a significant positive affect on the frequency of price cuts and price hikes.

Finding 4: There is considerable heterogeneity across the 11 COICOP divisions for monthly data in how frequency is affected by macroeconomic variables.

Finding 5: The quarterly frequency of price change is positively related to annual inflation and negatively related to the current quarters GDP growth.

Finding 6: Annual inflation is positively correlated with price-dispersion. Frequency is negatively correlated with price-dispersion. And price-dispersion is positively correlated with it previous value.

Finding 7. With quarterly data, aggregate price-dispersion as measured

[1] Sales and subsitutions are two types of price changes differ significantly from regular prices changes. And sales and substitutions have quite clear seasonal pattens and have bigger effect on some divisions of consumer goods. We distinguish those two types of price changes and compare the estimation results for those including/excluding sales and substitutions. Generally speaking, the overall estimation results are quite consistent no matter sales included or excluded. But there are also some exceptions. To make it easy to understand, we document key findings based on regular prices, and leave the other findings in tables maybe put in appendix. More specifically, we focus on the behavior of regular price, excluding the price quotes which are sales and substitutions. Outliers are also excluded in a way consistent with Alvarez et al. (2013).

by the CV is positively correlated to annual inflation and the lagged term of CV, but negatively related to current quarter GDP growth. There is a significant time trend, and some seasonality.

Finding 8: The dispersion of price-growth is negatively correlated with inflation, but not significantly correlated with output. It is declining for the VAT changes and has a very slight upward trend.

Finding 9: The smoothed frequency of price-change is negatively correlated with the smoothed dispersion of price-growth.

Finding 10: Price-growth Kurtosis is acyclic, seasonal and highly sensitive to VAT changes. Inflation has a positive effect and there is a small but significant downward trend.

Finding 11: (Quarterly data, system estimates) Inflation has a significant positive effect on the frequency of price change, the dispersion of price levels, price growth Kurtosis and a negative effect on price-growth dispersion. Output growth has a significant negative effect on frequency and price-level dispersion. The crisis dummy is insignificant for all 4 equations.

What are the implications of our findings for how we model monetary policy? We have found clear evidence of state-dependent pricing. Does this mean we must abandon time-dependent pricing models? In order to answer this question, we develop a simple "state dependent" Calvo model that allows for the Calvo reset probability to vary with inflation and output which can be calibrated to our empirical estimates. We can then compare the effect of macroeconomic variables on pricing implied by our estimates. In fact we find that there is little effect: the impulse response functions for the state-dependent Calvo model are not much different to the standard Calvo model. We believe that whilst pricing is clearly state-dependent, the feedback from macroeconomic variables to pricing is a second-order effect that will not normally be of importance when we model monetary policy. The reason for this is twofold. First, the effect of inflation is primarily found through annual inflation: in effect a 12 month moving average of monthly inflation. It takes time for monetary policy to affect this annual inflation figures: you need a sustained change in monthly inflation to feed through to annual inflation and hence to the Calvo reset probability. Secondly, a change in the current reset probability has little effect on the reset price: since pricing is forward looking, what matters is are the reset probabilities stretching into the future. You need a sustained increase in inflation to have a sustained effect on the reset probabilities. These two reasons mean that a short term monetary "shock" is unlikely to have much effect on pricing behavior.

The crisis of 2008-2010 had a big overall effect on the frequency of price-change. However, if we focus on the specific menu-cost model, our data suggests that the "crisis" is an aggregate shock which affected the whole economy. This is consistent with Finding 9, which was the opposite of what Vavra (2014) found for the US. We thus find no evidence for the "uncertainty shock" which the US data supports.

In section 1 and the appendix we describe the data. In section 2, we desribe the behaviour of the four price-setting statistics: frequencey of price change, dipsersion of price-levels, dispersion and Kurtosis of price-growth. In section 3 we present the time series analysis of the relationship between the macroeconomic variables and the price statisitics, both in a single equation approach and estimated together as a system in section 4. We present the state-dependent Calvo model to explore the implications of our findings for monetary policy in section 5 with section 6 concluding.

1 The Data.

In this study we use a longitudinal micro data set of monthly price quotes collected by the Office for National Statistics (ONS hereafter) from over ten thousand outlets to compute the national index of consumer prices. There are two basic price collection methods utilized by the ONS: local and central. Local collection is used for most items. There are about 150 locations around country, and around 110,000 quotations are obtained each month by local collection. For some items, collection in individual shops across the 150 areas is not required- for example, for larger chain stores who have a national pricing policy or where the price is the same for all UK residents or the regional variation in prices can be collected centrally. Central collected date cover about 33% of CPI, and are not available to our research[2]. Our CPI research data are locally collected[3], covering the remaining two thirds of total

[2]The central collected data set include price quotes for education, some of the energy goods, and some of the communication services.

[3]Local collection is usually done on the index day, which is always the second or third Tuesday of the month. Normally, there are four weeks between index days. However, there are five weeks between the index days for Decemeber and January, and April and May and on two other occasions during the year. Local collectors collect all prices every month except for seasonal items when they are not in season and periodic prices which are only collected in three or four months in each location. In the months when periodic

CPI. The sample spans over the time period from March 1996 to June 2013 and includes over 20 million observations. It is worth of notice that the price usually used is that for a cash transaction, inclusive of Value Added Tax (VAT) and compulsory service charges are included.

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). This is a hierarchical classification system comprising: *divisions* e.g. 01 Food and non-alcoholic beverages, *groups* e.g. 01.1 Food, *classes* e.g. 01.1.1 Bread and cereals, and *items* e.g. 210111 White sliced loaf branded 800g. In our locally collected data, there are about 500 items per month with description given by ONS. The CPI expenditure weights at COICOP 6-digit level are attached to each item. For concreteness, all the statistics we present on price setting features are weighted across items. The statistics at the item level are unweighted averages within the item.[4]

In our study, we concentrate on "regular prices": that is price-quotes excluding sales and substitutions (we discuss this in more detail in appendix). There are many possibilities about how to look at the data and we wanted to adopt an approach which is consistent within our paper and comparable with others. The raw "posted prices" including sales and substitutions just takes the data as it is and leaves nothing out. We follow most other authors in filtering out price-changes due to sales or substitution. Sales are either temporary price-reductions that are reversed or "end of season" reductions (for example with clothes). Substitution happens when the price-quote is obtained for a good that is not exactly the same as previously. We have also used the data filtered in different ways and unfiltered: the results we report are robust. There was an important change in methodology of collecting data in January 2007: energy prices ceased to be collected locally and became collected centrally. In order to construct a consistent dataset over the whole period 1996-2013, we removed all relevant energy prices from the data prior to 2007[5].

items are not collected in a location, the previous month's prices are carried forward.

[4]In US studies, such as Bils and Klenow (2004), Nakamura and Steinsson (2008),Klenow and Kryvtsov (2008), all statistics are calculated in similar way:"the statistics at the ELI level are unweighted averages within the ELI." (ELI:Entry Level Items) Also see Alvarez. et al (2013) adopted similar method on French CPI micro data.

[5]In our dataset, CPI component "Energy goods" is a combination of "Electricity,gas, and other fuels" within division "Housing and Utilities" and "Fuels and lubricants" within

We divide up the data into three periods: pre-crisis (pre-2008), crisis (January 2008 to December 2009) and the post-crisis period since January 2010. Whilst there can be little argument with the start of the crisis (when output began to fall), the precise end is somewhat more open to question. Since output is still below its 2007 level, the whole period since 2008 could be seen as relevant. We could restrict ourselves to the NBER definition of a recession, in which case the end is a little earlier in 2009. We found that the exact specification made little difference. Indeed, as we will argue in section 5, whilst the crisis dummy is significant in most single equation estimates, it becomes insignificant when we allow for endogeneity and the contemporaneous correlation of shocks.

2 What has happened to prices.

In this section, we outline and describe what has happened to prices over the period 1996-2013 as captured by our 4 price statistics.

2.1 The frequency of price-Changes.

If we focus on regular price (in which sales and substitutions are excluded) without outliers, we find that the mean monthly frequency over the whole pre-crisis period 1996:3 to 2007:12 is just 0.141.[6] Indeed, if we take the mean over the immediate pre-crisis period July 2005 to December 2007 the mean is about 0.134 (it is 0.137 for the calendar year 2007). Looking at the crisis period, January 2008 to December 2009 the frequency is 0.186 (0.172 excluding the VAT induced peaks of December 2008 and January 2010). This represents a significant proportional increase of 28% in the frequency of price changes excluding the temporary VAT changes. The proportion of price increases rises from 0.087 in (2005:7 to 2007:12) to 0.111 during the crisis: the frequency of price cuts rose by a similar proportion from 0.047 to 0.061. This finding contrasts with the French study of Berardi et al (2013), who found that the recession had little effect on the frequency of price change.

the division "Transport". The CPI weights for "Energy goods" in the data dropped from 10.6 per cent pre-2007 to 0.4 per cent post-2007. It largely affects the weight for division "Transport", dropping from 15 per cent pre-2007 to 5 per cent post-2007. However, the weight for division "Housing and Utilities" changes little.

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

Figure 1:The monthly frequency of price changes.

Finding 1: The monthly frequency of regular price changes increased by 40% from the pre-crisis level of 0.141 to a crisis level of 0.186, and then dropped to a post-crisis level of 0.157. If we exclude the temporary VAT changes, the crisis frequency reduces to 0.171, representing a 28% increase relative to its pre-crisis value. If we exclude the effect of the temporary VAT changes, both price cuts and price hikes increased by a similar amount.

Table1: The frequency of price-changes decomposed by sector and direction.

If we look at the 11 COICOP sectors for which we have data, we can see that the increase in frequency is not spread evenly across sectors. In some sectors there is a significantly larger increase in the overall frequency of price changes: *Communications* (COM), *Furniture, Household Equipment and Household Maintenance* (FHM), *Recreation and Cultures* (R&C), *Health* (HEA) and *Miscellaneous Goods and Services (*MGS*)* all go up by 60% or more; whilst *Housing,Water,Gas,Electricity and Other Fuels* (H&U) and *Restaurants and Hotels*(R&H) only increase merely over 16%. If we look at the frequency of price hikes versus cuts, we can see that for the COICOP sectors HEA, FHM, MGS, the above average increase in the overall frequency of price-changes is largely driven by a large increase in price-cuts (161.9% for HEA, 94.6% for FHM, and 93.8% for MGS). Also, *Communications* (COM) has price-hikes almost doubling. The time-series for each COICOP sector are included in Appendix 2. We can see that there is a great diversity in what the individual time-series look like. Seasonality if obviously very important for some sectors. For example, in ABT there are peaks in April (the month when Alcohol and Tobacco duties are changed each year), along with seasonal sales of alcohol (Christmas and the "mid-summer" barbecue season). *Housing,Water,Gas,Electricity and Other Fuels* (H&U) peaks every January when the frequency doubles from the rest of the years 10% or less up to 20%). Some sectors have a much less seasonal structure: for example COM.

2.2 Price-Dispersion.

Price dispersion can be thought of as the dispersion of prices for the same item across different sellers. The dispersion we observe in the ONS dataset 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-dispersion, we use two measures. Firstly, the coefficient of variation (CV) which is the standard deviation of prices divided by the mean. This is built up item by item and aggregated using CPI weights. There are about 500 items per month with descriptions given by ONS. The CPI expenditure weights at COICOP 6-digit level are attached to each item. Secondly, we use the interquartile range normalized by the median which we call the *standardized interquartile range*, SIQ. We need to divide by the median to correct for the natural drift in absolute price dispersion that results from the background inflation over the period: in the 14 years covered by our data, the general price level measured by CPI (or indeed other measures such as RPI or PPI) has increased by over one third. The CV and SIQ allow us to measure changes in dispersion against this background of inflation. The difference between the two measures lies in how they deal with the distribution of prices. 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. Whilst there is certainly an argument for ignoring outliers, we believe that the SIQ is too extreme: the price-data we are using has already been filtered by the ONS in order to remove outliers, and we lose the information from of half of the data. The CV in contrast uses all of the data and whilst we have to be careful to avoid the undue influence of outliers, it uses all of the available information. Whilst we focus on the CV as our measures of preference, we also report results relating to the SIQ as a measure that has been used in other recent studies such as Vavra (2014).

Figure 2: Price-dispersion as measured by the aggregate CV

We can see from the CV that there is a modest upward trend in price-dispersion until 2001 after which it flattens out. As with the frequency data, there is a blip in mid-2005 which we assume to be due to data collection issues. If we compare the CV for the pre-crisis period 2005:7 to 2007:12 with the crisis period 2008:1 to 2010:1 , the CV shows a small 1.8% increase from 37.6% to 39.4%: however, this increase disappears if we omit the two months with VAT change. We can thus see that although the crisis had a major effect on the frequency of price-changes, it did not result in a significant change in price-dispersion.

Table 2: Price dispersion in aggregate and by sector before and during the crisis.

If we look at the different COICOP sectors[7] in Table 2, we can see that there is some diversity across the sectors. Over the whole period, we can see that in some sectors the CV is trending upwards most of the time: ABT, C&F, H&U, FHM, HEA. In others it is pretty flat with some short-term fluctuations: TRA, R&H, MGS.

If we focus more on the period leading up to the crisis and the crisis itself we also see heterogeneity across sectors. Some sectors hardly change at all: FNB and R&H actually fall slightly, whilst FHM and HEA increase slightly. However, there are big changes in R&C, H&U and ABT. The biggest change of all is in COM: however, we believe that this reflects some change in methodology of collecting prices, as there is one off a step change in September 2009 after which the new level is maintained. Given the small weight of COM in the CPI basket (1.7%), this does not have any influence on the aggregate. A similar "step change" occurred for R&H in April 2000 which was reversed in January 2001: no doubt again the ONS methodology is the probable culprit.

For the SIQ we see a similar story to that told by the CV. Price-dispersion has a small jump before and after 1999, and then largely stay in the same level (the rise is from around 45% in the mid 90s to 50% since March 1999). There are minor fluctuations post 2001: in particular, from mid 2005 it falls from the 50% to just over 45%, but quickly recover to its higher level. As with the CV, there is no obvious impact of the crisis except for this mild upward trend.

2.3 The Dispersion of Price Growth.

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).

[7]The CV time series for each COICOP sector are depicted in Appendix 1 Figure A3.

However, in this section we follow the method of existing authors: Alvarez et al. (2013) and Eichenbaum, Jaimovich, Rebelo and Smith (2013) both argue that the majority of small changes and large changes are due to measurement error. In line with Alvarez et al. (2013), we therefore exclude price changes smaller than 0.1 percent, or larger than ln(10/3) (both in absolute value). The share of outliers under this criterion in the total data set is less than 0.3 percent.

Several studies have focussed on the size and dispersion of the growth in prices conditional on prices changing, i.e. excluding zero growth rates (see for example Midrigan 2011, Vavra 2013, Alvarez and Lippi 2014, Alvarez et al 2013, Berardi et al 2013). If we define the price-growth as for price i at time t as $\Delta P_{it} = \log P_{it} - \log P_{it-1}$ then we can measure the dispersion of price-growth using the interquartile range- IQR - since the growth rates are proportional to the levels, there is no need to standardize the IQR as we do when measuring price-level dispersion. We can also measure the standard deviation of price-growth SD, which includes the extremes of the distribution outside the middle 50%. In Figure 3, 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. In particular, for IQR there is an annual spike for February representing the recovery from the January sales. The three lowest levels of price-change dispersion occur at the times when VAT changes, when most firms are affected by the same "shock".

Figure 3: The time series of raw price-growth dispersion

2.4 Higher moments of the distribution of price-growth.

Midrigan (2011), Alvarez and Lippi (2014) and Alvarez et al (2013) have stressed the importance of the Kurtosis of the price-growth distribution. Kurtosis is a measure of two aspects of a distribution: positive Kurtosis is a reflects a high peak and heavy tails. The normal distribution has Kurtosis of 3, and many studies use excess Kurtosis as the measure, being Kurtosis minus 3 (so that the normal distribution has zero excess Kurtosis). The standard (S,s) model implies that there will not be many small price-changes: it will not usually be worth paying a fixed menu-cost to change your price a small amount. As has been known since Midrigan (2011) and confirmed by Alvarez and Lippi (2014) for US data and Alvarez et al (2013) for French data, there is a lot of Kurtosis in the price-growth distribution: there are many small changes and a long tail of larger changes. For example, looking at all price changes Alvarez et al (2013, Table 1) find Kurtosis of 20.8 if you exclude sales: this is not dissimilar to the magnitude found in US studies (Nakamura and Steinsson 2008). A large part of the explanation for this high value is the presence of a large mass of small price changes. Alvarez and Lippi (2013) have developed the (S,s) dynamic menu-cost model to the multiproduct monopolist. This assumes that when the firm pays the menu cost, it can change all of its prices at the same time at no additional cost. This will result in small price changes as well as larger ones (if the marginal cost of changing an extra price is zero, why not make even small adjustments if you are ready to change to least one price anyway).

We conduct two exercises. First, we replicate Alvarez et al (2013) and calculate Kurtosis across the whole time-period. We adopt two methods: one is to look at the distribution of price growth across all prices and all periods; the second is to look at each product and type of outlet and calculate the Kurtosis, then aggregating over all products. We also calculate this both including all observations and excluding outliers as in Alvarez at al (2013). The results are depicted in Table 3.

Table 3: Selected moments from the distribution of price changes

The UK results indicate that if we calculate Kurtosis across all price growth and exclude outliers, the resultant Kurtosis is 5.7 if we include sales, 7.8 if we exclude sales. With outliers, Kurtosis increases to 16.7 excluding sales, 23.6 including. Building up from the product-outlet type, we find that Kurtosis is larger (without outliers, 9.31 excluding sales and 11.92 including).

Figure 4: Time series of monthly Kurtosis

The second exercise is to construct a time-series of monthly Kurtosis calculated across all price changes in that month. The evidence here is that the average Kurtosis is consistent with the data across all periods as shown in Figure 4. Without sales, the average across all months is 8.00 across all products (with sales it is 5.70). The crisis has little effect except in the months affected by VAT changes when it is much larger (as we would expect - VAT changes cause a lot of prices to change together).

3 Time series estimates: single equation.

Having described our basic macroeconomic pricing aggregates and their behavior over the sample period, we now go on to analyse the relationship (if any) between price aggregeates and the macroeconomic variables of inflation and output. We do this in two stages: first we look in detail at each aggregate using a single equation methodology. Secondly, we estimate the whole system which enables us to better uncover the underlying relationships.

3.1 Frequency of price change.

Previous studies have not been able to find a significant time-series evidence relating inflation to the frequency of price-changes. 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 (2010) adopt an essentially cross-sectional approach looking at a range of economies or studies, relating the average inflation rate (amongst other explanatory variables such as type of product, market structure etc.) to the average frequency of price-setting. An exception is Hoffmann et al. (2006) who undertook a time series regression using overall frequency of price changes calculated from Germany micro CPI data. They found that VAT, Euro changeover along with seasonal dummies and trend significantly affect the frequency of price changes. However, the macroeconomic variables of inflation and output were not included.

In this paper we adopt a time-series approach which seeks to link variations in the monthly or quarterly frequency to the key macroeconomic variables of inflation and output growth. The advantage of this methodology is that we can start to disentangle why the observed frequency price change increased in response to the crisis. 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 encompasses monthly or quarterly change in CPI, annually change in CPI, monthly or quarterly growth in Industrial Output, annually change in Industrial Output, a trend variable, dummies for decrease in VAT (in Dec. 2008) and increases in VAT(in Jan. 2010, and Jan. 2011). We also include a Crisis dummy (it defines the crisis period as that between Jan. 2008 and Jan. 2010) that tests whether price adjustments in the crisis period were as frequent as in the non-crisis period. Calendar month or quarter dummies are added to capture the seasonality we observe in the data.

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 of 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 lag-structure, the individual weights 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 freqeuncy of price-change. Adding the current monthly inflation allows for it to have a different coefficient. The theoretical justification for annual inflation is fairly clear from menu-cost theory (see for example Sheshinski and Weiss (1977)). The optimal flexible price-level will depend on real microeconomic factors that determine real marginal cost (these could be due to sector and firm-specific shocks). However, it will also depend on the nominal price-level captured by the CPI index. Over time, if a nominal price is fixed, it will drift away from the optimal flex price as inflation cumulates over time. If inflation has been higher over time, the fixed-price is more likely to hit the critical (S,s) band and result in a price-change. Annual inflation is a good measure, since it is roughly equal to the cross-sectional mean of price-spells (as measured by Dixon and Tian (2013)). However, the key reason why we chose annual inflation rather than use a statistical criterion such a as maximum likelihood to choose the optimal lag structure is *behavioral*. 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". We believe that the equations we estimates using annual inflation are good (if not optimal) econometric model which captures the importance of annual inflation as a *perceived* influence on prices in the economy. The issues are slightly less clear for quarterly data, since we only have 4 lags over the year. Here we did experiment with allowing a general 4 quarter lag, but found the annual inflation parameterization to be almost as good.

Our choice of output variable for monthly data is restricted to industrial output. We use output growth as our measure, 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.

In this section, we first adopt a single equation estimation methodology focussing on OLS. One of main concern about OLS regression is the endogeneity bias and possibility of measurement error. We have conducted endogeneity test on inflation and industrial output growth. The Durbin-Wu-Hausman test suggests that those variables are weakly exogenous. However, we have also estimated with IV using lagged independent variables as instruments. Some of the main IV regression results are reported and yield similar findings to the OLS estimates[8]. There are two other concerns about OLS regression: serial correlation and heteroscadasticity. We use the Newey-West estimator where we test positive for autocorrelation and heteroskedasticity in the error terms. In section 6 we extend the single equation methodology to allow for system estimation using 3SLS which allows for a more systematic treatment of the covariance of errors and endogeneity.

3.2 Monthly Data

Table 4: Monthly Frequency time series results.

For the monthly data, we do find strong evidence of a link between annual CPI inflation and the frequency of price-change: it has a positive effect overall and on price-rises which are significant at the 1% level. The effect is positive but insignificant on price-cuts. Whilst we run the regression over the whole sample, the result is unchanged if we restrict our sample to the pre-crisis moderation period. The effect of current monthly inflation appears twice: once as part of the annual inflation rate (where it has equal weight with all lagged inflation terms) and second as an additional effect with its own coefficient. The coefficient of current monthly inflation is positive but only significant at the 10% level on the overall frequency and 5% for price hikes. This means that for a given level of annual inflation, more inflation in the current month may lead to a higher frequency. Neither inflation variable has a significant effect on the price-cut frequency. We find little or no evidence

[8]Full results are available upon request, as are IV results with principle components from a wider set of instruments.

for the effect of output on the frequency. This may well be because our output variable is not a good one, so we can reserve judgement until we look at the quarterly data.

Finding 2: The overall monthly frequency of price change is influenced positively by the annual inflation rate and is highly seasonal. Dummies for the temporary VAT change and the crisis are significant. There is a significant negative time trend.

Finding 3: (a) the frequency of price hikes is influenced positively by inflation, both annual and monthly. There is a significant negative time trend and two VAT increasing dummies are significant and there is strong evidence of seasonality and the crisis dummy is significant; (b) monthly inflation has a negative effect while annual inflation has a positive effect on frequency of price cuts. Both the VAT decreasing dummy is significant and the crisis dummy is significant, indicating that price cuts are more likely to happen when VAT drops and in crisis period.

Findings 2 and 3 represent a consistent story. The higher the inflation is, the more likely the price is going to change, especially to increase. Output appears to have no effect. The VAT dummies split up as we would expect: VAT increases only affects price hikes, while VAT decreases only affects price cuts. What is particularly interesting is that the crisis dummy appears to have significance for overall frequency and price cuts, but not for price hikes. In other words, explanatory variables are able to explain the behavior of price hikes without an explicit "crisis" effect. The equations are excellent in terms of diagnostics, explaining around 80% of the variation without recourse to lagged dependent variables. The significance of the crisis dummy in the single equation estimate does not carry over to the system estimates presented in section 5: once we are able to take into account the contemperaneous correlation of shocks and endogeneity the crisis dummy will become insignificant.

We now look at sectoral heterogeneity. Here we will simply use the same regressions across the 11 COICOP divisions: the tables are included in Appendix 2. Pricing behavior is very heterogeneous and this is reflected in the sectoral regressions, which we summarize:

Finding 4: There is considerable heterogeneity across the 11 COICOP for monthly data. (a) On overall frequency, annual inflation is significant in four divisions (FNB, FHM, R&C, MGS): monthly inflation is insignificant for all divisions except for ABT; On price cuts, annual inflation has a negative effect for H&U, but positively affect FNB, FHM, HEA, R&C, and MGS; On *price hikes annual inflation affect the same divisions significantly as it does for overall frequency. (b) Seasonality is significant across most sectors, for all price changes and price hikes: there are exceptions - COM shows no seasonality at all. (c) Industrial output growth affects some sectors: annual output growth has a negative effect on Div C&F,FHM, HEA (overall and up), TRA (overall and down), H&U (down only), R&C. (d) The trend, crisis and VAT dummies are significant across most sectors, but not all.*

3.3 Quarterly data.

Table 5: Quarterly Frequency time series results.

With quarterly data we are able to use the better aggregate GDP output variable, which will include elements relevant to all 11 COICOP sectors. In order to construct a quarterly frequency data series, we needed to define what we meant by the proportion of prices which changed in a given quarter. The definition we adopted was to use the microdata and measure the proportion of prices for which there was at least one price change within the calender quarter. In a macroeconomic context of a quarterly DSGE model, where shocks arrive at a quarterly rate, so long as the price changes at least once then the price will have been able to respond to that shock. Some prices may well change more than once in a quarter: however, this additional dimension of flexibility is not relevant when we consider quarterly data. One implication of our chosen measure is that the frequency of prices changing up and down need not add up to the overall frequency, since the same price may change down and up in the same quarter.

The main finding with quarterly data is that quarterly output growth now becomes significant and negative for the overall freqeuncy of price changes and that annual inflation remains significant and positive. The countercyclicality of the frequency may be surprising, since in most pricing frameworks, an increase in output acts like inflation in putting upward pressure on the flexible price. However, the countercyclical nature of the frequency has also been found by Vavra (2014) using US data (although his finding was for monthly data using industrial output). As Finding 4 indicated, although the negative effect of output was not significant overall, even with the monthly data there was a negative effect on industrial output.

If we define the quarterly frequency of price hikes and quarterly frequency of price cuts in the same way as we do for overall frequency, we can find that

CPI inflation and GDP growth both have asymmetric effect on price hikes and cuts. Specifically, annual inflation has a positive and significant effect on the frequency of price hikes, but a negative and insignificant effect on the frequency of price cuts. Quarterly GDP growth negatively affects the frequency of price hikes, but no significant effect on price cuts. The crisis dummy only affects the frequency of price hikes. Again,VAT cuts only affect price cuts,while VAT increases only have significant effect on price hikes. One interesting finding is that quarterly frequency of price hikes appear to be more seasonal. However, the quarterly frequency of price cuts show no seasonality.

Finding 5: *The quarterly frequency of price change is positively related to the annual inflation; the frequency is negatively related to the current quarter's GDP growth; there slight negative trend and significant VAT and crisis dummies; there is some seasonality. Macroeconomic variables do not have a significant effect on the freqeuncy of price-cuts.*

If we look at the individual divisions, there is even more heterogeneity than with monthly data. Quarterly inflation is significantly positive in FNB, but significantly negative in ATB, C&F, and COM. Among COICOP sectors, annual inflation is significant in 7 out of 11, current output in 5 sectors, the trend in 2 sectors, and the crisis dummy in 3. There is no seasonality in 7 sectors. Some of the loss in significance is due to aggregation over months. For example, the VAT dummy has a specific effect on one month (December 2008): in the quarterly data this has to be large enough to show through into the 3 months October-December 2008. Likewise the seasonality: this can be quite specific to particular months (for example April when duties on Alcohol and tobacco change). As with the monthly data, the relationship that shows through most consistently is the annual inflation rate.

Overall, we can see that the frequency of price-change went up in the crisis years 2008-2010. This can be decomposed into three effects. First, there is the effect running from inflation: in the crisis year 2008 inflation dropped and then increased to a high level. Other things being equal, this would have led to a fall in the frequency at least in 2008. However, In 2008 output dropped rapidly, which would counteract the behavior of inflation: after dropping in 2008, output remained roughly constant through 2009. The fact that the crisis dummy is positive and significant reflects the fact that the behavior of our two macroeconomic variables are unable to explain the increase in the freqeuncy and indicates that there was an additional "crisis effect". However, as with the monthly analysis, this crisis dummy becomes insignificant when we estimate the system in section 5.

3.4 Price-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. With the OLS regression method used in the previous sections we find that there is significant serial-correlation. We therefore correct for this using a lagged dependent variable. Furthermore, we added the frequency variable as an explanatory variable[9] (as Ascari and Sbordone (2013) derived in a Calvo-Yun model, frequency and price-dispersion are negatively correlated). With these two modifications, we found that annual inflation has a positive effect significant at the 5% level as shown in Table 6[10].

Table 6: Monthly OLS & IV estimates

Finding 6: Annual inflation is positively correlated with price-dispersion. Frequency is negatively correlated with price-dispersion. Price-dispersion is positively correlated with it previous value.

The fact that current dispersion is positively related to lagged dispersion is consistent with Van Hoomissen's (1988) "information investment" model.

If we turn to the quarterly data, the results reported in Table 7 are more robust: annual inflation has a *positive* effect which is significant at the 5% level, whilst current quarterly output growth has a *negative* effect.

Finding 7. With quarterly data, aggregate price-dispersion as measured by the CV is positively correlated to annual inflation and the lagged term of CV, but negatively related to current quarter GDP growth. There is a significant time trend, and some seasonality.

Table 7: Quarterly OLS &IV estimates

The presence of a lagged dependent variable indicates that the short and long-run dynamics differ significantly. This is not surprising: the current distribution of price levels behaves like a state-variable: it is the accumulation

[9] The Durbin-Wu-Hausman test result suggests that frequency is weakly exogenous.

[10] In an earlier literature, Lach and Tsiddon (1992) and Reinsdorf (1994) suggested decomposing inflation into actual and expected. When we do this for our data, both expected and unexpected inflation are insignificant.

of the result of prices set over a long-period. In a given quarter, about a third of prices are reset at least once. An increase in inflation of 0.01 (1%) will cause an increase in the CV of 0.0017. Given that the value of CV is around 0.37, this is a small effect (just under 0.5%). However, in the long-run if the increase in inflation is sustained, the effect more than doubles: a sustained 1% increase in inflation leads to a proportional increase of 1% in the CV (0.0035). In fact, from table 2 the CV increased by about 10% from 0.36 pre-crisis to 0.394.

3.5 Price growth dispersion.

Following the methodology of the previous sections, we can regress the IQR and SD on the macroeconomic variables and dummies, the results of which are shown in Table 8.

Table 8: Regression results for raw price-growth dispersion

Finding 8: The dispersion of price-growth is negatively correlated with inflation, but not significantly correlated with output. It is declining for the VAT changes and has a very slight upward trend.

Our results show that there is a significant negative effect of annual inflation, a significant negative effect of monthly inflation (OLS for IQR regression), a positive but insignificant effect of annual industrial output growth, significant (negative) VAT dummies happened in Dec. 2008, Jan. 2010, and Jan. 2011 and a statistically significant but tiny positive time trend. The crisis dummy is insignificantly negative and seasonality is strongly present[11].

Overall our results for price-growth dispersion are interesting, because they are the *opposite* of what is found in Vavra (2014) with US data covering the similar but longer period 1988-2012: he finds that output has a *negative* effect on price-growth dispersion and inflation has a *positive* effect. However, the empirical methodology of Vavra is somewhat different to the one

[11] We also adopted an alternative approach following Reinsdorf (1994), regressing price-change dispersion on its lagged value, expected and unexpected inflation along with the other explanatory variables. The results can be found in the Cardiff working paper E2014/7 version Table 8. Price-change dispersion remains negatively correlated with both unexpected monthly inflation as well as expected annual inflation. In contrast with Reinsdorf (1994),expected annual inflation has a negative effect on price change dispersion (SD). Consistent with Konieczny and Skrzypacz (2005), our result suggests an environment in which menu costs matter.

adopted in Table 8: we need to see if the difference in the results is robust across estimation methodology. Vavra does not use the raw data, but instead bases his analysis on the seasonally adjusted data smoothed by a 6 month moving average, which we will denote by $IQRsama$ and $SDsama$ respectively, or smoothed using bandpass filters (these are depicted in Figures 5 and 6). In Table 9, we present results comparable to Vavra, showing correlations between our smoothed dependant variables and smoothed independent variables with monthly data.

Figure 5: Bandpassed regular price changes over business cycle

Figure 6: Smoothed regular price changes over time

Table 9: Correlations at Business cycle frequencies

As we can see, the results are similar to the regression analysis with the raw data. Inflation has a negative effect on the IQR and SD of price-growth (regressions 3,4, 6) which is very significant for annual inflation (3). Output variables always have a positive sign (regressions 1,2,5) which is significant for the bandpass filter (5) and annual growth (2). There is no evidence for the signs found by Vavra when we use exactly the same methodology: as in the time-series regressions, we find only evidence for the opposite signs.

Vavra also links together the frequency of price-change with the standard deviation of price-growth. We can perform the same exercise for the UK data, which we present in Table 10. Newey-West standard errors are in parentheses, all data is seasonally adjusted using 12 monthly dummies. Regressions in first two columns include a quadratic time-trend. All data for regressions in the last two columns are bandpass-filtered using a Baxter King (18,96, 33) filter.

Table 10: correlations between frequency and price-growth dispersion

The results are highly consistent: we find that the seasonally adjusted and the filtered data both display negative correlations between price-growth dispersion and the frequency of price-change. The results tell the same story as the time-series results reported in Tables 7 and 9: we find the opposite relationships to those found by Vavra (2014).

Finding 9: The smoothed frequency of price-change is negatively correlated with the smoothed dispersion of price-growth.

Whilst the empirical results for the UK are at odds with the US results of Vavra, our results are quite consistent with the theoretica framework put forward by Vavra. Vavra adopts the (S,s) model found in Barro (1974), Sheshinski and Weiss (1977), Dixit (1991) and elsewhere, arguing that "volatility shocks" will lead to increases in both the freqeuncy of price adjustment and the standard deviation of price growth. The (S,s) model is of course every 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 Weiner process. However, as Vavra's own Proposition 2 shows, an aggregate shock can lead to exactly the behavior we find in the data: an *increase* in the frequency of price changes coupled with a *decrease* in the standard deviation of price growth. Thus although our results for the UK indicate the opposite of what Vavra finds, the theoretical framework in his paper is consistent with our findings. Rather than interpreting the crisis as resulting from an increase in uncertainty (as in Vavra), our results can be interpreted as suggesting an aggregate (first moment) shock to the optimal price-level The intuition for this is that if all firms are pushed by the same shock then this leads to more being pushed out of their (S,s) band of inaction and hence changing price. However, whilst more firms change price, since they are reacting to a common shock, the firms that change their price will tend to change their price by a similar amount, thus reducing the dispersion of price-growth[12]. It is essentially the same argument as for the VAT dummies: a change in tax causes prices to change (a increase in freqeuncy) and many change by the same amount (a fall in the dispersion).

3.6 Price growth Kurtosis.

Using the time series of Kurtosis, we follow exactly the same procedure as we did for the time series analysis of IQR, with the regression results reported in Table 11. We find that both monthly and annual inflation have a significant positive effect and there is a significant but very small negative time trend. The VAT dummies are significant,and the crisis dummy is significant and

[12]As Vavra explains: "aggregate first moment shocks will, by definition, affect all firms'desired price changes in the same way. Thus, firms must all be pushed out of the inaction region in the same direction. While this leads to an increase in the frequency of adjustment, more price changes are then in the same direction, which leads to a decrease in price change dispersion."

positive. The clear seasonality is picked up by the monthly dummies. However, across all estimation methodologies there is no evidence of any effect of output on price-growth Kurtosis.

Table 11: Regression results for monthly kurtosis

Finding 10: Price-growth Kurtosis is acyclic, seasonal and highly sensitive to VAT changes. Inflation has a positive effect and there is a small but significant downward trend.

Alvarez et al 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.

The absolute value of skewness in the UK data is small and does not represent any significant asymmetry by Bulmer's criterion[13]. However, skewness of the price-growth distribution has also been the focus of some research: Ball and Mankiw (1995) found a positive correlation with inflation, which they took as evidence for the menu cost model of price setting behavior. Silver and Ioannidis (2001) used monthly data for CPI from the Eurostat database 1981-1989 and found the same positive correlation. Bryan and Cecchetti (1999) found a *negative* correlation between skewness and inflation. We follow the Vavra (2014) approach and find that skewness is negatively but insignificantly correlated with CPI inflation. Our results based on a large sample thus support Bryan and Cecchetti's finding.

4 System estimation of the time-series.

Up until now, we have considered only single equation regressions on our dependant variables of interest: frequency, the level of price-dispersion as measured by the CV, the dispersion of price-growth as measured by the IQR and Kurtosis. We did introduce frequency into the CV equation, but have not considered systematically the possibility of interactions between the endogenous variables. However, whilst our primary interest is to capture the effect of macroeconomic variables on our variables of interest, it is also quite

[13]Bulmer (1979), indicates that Skewness over 1 in absolute value is highly skewed, between 1 and 0.5 "moderately skewed", and less than 0.5 is "approximately symmetric".

possible that they are linked together in some way. For example, if there is more price dispersion (CV), then perhaps more prices are likely to change (frequency). If more price change (freqeuncy), then this might affect price-dispersion and the distribution of price-growth. If this is the case, then it throws open the possibility that inflation can have direct and indirect effects on the variables of interest. For example, if inflation affects freqeuncy and frequency affects Kurtosis, then we need to see if inflation has a direct effect on Kurtosis over and above the indirect effect via frequency. System estimators are able to systematically deal with this issue of exogeneity. A second advantage of system estimation is that it can exploit "seemingly unrelated regressions" estimation, allowing for the correlation between errors across the four equations. In a macroeconomic model this is an important feature: macroeconomic shocks can affect pricing behavior across a range of dimensions.

We can only explore this issue through executing a system estimation of all the equations together. We do this using 3SLS and will focus on the quarterly data, since this has the best output measure. We allow for two endogenous variables to affect the others: frequency and CV. We do not let the price-growth variables affect each other or frequency and CV. This seems a reasonable restriction, since the two price-growth variables are conditioned on price change and hence cannot have a direct causal effect on the frequency.

Table 12: 3SLS system estimation of monthly series

Table 13: 3SLS system estimation of Quarterly series

We report the system estimates for both monthly and quarterly time-series in Tables 12 and 13 respectively. In all cases, we find that the macroeconomic variables (inflation and output) both have the same effects when we estimate the system. Turning first to frequency, we find that the single equation signs are confirmed in the system estimates: inflation (both the current quarter and the annual rates) has a positive effect, output a negative effect. However, we also find that CV has a significant *negative* effect on the frequency. What is perhaps more important is that output also has a significant effect in the monthly version which it did not have in the single equation estimate. For the CV we use the same basic form as in the single equation, including the lagged CV. Here we find that both inflation variables have a positive effect, output a negative effect. Again, there is a significant negative effect of freqeuncy on CV. Turning to the price-growth variables, frequency is significant for both: a negative effect on IQR and a positive effect on Kurtosis. CV has a significant negative effect on Kurtosis. Inflation (current quarter) has a negative effect on price dispersion and a positive effect on Kurtosis (both annual and current quarters inflation). Output has no effect on dispersion, and a negative effect on Kurtosis.

We can see the system estimates as confirming the single equation OLS results. Inflation has a positive effect on the frequency: this will indirectly effect the other variables of interest - CV, IQR and Kurtosis. However, even when we allow for this indirect effect, inflation still remains a significant direct effect on these three variables. The system estimates also show that the effect of output comes through more clearly than in the single equation approach. The great advantage of the system estimates is that they can disentangle direct and indirect effects in addition allowing for correlated shocks across the equations. The 6 contemporaneous correlations of errors are all significantly non-zero at the 1% level (LM test), which indicates that the SUR dimension is important.

The main difference between the system estimates and the single equation OLS results is that the crisis dummy is not significant in the system estimates. This indicates that the significance of the dummy in the single equation estimates results from the omission of the effect of the endogenous variables (CV and frequency) and the instantaneous correlation of shocks across the equations. We cam summarize these findings from Table 14:

Finding 11: (Quarterly data) Inflation has a significant positive effect on the frequency of price change, the dispersion of price levels, price growth Kurtosis and a negative effect on IQR. Output growth has a significant negative effect on freqeuncy and price-level dispersion. Freqeuncy has a positive effect on CV and Kurt, a negative effect on IQR. CV has a significant negative effect on frequency and Kurt. The crisis dummy is insignificant for all 4 equations. The contemporaneous correlation of shocks are all significantly non-zero.

5 Implications for pricing models.

We have seen that the behavior of prices changed significantly during the crisis period 2008-2010. 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 state-dependence of prices 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?

In order to examine this issue we develop a simple state-dependent Calvo model, where we allow the Calvo reset probability to be dependent on macro-economic variables (inflation, output). We can then calibrate the model using the estimated relationship from the data and see how this "state-dependence" influences the behavior of the model in terms of monetary policy impulse response functions.

5.1 A simple state dependent Calvo pricing model.

We first develop a simple date dependent Calvo model where the Calvo reset probability to vary with the date. The reset probabilities to be the same for all firms in each period, with probabilities that may vary from period to period. This means that the reset probability is not *duration* dependent, but is *date* dependent. We might expect the reset probability to be date dependent if it depends on seasonal factors or macroeconomic conditions (or indeed any time-varying factors). We thus have a sequence of reset probabilities, one for each period t. For simplicity, we will adopt a perfect-foresight framework.

$$\{h_t\}_{t=0}^{\infty}$$

We will need to distinguish between forward looking variables, which we will denote with a "$+$" superscript, and backward looking ones which will have a "$-$"superscript. Let us define the forward looking probability that a price set set in period t is still in force $i > 1$ periods in the future (the *survival probability*) $(S_t^0 = 1)$:

$$S_t^{+i} = \prod_{s=1}^{i-1}(1 - h_{t+i-1})$$

Hence the reset price x_t becomes

$$x_t = \bar{h}_t^+ \sum_{i=0}^{\infty} S_t^{+i} P_{t+i}^* \tag{1}$$

where $\bar{h}_t^+ = \left(\sum_{i=0}^{\infty} S_t^{+i}\right)^{-1}$ and P_t^* is the optimal flex-price at period t. The weights applied to future prices vary due to the fact that the reset probabilities vary over future dates. It thus matters not only how many periods in the future a particular date is, but also what that date is. Note that since all firms have the same h_t in each period, $S_{t+1}^{+i-1} = S_t^{+i}/(1-h_t)$. Hence the sequence $\{h_t\}$ gives rise to a sequence $\left\{\bar{h}_t^+\right\}$ satisfying the dynamic relationship:

$$\bar{h}_{t+1}^+ = \frac{\bar{h}_t^+}{1-\bar{h}_t^+}(1-h_t) \tag{2}$$

Note that variations in $\bar{h}_t^+$ will be very small. In the appendix we show that with a steady-state value $\bar{h}$, we have:

$$\bar{h}_t^+ - h_t \simeq -\frac{h_t - \bar{h}}{1+\left(h_t - \bar{h}\right)} \tag{3}$$

Since $h_t - \bar{h}$ is likely to be "small", deviations in $\bar{h}_t^+$ will also be small.

From (1), using (2) we can express the forward looking relationship between the current and following reset price as:

$$\begin{aligned} x_t &= \bar{h}_t^+ P_t^* + \bar{h}_t^+ (1-h_t) \sum_{i=0}^{\infty} S_{t+1}^{+i} P_{t+1+i}^* \\ &= \bar{h}_t^+ P_t^* + \left(1-\bar{h}_t^+\right) \bar{h}_{t+1}^+ \sum_{i=0}^{\infty} S_{t+1}^{+i} P_{t+1+i}^* \end{aligned}$$

Hence:

$$x_t = \bar{h}_t^+ P_t^* + \left(1-\bar{h}_t^+\right) x_{t+1} \tag{4}$$

We can now decompose the price backwards. Define the backward looking variables for $i > 1$

$$\begin{aligned} S_t^{-i} &= \prod_{s=1}^{i} (1-h_{t-i}) \\ \bar{h}_t^- &= \left(\sum_{i=1}^{\infty} S_t^{-i}\right)^{-1} \end{aligned}$$

Again, note that $S_t^{-i} = (1 - h_t)\, S_{t-1}^{-(i-1)}$ and $\bar{h}_t^- = (1 - h_t)\, \bar{h}_{t-1}^-$. Starting from the accounting identity for P_t we obtain the backward looking relationship:

$$P_t = x_t h_t + (1 - h_t)\, P_{t-1} \tag{5}$$

For the macroeconomic framework we use the simple Quantity Theory model and the flexible price is defined in the usual manner:

$$\begin{aligned} P^* &= P_t + \gamma Y_t \\ M_t &= P_t + Y_t \\ M_t &= \rho M_{t-1} + \varepsilon_t \end{aligned}$$

where we set $\gamma = 0.2$, $\rho = 0.5$ and ε_t is the monetary shock. To obtain the impulse-response finctions, the shock is non-zero for one period, so that the model is perfectly deterministic thereafter.

To complete the model, we specify the date dependent reset probability using the quarterly estimates:

$$h_t = \bar{h} + h_\pi \pi_t^A + h_y y_t^A$$

where $\bar{h} = 0.4$, $h_\pi = 0.5$ and $h_y = -1.65$, where $\pi_t = \pi_t - \pi_{t-4.}$

Under this framework, we can simulate monetary policy. The impulse response functions are almost exactly the same as if we set the Calvo reset probability constant and equal to its mean $\bar{h}$. There are two reasons for this. Firstly, it is annual inflation that matters: thus monetary policy needs to have a sustained cumulative effect on quarterly inflation so that annual inflation will change significantly. Since annual inflation is a moving average, it is far less volatile than quarterly or monthly inflation. The second reason has to do with Calvo pricing being forward looking. The reset price (1) depends on the reset probabilities now and in the future, summarized by variations in h_t^+ which from (3) will be small. Small variations in the current value of the reset probability will have little or no effect on the reset price. Thus, whilst a permanent increase in monetary growth leading to permanently higher inflation would have an effect on how monetary policy shocks feed through into the economy, a temporary monetary shock that dies away will have little or no effect.

Fig 7: State dependent reset probability

In Figure 7, we depict the reaction of h_t and $\bar{h}_t^+$ to a monetary shock. As we can see, there is a small change in these variables: they both fall (this is in response to the increase in output) by about 1%. This is a very small change, which results in almost no difference in the time-path of output and inflation as compared to the constant non-state-dependent reset probability (we have not reproduced the impulse responses, since they are visually identical).

6 Conclusions.

In this paper we have focussed on the affect of macroeconomic variables on the pricing behavior of firms as reflected in aggregate statistics such as the freqeuncy of price change, the dispersion of price-levels and the dispersion of price-growth. Our main finding is that there is clear evidence of a link between annual inflation and most of these: we find this both for monthly and quarterly data, and for single equation and system estimates. This we believe is very robust. We also find a link between output and some of the pricing variables: this is clearer in the quarterly data than the monthly, probably because the quarterly output variable (GDP growth) is better than the monthly variable (industrial output growth). Whilst we find that there are these "endogenous" macroeconomic affects on pricing, we believe that these are small and do not indicate the need for monetary policy to take them into account: indeed, time-dependent models will remain an excellent approximation.

With single equation estimates, we often find a significant "exogenous" macroeconomic effect of the crisis, as reflected in the significance of the crisis dummy. However, the system estimates indicate that this is a spurious significance resulting form the failure to estimate the three relations as a system. The relationships between output growth and inflation and some of the aggregate statistics are different to those found in the US data by Vavra (2014). It remains to be seen when we look at data from more economies whether the picture remains mixed or most countries follow the correlations found in the US or UK.

7 Bibliography.

1. Aguirregabiria, V. (1999): "The Dynamics of Markups and Inventories in Retail Firms," *Review of Economic Studies*, 66, 275-308.

2. Alvarez, Fernando E and Francesco Lippi (2014), "Price setting with menu cost for multi-product firms", *Econometrica*, 82, 89-135.

3. Alvarez F, Le Bihan H, Lippi F. (2013). "Small and large price changes and the propogation of monetary shocks." CEPR DP 9770.

4. Anderson, E., E. Nakamura, D. Simester, and J. Steinsson (2012): "Decomposing Data on Retail Prices," Working Paper, Columbia University.

5. Ascari, G., and Sbordone, A. M., 2013. The macroeconomics of trend inflation. FFB of New York Staff Report No.628

6. Ball, L. and Mankiw, G., 1995. Relative-Price Changes as Aggregate Supply Shocks," *Quarterly Journal of Economics*, 110, 161-193.

7. Ball, L., Mankiw, G., and Romer, D., 1988. The New Keynesian Economics and the Output-Inflation Trade-off, *Brookings Papers on Economic Activity*, vol. 19(1), 1-82

8. Barro, R. (1972). A theory of monopolistic price adjustment. Reviews of Economic Studies 39 (1)..

9. Barro, R. J. (1977): "Long Term Contracting, Sticky Prices and Monetary Policy," *Journal of Monetary Economics*, 3, 305-316.

10. Berardi N., Erwan Gautier E, and Le Bihan H, (2013), More facts about prices: France before and during the Great Recession, Banque de France, working paper 425.

11. Bils, M and Klenow, P (2004). Some evidence on the importance of Sticky prices, *Journal of Political Economy*, 112, 947-985.

12. Bryan, M., and Cecchetti, S., 1999. Inflation and the distribution of price changes, *Review of Economic Statistics*, 81(2), 188-196

13. Bulmer, M.G., *Principles of Statistics.* (Dover, 1979).

14. Bunn P, Ellis C. (2009). Price setting behavior in the UK, *Bank of England Quarterly Bulletin*, 49, 28-36.

15. Bunn P, Ellis C. (2012), . How do individual UK consumer prices behave? *Economic Journal*, 122, F35-F55.

16. Burstein, A. T. (2006): "Inflation and Output Dynamics with State-Dependent Pricing Decisions," *Journal of Monetary Economics*, 53, 1235-1275.

17. Calvo, G. (1983) "Staggered Prices in a Utility-Maximizing Framework", *Journal of Monetary Economics,*12(3),pp.383-398

18. Carvalho, C (2006) "Heterogeneity in Price Stickiness and the Real Effects of Monetary Shocks," *Frontiers of Macroeconomics*: Vol. 2 : Iss. 1, Article 1.

19. Chahrour, R. 2011. Sales and price spikes in retail scanner data, *Economics Letters*, 110(2), 143-146.

20. Chevalier, J. A., and A. K. Kashyap (2011): "Best Prices," NBER Working Paper No. 16680.

21. Consumer Price Indices Techinical Manual, 2007 edition, Office for National Statistics, London.

22. Coibion, O., Gorodnichenko, Y., Hong, G., 2012, The cyclicality of sales, regular and effective prices: business cycle and policy implications, Working Paper, University of California at Berkeley.

23. Dhyne, E., Alvarez, L. J., Le Bihan, H., Veronese, G., Dias, D., Hoffmann, J., Jonker, N., Lunnemann, P., Rumler, F., and Vilmunen, J. (2006). Price setting in the Euro area: some stylized facts from individual consumer price data, *Journal of the European Economic Association*; 4, . 575-584.

24. Dixit, A.(1991). Analytic approximations in models of hysteresis. *Reviews of Economic Studies* 58 (1).

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

26. Dixon H., and Tian, K., 2013, What we can learn about the behavior of firms from the average monthly frequency of price-changes: an application to the UK CPI data, Cardiff Working Paper (E2013/1)

27. Eichenbaum, M., Jaimovich, N., Rebelo, S., 2011. Reference prices, costs, and nominal rigidities, *American Economic Review*, 101(1), 234-262.

28. Eichenbaum, M., Jaimovich, N., Rebelo, S., Smith, J., 2013. How frequent are small price changes?, forthcoming *American Economic Journal: Macroeconomics*

29. Golosov, Mikhail, and Robert E. Lucas, 2007, "Menu Costs and Phillips Curves," *Journal of Political Economy,* 115, 171-199.

30. Guimaraes, Bernardo and Sheedy, Kevin D (2011). Monetary Policy and Sales, *American Economic Review*, 111, 844-76.

31. Head, Allen and Alok Kumar. 2005. Price Dispersion, Inflation, and Welfare. *International Economic Review* 46:533-72.

32. Hendel, I., and A. Nevo (2006): Measuring the Implications of Sales and Consumer Stockpiling Behavior, *Econometrica*, 74(6), 1637-1673.

33. Hoffmann, J., and Kurz-Kim, J., 2006. Consumer price adjustm,ent under the microscope: Germany in a period of low inflation. ECB Working Paper Series 652.

34. Hosken, D., and D. Reiffen (2004): "Patterns of Retail Price Variation," *Rand Journal of Economics*, 35(1), 128-146.

35. Kehoe, P., and Midrigan, V., 2010. Prices are sticky after all, Working Paper, New York University.

36. Klenow P and Krytsov O (2008). State-Dependent vs. Time-Dependent Pricing: Does it Matter for Recent U.S. Inflation? *The Quarterly Journal of Economics,* 123, August 2008, 863-904.

37. Klenow, P., and Malin,B., 2011. Microeconomic evidence on price-setting, Handbook of Monetary Economics, in: Friedman, B., and Woodford, M., (ed.), Handbook of Monetary Economics, edition 1, volume 3, chapter 6, 231-284

38. Klenow, P. J., and J. L. Willis (2007): "Sticky Information and Sticy Prices," *Journal of Monetary Economics*, 54, 79{99.

39. Konieczny, J. D.Skrzypacz, A.2005, Inflation and Price Setting In a Natural Experiment. *Journal of Monetary Economics*, 52:621-632, .

40. Lach, S., Tsiddon, D., 1992. The behavior of prices and inflation: An empirical analysis of disaggregated pricedata. *Journal of Political Economy* 100, 349–389.

41. Lazear, E. P. (1986) Retail Pricing and Clearance Sales, American Economic Review, 76(1),14-32.

42. Mackowiak, B., and Smets, F., 2008. On implications of micro price data for macro models. CEPR Discussion Papers 6961.

43. Mankiw, N. G., and R. Reis (2002): "Sticky Information Versus Sticky Prices: A Proposal to Replace the New Keynesian Phillips Curve," Quarterly Journal of Economics, 117(4), 1295-1328.

44. Midrigan, Virgilu,"Menu costs, multiproduct firms and aggregate fluctuations" *Econometrica* 79 (2011), 1139-1180.

45. Nakamura, E., and Steinesson J, 2008. "Five Facts about Prices: A Reevalution of Menu Cost Models," *The Quarterly Journal of Economics,* MIT Press, vol. 123(4), pages 1415-1464,November.

46. Nakamura, E., and Steinesson J, 2010. More Facts About Prices. Supplement to: "Five Facts about Prices: A Reevalution of Menu Cost Mode"

47. Reinsdorf, M., 1994. New evidence on the relation between inflation and price dispersion. *American Economic Review* 84, 720–731.

48. Rotemberg, J.J., 1983. Aggregate consequences of fixed costs of price adjustment. *American Economic Review* 73, 433-436 June.

49. Salop, S., and Stiglitz, J., 1982. The theory of sales: a simple model of equilibrium price dispersion with identical angents, *American Economic Review*, 72(5), 1121-1130.

50. Sheshinski, E., Weiss, Y., 1977. Inflation and costs of price adjustment. *Review of Economic Studies* 44, 287–303.

51. Silver, M., Ioannidis, C., 2001. Intercountry difference in the relationship between relative price variability and average prices. *Journal of Political Economy* 109 (2), 355-374.

52. Sims, C.A., 2011. Rational inattention and monetary economics, in Handbook of Monetary Economics, ed. by Friedman, B., and Woodford, M., 155-181, Amsterdam, Holland. Elsevier.

53. Sobel, J. 1984. The timing of sales, Review of Economic Studies, 51(3), 353-368.

54. Stigler, George J. and Kindahl, James K. *The behavior of industrial prices*, National Bu-reau of Economic Research General Se-ries No. 90. New York: Columbia Univer-sity Press, 1970.

55. Van Hoomissen, 1988. Price dispersion and inflation: Evidence from Israel. *Journal of Political Economy* 96,1303–1314.

56. Varian, H. R. 1980. A model of sales, American Economic Review, 70(4), 651-659.

57. Vavra, J. 2014. Inflation dynamics and time-varying volatility: new evidence and an Ss interpretation. *Quarterly Journal of Economics*, vol 129,1.

58. Woodford, M. 2009. Information-constrained state-dependent pricing. Journal of Monetary Economics, 56(Supplement 1), S100-S124.

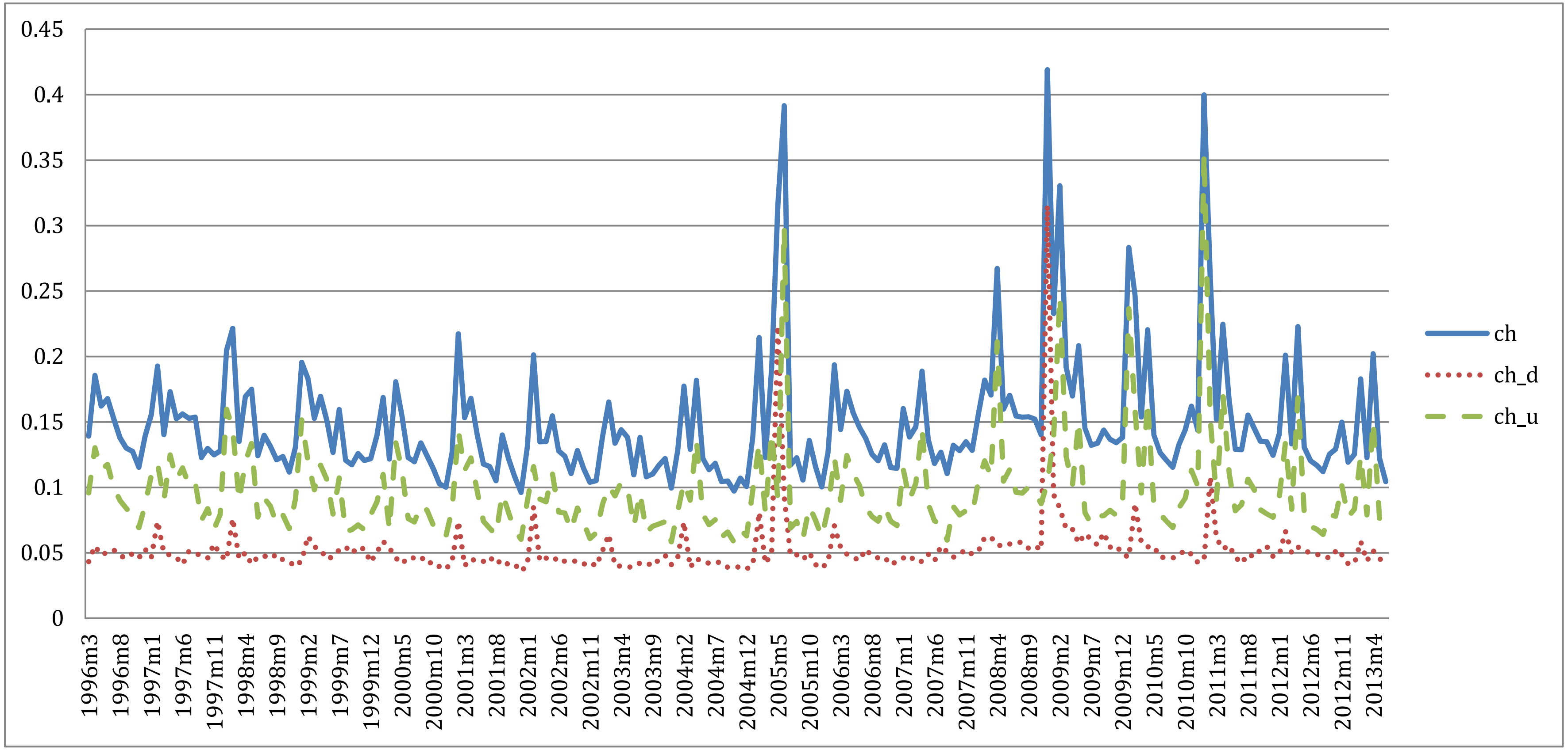

Figure 1: The monthly frequency of price changes.

Note: “ch” stands for frequency of price change; “ch_d” stands for frequency of price cuts; “ch_u” stands for frequency of price hikes.

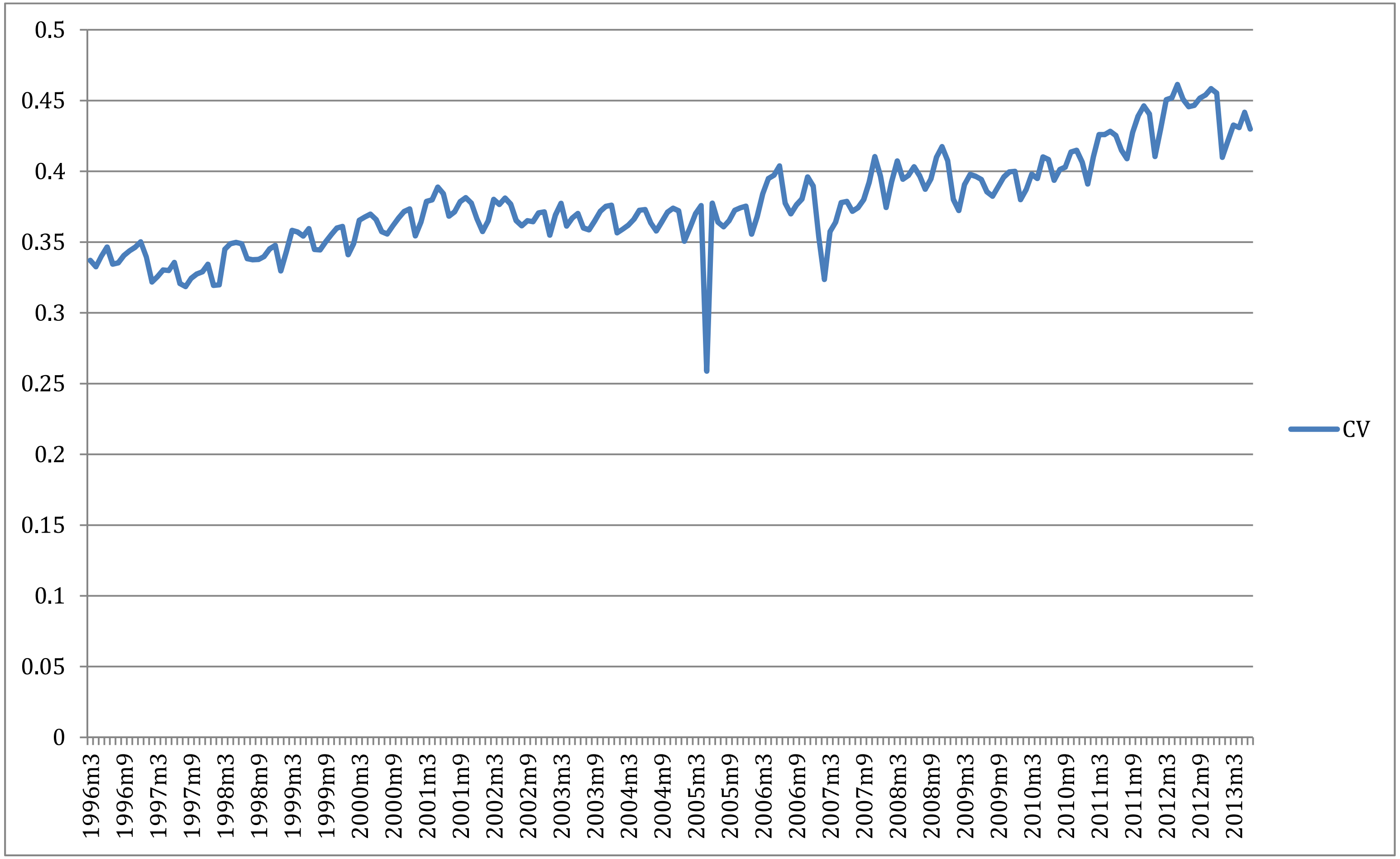

Figure 2: Price-dispersion as measured by the aggregate Coefficient of Variation.

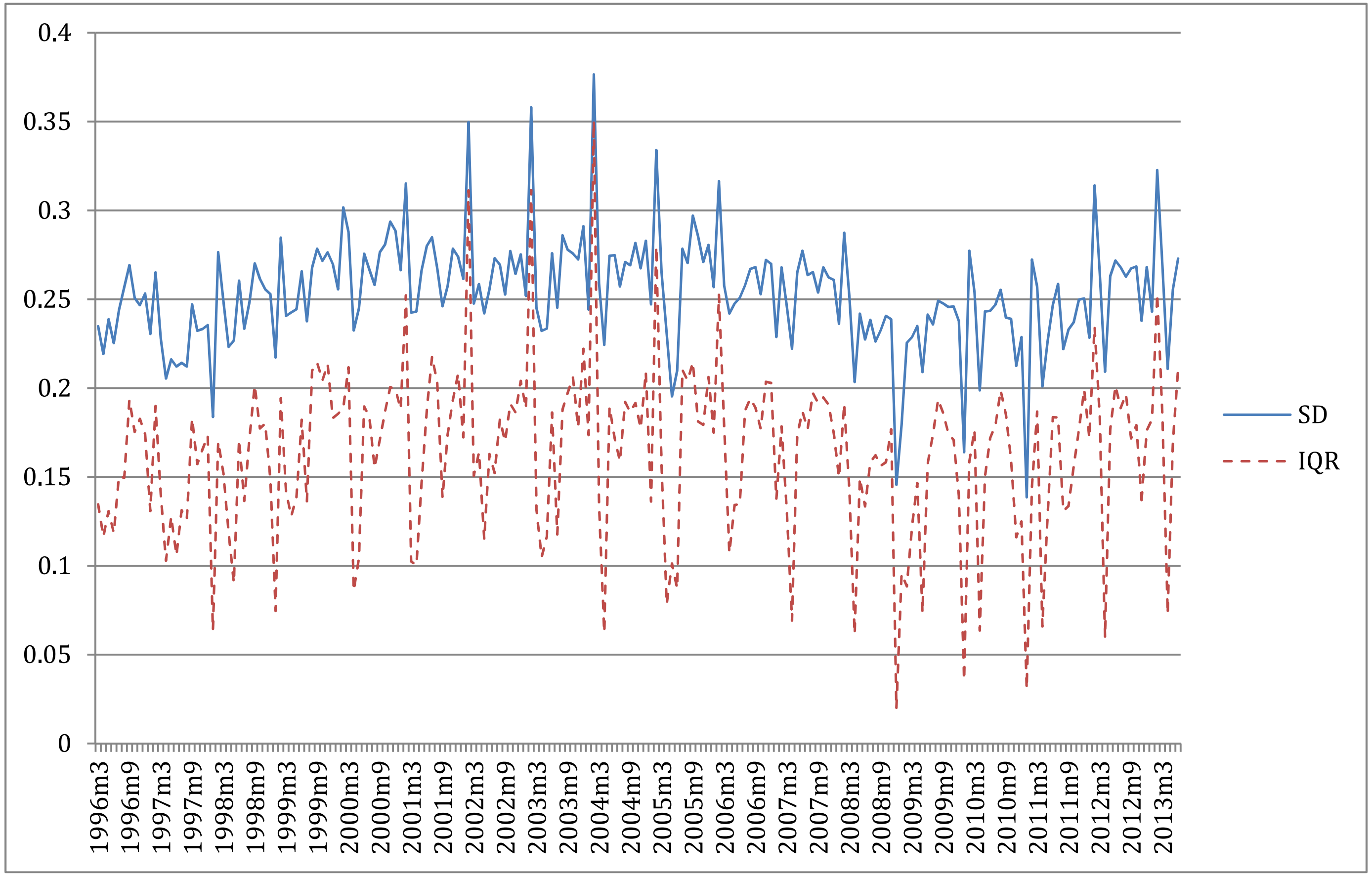

Figure 3: The time series of raw price-growth dispersion
Note: “SD” stands for standard deviation; “IQR” stands for interquartile range.

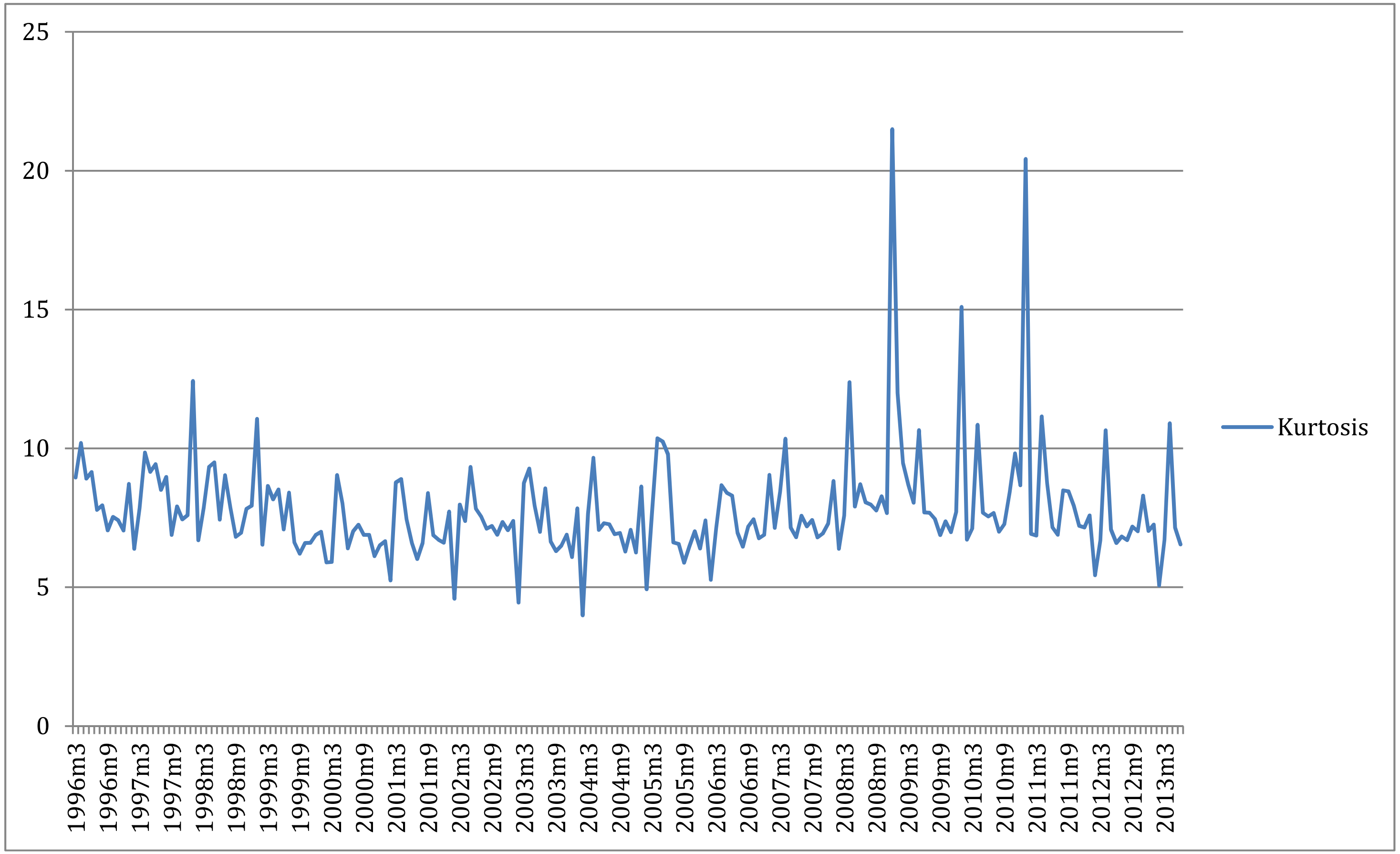

Figure 4: Time series of monthly Kurtosis

Note: Sales and substitutions are excluded. Outliers as defined by Alvarez et al. (2013) are also excluded.

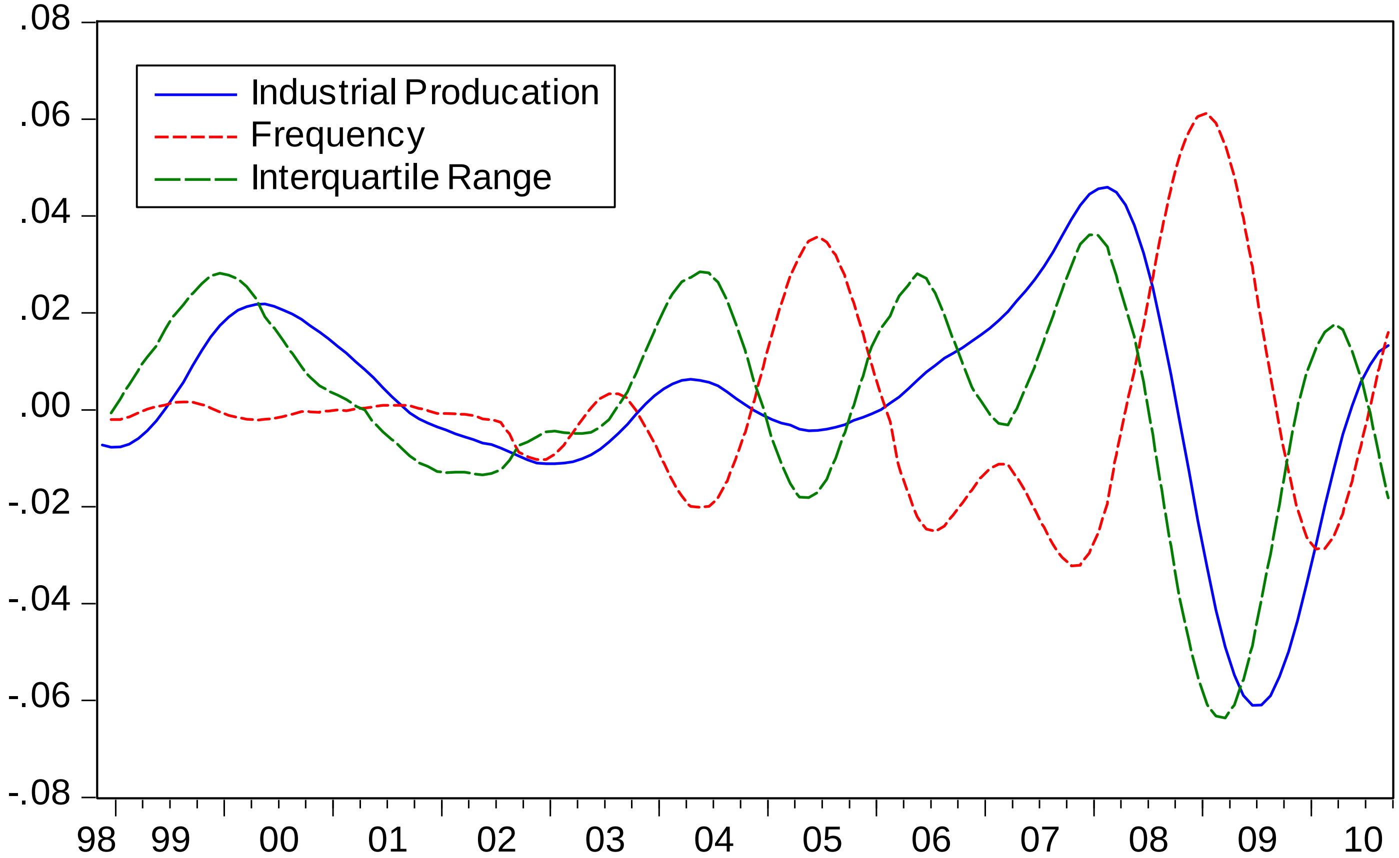

Figure 5: Bandpass filtered regular price changes over business cycle

Note: All series are seasonally adjusted using monthly dummies. All series are bandpass filtered with a Baxter-King (18,96,33) filter. Frequency is the median frequency of price changes. Sales and substitutions are excluded. Interquartile Range is the interquartile range of price changes excluding all zeros.

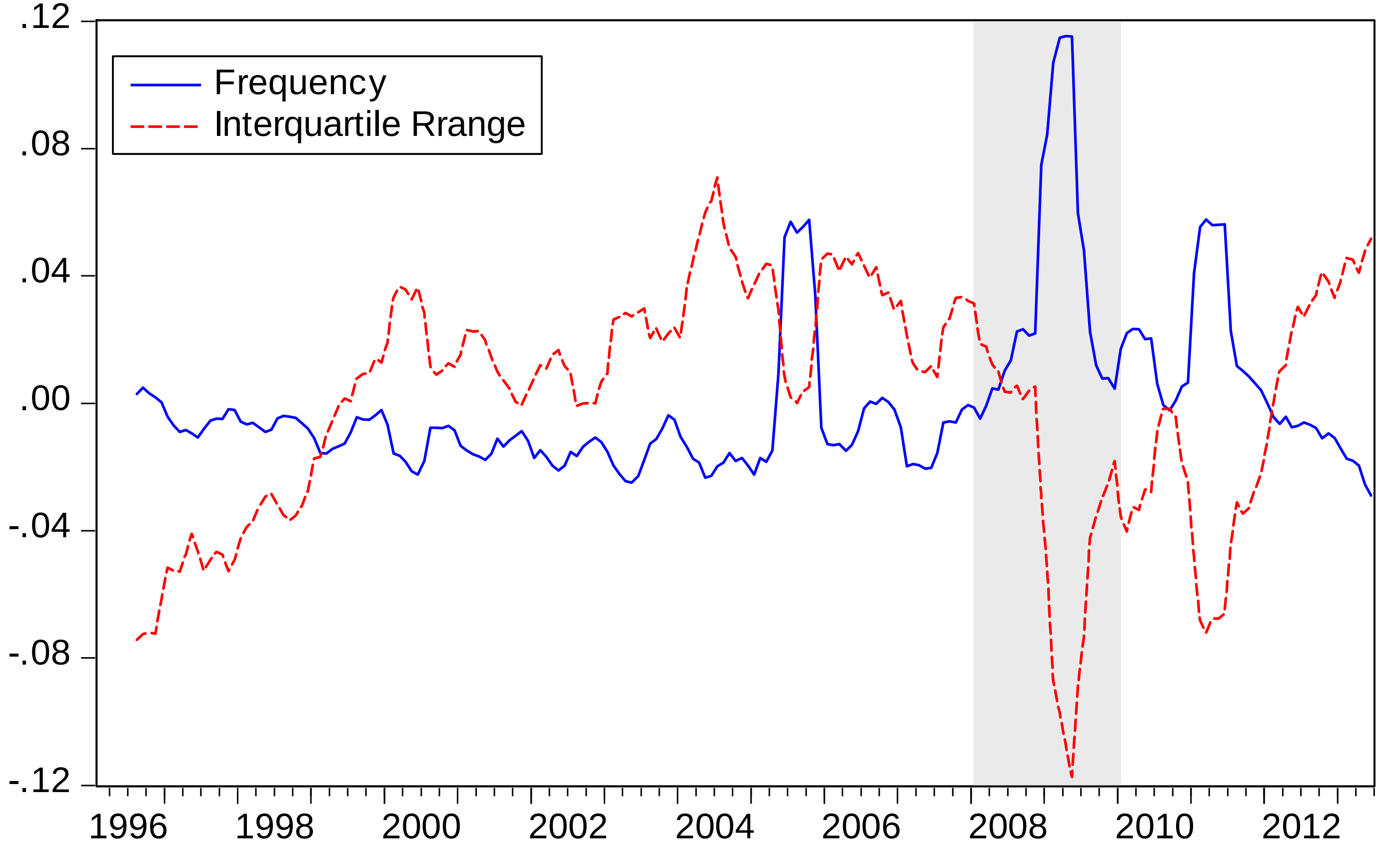

Figure 6: Smoothed regular price changes over time.

Note: The shade area shows the crisis period. Data is seasonally adjusted using 12 monthly dummies and smoothed with a 6 month moving average. Interquartile Range is the interquartile range of price changes excluding all zeros. Frequency is the median frequency of price changes. Both data series exclude price quotes belonging to sales and product substitutions.

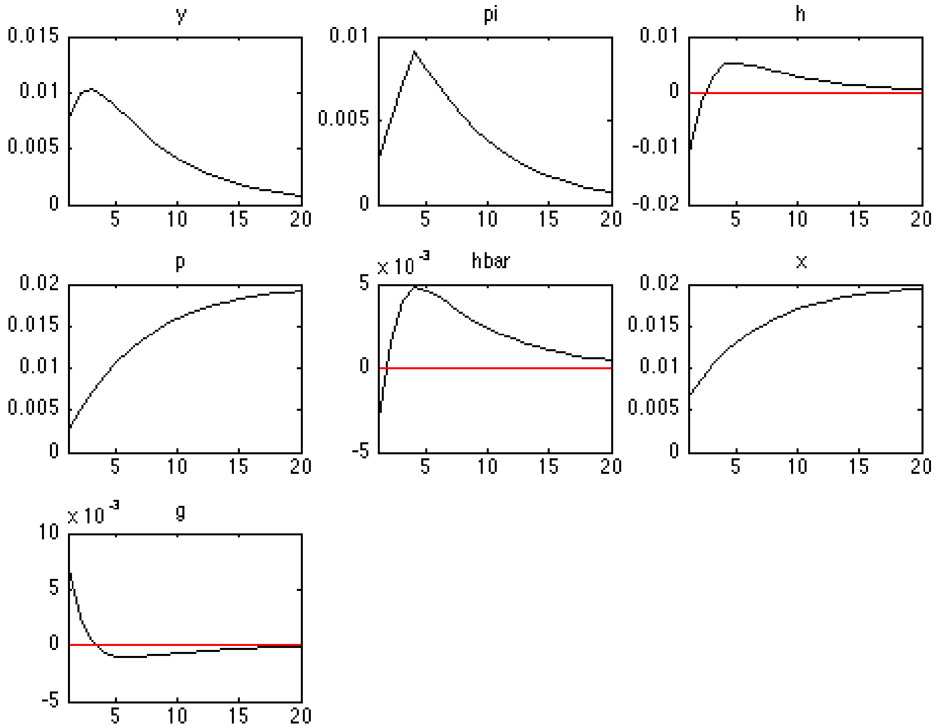

Figure 7: Impulse response function for monetary shock in Quantity Theory model with state-dependent Calvo pricing.

Note: y—output, pi—inflation, p—price level, x—flexible price level, g—monthly growth of output, h—Calvo reset probability, hbar—the inverse of the sum of the survival probabilities.

Table 1: The frequency of price changes decomposed by sector and direction

COICOP division	Frequency of price-changes			Frequency of price-hikes			Frequency of price-cuts		
	Pre-crisis	Crisis	Post-crisis	Pre-crisis	Crisis	Post-crisis	Pre-crisis	Crisis	Post-crisis
Food and Non-Alcoholic Beverages	0.197	0.243	0.199	0.113	0.141	0.124	0.084	0.102	0.075
Alcoholic Beverages and Tobacco	0.222	0.313	0.297	0.174	0.234	0.235	0.049	0.079	0.062
Clothing and Footwear	0.084	0.120	0.067	0.050	0.064	0.042	0.034	0.056	0.025
Housing and Utilities	0.124	0.145	0.128	0.073	0.078	0.076	0.051	0.067	0.053
Furniture, and Home Maintenance	0.095	0.175	0.142	0.059	0.103	0.091	0.037	0.072	0.050
Health	0.078	0.132	0.091	0.057	0.076	0.059	0.021	0.055	0.032
Transport	0.103	0.154	0.106	0.071	0.094	0.069	0.032	0.059	0.036
Communication	0.100	0.208	0.226	0.040	0.120	0.109	0.059	0.089	0.117
Recreation and Culture	0.105	0.180	0.154	0.060	0.101	0.085	0.045	0.079	0.069
Restaurants and Hotels	0.153	0.181	0.059	0.105	0.122	0.123	0.048	0.059	0.053
Miscellaneous Goods and Services	0.099	0.159	0.109	0.067	0.098	0.074	0.032	0.062	0.034

Note: These are for regular price changes only.

Table 2: Price dispersion in aggregate and by sector before and during the crisis

date	All	FNB	ABT	C&F	H&U	FHM	HEA	TRA	COM	R&C	R&H	MGS
Whole sample	0.378	0.252	0.119	0.715	0.528	0.641	0.421	0.383	0.714	0.458	0.238	0.538
96m3-07m12	0.360	0.253	0.113	0.630	0.498	0.625	0.405	0.384	0.535	0.437	0.232	0.539
05m7-07m12	0.376	0.256	0.124	0.771	0.524	0.695	0.430	0.349	0.602	0.432	0.243	0.476
08m1-10m1	0.394	0.249	0.132	0.835	0.584	0.700	0.461	0.373	1.325	0.481	0.243	0.528
10m2-13m6	0.426	0.252	0.129	0.933	0.597	0.661	0.450	0.387	0.958	0.518	0.255	0.538
Excl.VAT date	0.394	0.249	0.132	0.835	0.584	0.700	0.461	0.373	1.325	0.481	0.243	0.528

Note: “All” stands for aggregate level. “FNB”: Food and Non-Alcoholic Beverages; “ABT”: Alcoholic Beverages and Tobacco; “C&F”: Clothing and Footwear; “H&U”: Housing and Utilities; “FHM”: Furniture, and Home Maintenance; “HEA”: Health; “TRA”: Transport; “COM”: Communication; “R&C”: Recreation and Culture; “R&H”: Restaurants and Hotels; “MGS”Miscellaneous Goods and Services.

Table 3: Selected moments from the distribution of price changes

	Data(Outliers excluded) Method(Aggregated from all price changes)		Data(Outliers included) Method(Aggregated from all price changes		Data(Outliers excluded) Method(Aggregated from each product)		Data(Outliers included) Method(Aggregated from each product)	
	All records	Exl.sales	All records	Exl.sales	All records	Exl.sales	All records	Exl.sales
Frequency of price changes	18.48	14.89	18.73	15.13	18.40	14.82	18.65	15.06
Fraction of price changes that are decreases	41.98	35.03	42.11	35.28	41.94	34.95	42.08	35.21
Moments for the size of price changes								
Average	-0.21	2.52	-0.13	2.65	-0.17	0.90	-0.10	0.93
Standard deviation	28.14	25	33.74	31.82	25.53	23.73	29.40	26.97
Kurtosis	5.66	7.80	16.73	23.60	9.31	11.92	11.04	12.22
Moments of standardized price changes								
Kurtosis	9.98	13.78	11.70	15.06	9.31	11.92	11.04	12.22
Moments for the absolute value of standardized price changes								
Average	0.69	0.66	0.67	0.64	0.69	0.66	0.67	0.64
Fraction of observations<0.25*E(|z|)	20.5	24.8	21.5	25.4	20.4	24.0	21.4	25.4
Fraction of observations<0.5*E(|z|)	36.7	42.5	38.5	42.4	36.6	40.8	38.5	42.4
Fraction of observations>2*E(|z|)	14.6	13.7	14.4	15.0	14.6	15.2	14.4	15.0
Fraction of observations>4*E(|z|)	1.7	2.2	2.3	3.0	1.7	2.6	2.3	3.0
Number of obs. With $\Delta p \neq 0$	3,481,459	2,344,945	3,549,565	2,400,432	3,481,459	2,344,945	3,549,565	2,400,432

Table 4: Monthly frequency time series results

	OLS			IV		
VARIABLES	CH	CH_D	CH_U	CH	CH_D	CH_U
inflm	1.487*	-0.525*	2.013**	6.304	-2.690	8.994
	(0.889)	(0.279)	(0.810)	(6.719)	(3.548)	(6.009)
infly	0.913***	0.210**	0.703***	0.961***	0.219	0.742***
	(0.170)	(0.086)	(0.123)	(0.303)	(0.160)	(0.271)
gqm	-0.125	-0.033	-0.091	-0.033	-0.596	0.563
	(0.164)	(0.068)	(0.144)	(0.740)	(0.391)	(0.662)
gqy	-0.097	-0.035	-0.061	-0.142	-0.075	-0.067
	(0.108)	(0.034)	(0.086)	(0.133)	(0.070)	(0.119)
crisisd	0.018**	0.007**	0.011**	0.012	0.004	0.008
	(0.007)	(0.003)	(0.005)	(0.013)	(0.007)	(0.011)
dumvat08	0.283***	0.256***	0.027***	0.326***	0.233***	0.093
	(0.008)	(0.004)	(0.006)	(0.069)	(0.036)	(0.062)
dumvat10	0.101***	-0.010**	0.111***	0.090**	0.003	0.086***
	(0.010)	(0.004)	(0.008)	(0.037)	(0.020)	(0.033)
dumvat11	0.234***	-0.002	0.235***	0.204***	0.018	0.186***
	(0.010)	(0.003)	(0.008)	(0.053)	(0.028)	(0.048)
trend	-0.000***	-0.000	-0.000***	-0.000**	0.000	-0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	0.151***	0.041***	0.110***	0.185***	0.025	0.160***
	(0.011)	(0.003)	(0.009)	(0.048)	(0.026)	(0.043)
Durbin-Wu-Hausman Test (p-val)				0.127	0.487	0.016
F-test for seasonal dummies(p-val)	0.000	0.000	0.000	0.000	0.000	0.000
Observations	208	208	208	206	206	206
R-squared	0.803	0.680	0.659	0.630	0.594	0.499

Note: Newey-West standard errors are reported in parentheses, which are used to account for autocorrelation and heterosckedasticity. *** 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 hikes. “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

Table 5: Quarterly frequency time series results

	OLS			IV		
VARIABLES	CH	CH_D	CH_U	CH	CH_D	CH_U
inflq	-0.284	-0.287	0.419	-0.827	-0.470	0.171
	(1.315)	(1.050)	(1.275)	(2.982)	(2.365)	(2.903)
infly	0.448**	-0.007	0.404**	0.469**	0.003	0.399**
	(0.193)	(0.154)	(0.187)	(0.208)	(0.165)	(0.203)
gqq	-1.650**	0.365	-1.554**	-2.345**	0.453	-2.376**
	(0.739)	(0.590)	(0.717)	(1.141)	(0.905)	(1.111)
gqy	0.103	-0.228	0.166	0.198	-0.190	0.243
	(0.277)	(0.221)	(0.268)	(0.328)	(0.260)	(0.319)
crisisd	0.061***	0.018	0.049**	0.060**	0.022	0.043
	(0.020)	(0.016)	(0.020)	(0.028)	(0.022)	(0.027)
dumvat08	0.144***	0.198***	-0.026	0.130***	0.198***	-0.039
	(0.034)	(0.027)	(0.033)	(0.042)	(0.034)	(0.041)
dumvat10	0.106***	0.017	0.101***	0.111***	0.019	0.105***
	(0.030)	(0.024)	(0.029)	(0.033)	(0.026)	(0.032)
dumvat11	0.183***	0.040	0.174***	0.191***	0.043	0.179***
	(0.033)	(0.027)	(0.032)	(0.046)	(0.036)	(0.044)
trend	-0.001**	0.000	-0.001**	-0.001*	0.000	-0.001*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	0.282***	0.107***	0.216***	0.283***	0.104***	0.220***
	(0.015)	(0.012)	(0.014)	(0.020)	(0.016)	(0.020)
Durbin-Wu-Hausman Test (p-val)				0.704	0.913	0.662
F-test for seasonal dummies (p-val)	0.000	0.498	0.000	0.000	0.631	0.000
Breusch-Godfrey LM Test	0.744	0.831	0.958	0.444	0.783	0.782
Breusch-Pagan Test	0.695	0.936	0.816	0.911	0.942	0.936
Observations	69	69	69	67	67	67
R-squared	0.808	0.681	0.763	0.803	0.680	0.754

Note: Standard errors 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 hikes. "inflq" quarterly inflation, "infly" annual inflation, "gqq" quarterly GDP growth, "gqy" annual GDP growth, "crisisd" crisis dummy, "dumvat08" ,"dumvat10", and "dumvat11" are VAT change dummies

Table 6: Monthly CV regression results

VARIABLES	OLS cv	IV cv
freq	-0.204***	-0.173***
	(0.033)	(0.046)
cv(-1)	0.910***	0.956***
	(0.057)	(0.065)
inflm	0.531	-1.035
	(0.380)	(1.804)
infly	0.260**	0.265**
	(0.101)	(0.115)
gqm	0.004	0.302
	(0.079)	(0.214)
gqy	0.003	0.061
	(0.034)	(0.046)
crisisd	0.005	0.010**
	(0.003)	(0.004)
dumvat08	0.053***	0.032
	(0.014)	(0.028)
dumvat10	0.019*	0.014
	(0.011)	(0.012)
dumvat11	0.050***	0.048***
	(0.013)	(0.014)
trend	0.000	0.000
	(0.000)	(0.000)
Constant	0.040**	0.009
	(0.020)	(0.027)
F test for seasonal dummies (p-val)	0.000	0.000
Durbin-Wu-Hausman test (p-val)		0.153
Observations	207	204
R-squared	0.919	0.901

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Note: “freq” frequency of price changes; “cv(-1)” one period lagged value of coefficient variation; “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.

Table 7: Quarterly CV regression results

VARIABLES	OLS cv	IV cv
freq	-0.195***	-0.195***
	(0.071)	(0.039)
cv(-1)	0.508***	0.510***
	(0.123)	(0.086)
inflq	-0.116	-0.114
	(0.422)	(0.374)
infly	0.242**	0.237***
	(0.105)	(0.066)
gqq	-0.765**	-0.764***
	(0.337)	(0.224)
gqy	0.090	0.091
	(0.080)	(0.079)
crisisd	0.009	0.009
	(0.007)	(0.006)
dumvat08	0.032***	0.032***
	(0.009)	(0.011)
dumvat10	0.014	0.014
	(0.009)	(0.009)
dumvat11	0.038**	0.038***
	(0.015)	(0.012)
trend	0.000**	0.000***
	(0.000)	(0.000)
Constant	0.208***	0.207***
	(0.056)	(0.035)
F-test for seasonal dummies (p-val)	0.000	0.000
Observations	68	67
R-squared	0.943	0.941

Note: Newey-West Standard errors in parentheses. “freq” frequency of price changes; “cv(-1)” one period lagged value of coefficient variation; “inflq” quarterly inflation, “infly” annual inflation, “gqq” quarterly GDP growth, “gqy” annual GDP growth, “crisisd” crisis dummy, “dumvat08” ,“dumvat10”, and “dumvat11” are VAT change dummies. *** p<0.01, ** p<0.05, * p<0.1

Table 8: Regression results for price-growth dispersion

	OLS		IV	
VARIABLES	SD	IQR	SD	IQR
inflm	-0.716	-3.554***	-1.470	-12.843
	(0.718)	(1.184)	(4.393)	(7.921)
infly	-1.193***	-0.944***	-1.229***	-1.039***
	(0.181)	(0.225)	(0.198)	(0.357)
gqm	0.074	0.150	0.866*	-0.056
	(0.121)	(0.230)	(0.484)	(0.873)
gqy	0.038	0.064	0.138	0.153
	(0.089)	(0.127)	(0.087)	(0.156)
crisisd	-0.017***	-0.015*	-0.007	-0.003
	(0.007)	(0.008)	(0.008)	(0.015)
dumvat08	-0.100***	-0.172***	-0.101**	-0.256***
	(0.008)	(0.011)	(0.045)	(0.081)
dumvat10	-0.045***	-0.084***	-0.056**	-0.062
	(0.008)	(0.012)	(0.024)	(0.044)
dumvat11	-0.084***	-0.095***	-0.089**	-0.037
	(0.008)	(0.013)	(0.035)	(0.063)
trend	0.000***	0.000***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
Constant	0.242***	0.130***	0.238***	0.065
	(0.009)	(0.014)	(0.032)	(0.057)
F-test for seasonal dummies (p-val)	0.000	0.000	0.000	0.000
Observations	208	208	206	206
R-squared	0.6	0.675	0.601	0.458

Note: price-growth dispersion is measured either by Standard Deviation (SD) or Interquartile Range (IQR). Newey-West standard errors are in parenthesis. “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.
*** p<0.01, ** p<0.05, * p<0.1

Table 9: Correlation at business cycle frequencies

Dependent Variable	S.D.	IQR	Freq	Med	Skew	Kurt	IQR/Med
(1) IP growth(monthly change)	0.361*	0.571	-0.436	-0.459	-10.710**	113.868	11.065*
	(0.208))	(0.367))	(0.337)	(0.300)	(4.936)	(122.252)	(5.670)
(2) IP growth(annually change)	0.292*	0.485*	-0.282	-0.296	-2.567**	46.368	6.383*
	(0.154)	(0.280)	(0.246)	(0.250)	(1.097)	(52.562)	(3.684)
(3) CPI monthly inflation	-0.988	-3.005	1.032	-0.157	-1.856	-531.793	-40.091
	(1.572)	(2.564)	(3.406)	(3.194)	(25.829)	(857.571)	(42.404)
(4) CPI annually inflation	-1.248***	-2.435***	1.710***	1.568***	-0.903	-93.258	-44.904***
	(0.379)	(0.698)	(0.430)	(0.421)	(4.615)	(164.815)	(9.676)
(5) IP (Bandpass)	0.004***	0.007***	-0.003**	-0.004**	-0.002	-0.052	0.073***
	(0.001))	(0.001)	(0.002)	(0.002)	(0.015)	(0.509)	(0.019)
(6) CPI (Bandpass)	-0.005	-0.009	0.014*	0.014*	-0.122	5.702**	-0.182
	(0.005)	(0.009))	(0.008)	(0.008)	(0.101)	(2.777)	(0.120)
(7) Crisis	-0.334***	-0.061***	0.047**	0.041**	0.071	2.148	-1.052***
	(0.012)	(0.020)	(0.018)	(0.019)	(0.091)	(3.006)	(0.226)
Mean of Dep. Var. Non-Crisis:	0.300	0.289	0.143	0.110	-0.095	22.767	2.782
Mean of Dep. Var. Crisis:	0.281	0.246	0.193	0.155	0.081	24.008	1.906
Mean of Dep. Var.:	0.298	0.284	0.149	0.115	-0.074	22.916	2.677
Coefficient of Variation	0.147	0.266	0.413	0.516	7.836	0.335	0.399

Each column reports a time-series correlation of a price dispersion statistics with a measure of the business cycle. Mean of Dep. Var. shows the means of the overall mean of these variables as well as their average values during and outside crisis. Zeros are excluded when computing dispersion. All data is seasonally adjusted using 12 monthly. Regression in rows (1) – (4) and (7) include linear and quadratic time-trends. All data for regressions in row (5) and (6) are bandpass filtered using a **Baxter-King** (18,96, 33) filter. IP in (1), (2) and (5)=Industrial Production; Crisis in (3)=1 during 2008m1 and 2010m1, otherwise=0; IQR=Interquatile Range; SD=Standard Deviation; Freq=mean Frequency of price changes; Med=Median Frequency of price changes; Skew=Skewness; Kurt=Kurtosis. Number of observation *n*=209 for (1)-(3) and (7), *n*=142 for (5) and (6). ***=at least 1% significance,**=5% significance, *=10% significance. (Newey-West standard errors in parentheses, which are used to account for autocorrelation)

Table 10: Correlation between Frequency and Price-growth Dispersion

Dependent Variable	1. S.D	2. IQR	3. S.D.(Bandpass)	4. IQR(Bandpass)
Freq	-0.439***	-0.746***	-0.760***	-0.451***
	(0.049)	(0.097)	(0.122)	(0.081)
Med	-0.467***	-0.824***	-0.824***	-0.493***
	(0.049)	(0.107)	(0.104)	(0.069)

This table reports correlations between measures of frequency and price change dispersion. Newey-West standard errors are in parentheses, which are used to account for autocorrelation. Zeros are excluded when computing dispersion. All data is seasonally adjusted using 12 monthly. Regressions in first two columns include a quadratic time-trend. All data for regressions in the last two columns are bandpass filtered using a **Baxter King**(18,96, 33) filter. IQR=Interquartile range, Freq=Mean frequency of price changes, Med=Median frequency of price changes, S.D.=Standard deviation, IQR= Interquartile range. Number of observation n=208 for the first two columns. n=142 for the last two columns. ***=at least 1% significance,**=5% significance, *=10% significance.

Table 11: Regression results on monthly kurtosis

	OLS	IV
VARIABLES	kurtosis	kurtosis
inflm	82.200**	361.344
	(34.294)	(234.190)
infly	39.897***	40.436***
	(7.186)	(10.557)
gqm	-4.639	0.455
	(7.164)	(25.804)
gqy	-2.563	-5.696
	(4.091)	(4.626)
crisisd	0.552**	0.181
	(0.243)	(0.448)
dumvat08	14.251***	16.733***
	(0.352)	(2.400)
dumvat10	5.498***	4.848***
	(0.474)	(1.305)
dumvat11	11.160***	9.474***
	(0.485)	(1.854)
trend	-0.007***	-0.009***
	(0.002)	(0.003)
Constant	8.905***	10.856***
	(0.542)	(1.688)
F-test for seasonal dummies (p-val)	0.000	0.000
Observations	208	206
R-squared	0.797	0.719

Note: Newey-West standard errors are in parenthesis. “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.

*** p<0.01, ** p<0.05, * p<0.1

Table 12: 3SLS system estimation of monthly series

VARIABLES	FREQ	CV	IQR	KURT
inflm	2.728***	1.641***	1.717***	-75.680***
infly	1.043***	0.248*	-0.414	24.290**
gqm	-0.393	-0.034	0.238	-16.365
gqy	-0.244*	-0.066	-0.115	1.151
crisisd	-0.002	-0.005	-0.021	0.126
trend	0.000***	0.000***	0.000***	-0.009***
dumvat08	0.272***	0.058***	0.018	9.428***
dumvat10	0.110***	0.010	-0.054	5.194***
dumvat11	0.233***	0.029*	-0.016	9.819***
Constant	0.519***	0.219***	0.467***	1.970
CV(-1)		0.398***		
FREQ		-0.184***	-0.505***	12.041***
CV	-1.190***		-0.701***	11.611*
Seasonal dummies	Yes	Yes	Yes	Yes
Observations	204	204	204	204
R-squared	0.419	0.813	0.278	0.634

***p<0.01, **p<0.05, *p<0.1

Table 13: 3SLS system estimation of quarterly series

VARIABLES	FREQ	CV	IQR	KURT
inflq	6.155***	2.386***	-1.336**	63.217***
infly	0.820***	0.255***	-0.094	10.959***
gqq	-4.388***	-1.098**	0.918	-0.219
gqy	-0.363	-0.122	0.145	-7.705*
crisisd	-0.015	-0.009	0.006	-0.294
trend	0.001*	0.000**	0.000	0.003
dumvat08	0.156***	0.055***	0.039**	2.780***
dumvat10	0.041	0.002	0.021	-0.055
dumvat11	0.107***	0.018	0.073***	0.477
Constant	1.107***	0.388***	0.314***	11.249***
CV(-1)		0.222		
FREQ		-0.260***	-0.585***	13.377***
CV	-2.152***		-0.030	-20.984***
Seasonal dummies	Yes	Yes	Yes	Yes
Observations	67	67	67	67
R-squared	0.607	0.868	0.817	0.887

***p<0.01, **p<0.05, *p<0.1