SFB 649 Discussion Paper 2011-019

What Drives the Relationship Between Inflation and Price Dispersion? Market Power vs. Price Rigidity

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This research was supported by the Deutsche Forschungsgemeinschaft through the SFB 649 "Economic Risk".

http://sfb649.wiwi.hu-berlin.de
ISSN 1860-5664

SFB 649, Humboldt-Universität zu Berlin
Spandauer Straße 1, D-10178 Berlin

SFB 649 ECONOMIC RISK BERLIN

What Drives the Relationship Between Inflation and Price Dispersion? Market Power vs. Price Rigidity

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March 22, 2011

Abstract

Recent monetary search and Calvo-type models predict that the relationship between inflation and price dispersion is U-shaped, implying an optimal rate of inflation above zero. Moreover, monetary search models emphasize a critical dependence of the real effects of inflation on sellers' market power, whereas Calvo-type models suggest that the degree of price rigidity significantly affects the inflation - price dispersion nexus. Using a new set of highly disaggregated sectoral price data from a panel of European countries, this paper contributes to the literature by testing the empirical relevance of these two theoretical predictions. In line with monetary search theory, a U-shaped profile is found, provided that markups are sufficiently high, but the relationship breaks down under a more competitive environment. Contrarily, no evidence is found to support the contentions of Calvo-type models: U-shaped effects of inflation occur in product sectors with sticky as well as highly flexible prices.

Keywords: Inflation; Relative price variability; Price level index; Euro-area; Market structure; Monetary search model; Dynamic panel data models

JEL classification: C23, D40, E31, F15

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*This research was supported by the Deutsche Forschungsgemeinschaft through the CRC 649 "Economic Risk." I am grateful to Eurostat for providing the data analyzed in this paper. Eurostat bears no responsibility for the analysis and conclusions reported here. I also thank Jorgo Georgiadis, Dieter Nautz and Lars Svennebye for helpful comments and suggestions. Financial support by the Monetary Stability Foundation is gratefully acknowledged. E-mail: sascha.becker@fu-berlin.de.

1 Introduction

With important implications for the welfare costs of inflation and the theorem of monetary neutrality, the relationship between inflation and price dispersion has been the subject of intensive investigation. Earlier research typically points to a positive monotonic linkage (see e.g. Debelle and Lamont, 1997), but later work suggests that the relationship is more complex. According to recent empirical evidence, the inflation-price dispersion nexus is non-monotonic and exhibits significant variation over inflation regimes (see e.g Fielding and Mizen, 2008, and Bick and Nautz, 2008). On the theoretical front, recent monetary search and Calvo-type models (see Head and Kumar, 2005 and Choi, 2010) predict the inflation-price dispersion nexus to be U-shaped, implying an optimal rate of inflation above zero. Interestingly, these two models make very different predictions about the economics behind the U-shaped profile. Using a new set of highly disaggregated sectoral price data from a panel of European countries, this paper contributes to the literature by testing the empirical relevance of recent monetary search and Calvo-type models.

Based on an asymmetric information environment, the monetary search model described by Head and Kumar (2005) predicts U-shaped effects of inflation provided that firms have a high degree of market power. Moreover, if a market is highly competitive, i.e. price mark-ups are low, the relationship between inflation and price dispersion breaks down and the classic dichotomy holds. Choi (2010) introduces a Calvo model of sticky prices with heterogeneous sectors and shows that in an environment of more rigid price setting, the relationship between inflation and price dispersion is again U-shaped. Yet when price adjustment is highly flexible, real effects of inflation disappear.

To capture such dependencies, this study focuses on various product markets that exhibit a great amount of heterogeneity in the degree of competition and price stickiness and examines the inflation-price dispersion nexus subject to the market under consideration. In particular, the pooled mean group model (Pesaran et al., 1999) as well as the recently developed conditional pooled mean group model (Binder et al., 2010) are employed. The conditional pooled mean group model offers a very flexible framework for analyzing the inflation-price dispersion linkage. In this framework, the long-run effect of inflation on price dispersion is allowed to vary depending on the level of mark-ups and the degree of price rigidity in a given market such that a direct discrimination between monetary search and Calvo-type models is feasible.

Even though theoretical models have direct implications for the relationship between inflation and relative *price* variability (RPV), most of the empirical literature focuses on relative *inflation* variability (RIV), see e.g. Parks (1978), Aarstol (1999), Silver and Ioannidis (2001), Becker and Nautz (2009), or Choi (2010).[1] The use of RIV is mainly driven by data constraints. Due to the lack of actual price-level data, researchers employ price index data to analyze the inflation-price dispersion nexus.[2] But, since those data are indices, they cannot be compared directly across countries to investigate differences in price levels. In the base year of the price index, by definition RPV equals zero regardless of the true amount of price dispersion. A RPV measure with index data is therefore not feasible and the computation of inflation rates is inevitable.

To overcome this problem, the data used in this article are Price Level Indices (PLIs) provided by the Eurostat database. The PLIs are calculated as the ratio between Purchasing Power Parities and the Euro exchange rates for each country. They allow a direct comparison of Euro-area countries' price levels with respect to the Euro-area average such that computation of RPV is feasible. In addition, Eurostat PLI data have

[1]The concept of RPV is used in the empirical literature to calculate the dispersion of price *levels*. Intramarket RPV is defined as the cross-sectional standard deviation of individual product prices with respect to the product average. In contrast, RIV measures the tendency of relative prices to *change* over time and is usually proxied by the cross-sectional standard deviation of individual rates of price change around the average inflation rate.

[2]A minority of studies on the relationship between inflation and RPV use highly disaggregated price level data and typically focus on only a few specific commodities, see e.g. Lach and Tsiddon (1992), Reinsdorf (1994), Parsley (1996), or Caglayan et al. (2008). However, results obtained in the analysis of a small sample of goods may say little about the inflation-RPV nexus in the whole market.

been collected for an adequate sample of goods, thus permitting determination of more general patterns, as opposed to studies that focus on a single product or small product sets.[3]

Especially for the Euro-area, quantitative results could be strongly dependent on the dispersion measure used. For example, if there were large differences in price levels across the Eurozone before January 1, 1999, but the introduction of the euro caused rapid price convergence, then one might expect to see very different rates of price changes. The high rate of inflation in Ireland and the relatively low rate of inflation in Germany may simply represent convergence in prices. As a result, the RPV measure should exhibit a clear downward trend while RIV remains high. Moreover, the deterministic components of the RPV series may undergo transitions, perhaps due to the ongoing integration process in the European Union, i.e. implementation of the Single Market Program in 1992 and introduction of the Euro in 1999. A common currency eliminates transaction costs and exchange rate risks and, through price transparency, increases trade and competition, thereby contributing to lower price dispersion. In contrast to the majority of the empirical literature in which price series are de-trended via simple first differencing, this study employs smooth transition analysis so as to filter out deterministic trends, see Leybourne et al. (1998) and Fielding and Mizen (2000). Modeling structural changes via smooth transition analysis is appealing because the transition from one trend path to another is gradual, but with limiting cases allowing non-transition or a discrete break in trend.

In line with both theoretical models, the first set of estimation results which employs the pooled mean group (PMG) model strongly suggest that the relationship between inflation and price dispersion depends on market characteristics. The estimated coefficients on inflation vary significantly across the different product panels. Those results

[3]So far, the PLI data set has attracted little attention, mainly because Eurostat publishes only annual averages of PLIs from 1996 onwards. Hence, only a limited number of data on PLIs is available. The analysis presented here solves this problem by setting up an algorithm which employs monthly inflation data to generate also monthly measures of PLI data.

were confirmed by the conditional pooled mean group (CPMG) model. More interestingly, the CPMG analysis reveals a significant empirical discrimination between the monetary search and the Calvo-type model predictions. The inflation-RPV nexus is U-shaped around a positive vertex for markets exhibiting high mark-ups. With increasing competition, the U-shaped profile becomes progressively flatter and inflation has less of an impact on price dispersion. Indeed, when mark-ups fall slightly below the Euro-area average of 37%, the non-linear U-shaped effect of inflation disappears altogether. Consequentially, the empirical results clearly support the predictions made by the Head and Kumar monetary search model. The CPMG analysis, however, finds no evidence for a significant dependence of the inflation-RPV nexus on the degree of price stickiness. The existence of a non-linear U-shaped inflation-RPV linkage is not affected by price rigidity. U-shaped effects of inflation occur in sectors with sticky as well as highly flexible prices. Accordingly, the empirical results do not support the predictions made by the recent Calvo-type model of Choi.

The paper is organized as follows. Section 2 reviews recent theoretical and empirical contributions on the relationship between inflation and price dispersion. Section 3 specifies the price variability and inflation measures, describes the data set on price dispersion, mark-ups, and price rigidities in Europe, and employs smooth transition analysis to filter out deterministic trends in price dispersion. Section 4 introduces the empirical model and presents results on the European inflation-price dispersion relationship using the PMG as well as the CPMG model. Concluding remarks are offered in Section 5.

2 The Non-Linear Inflation-RPV Nexus

2.1 Theoretical Literature

The impact of inflation on price dispersion varies significantly across different classes of models. According to classic menu-cost (Rotemberg, 1983) or Lucas-type misperception models (Barro, 1976), inflation increases relative price variability (RPV), distorts the information content of prices, and, thereby, impedes efficient allocation of resources. Both types of models imply a monotonic inflation-RPV relationship in which inflation always lowers welfare. In contrast, recent monetary search (Head and Kumar, 2005) and Calvo-type (Choi, 2010) models predict the relationship to be non-linearly U-shaped, with an optimal rate of inflation above zero. Interestingly, the Head and Kumar monetary search model suggests a critical dependence of the real effects of inflation on sellers' market power, whereas in Choi's Calvo-type model the degree of price stickiness significantly affects the inflation-price dispersion nexus.

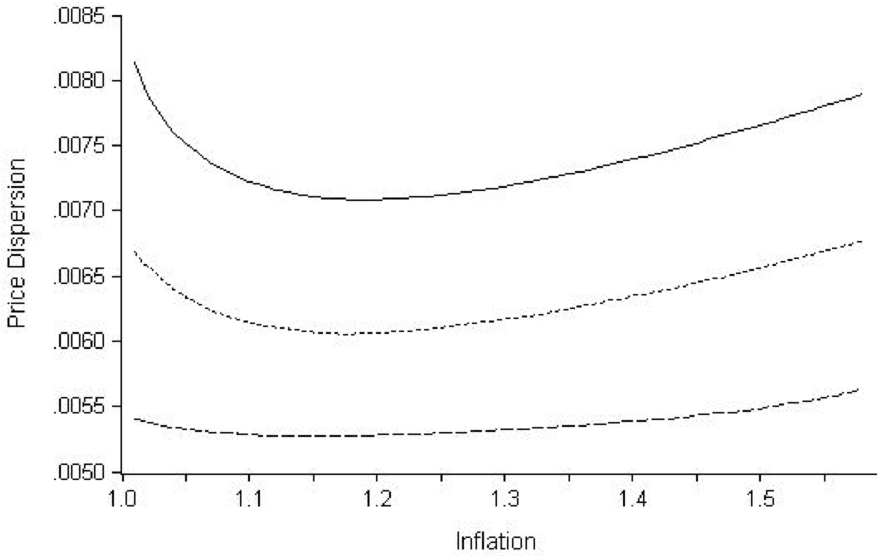
Monetary Search Theory and the Role of Market Power

The Head and Kumar (2005) monetary search model emphasizes that buyers have only incomplete information about prices offered by different sellers. In this model, the overall effect of inflation on price dispersion is not always obvious. On the one hand, higher inflation lowers the value of fiat money, which increases demand for goods and, thereby, sellers' market power. Since market power differs across sellers, higher inflation leads to higher price dispersion. On the other hand, buyers respond to an increase in price dispersion by searching more intensively, which lowers sellers' market power and, thus, RPV. At low levels of inflation, the latter effect dominates, leading to a reduction in price dispersion and an improvement in welfare. Contrarily, at high levels of inflation, the former RPV increasing effect dominates, such that the overall inflation-RPV nexus is U-shaped around a positive vertex.[4] The economics behind this U-shaped pattern can be explained as follows: When inflation is low, a relatively large fraction of buyers observe only a single price quote. In this situation, an increase in inflation induces strong increases in buyers' search intensity in order to avoid inflation-induced increases of sellers' market power. Accordingly, changes

[4]Head et al. (2010) establish a stochastic version of the Head and Kumar (2005) model to study the extent of real and nominal price adjustments to fluctuations in productivity and the inflation rate.

in inflation have relatively large effects on search intensity and, thus, price dispersion declines. As the rate of inflation rises, the share of buyers observing only one price quote decreases. Therefore, any further increase in inflation has a smaller effect on search intensity such that the RPV decreasing effect becomes less important. Finally, at a certain inflation level, the increasing effect, stemming from a lower purchasing power of money, dominates and price dispersion goes up.

Figure 1: The Head and Kumar Monetary Search Model



Notes: Figure plots price dispersion versus inflation for varying levels of price mark-ups: i) high mark-up (upper graph) ii) moderate mark-up (middle graph) and iii) low mark-up (lower graph). See Head and Kumar (2005) and Becker and Nautz (2010) for more details on the simulation exercise.

Becker and Nautz (2010) show that U-shaped effects of inflation require the level of search costs, i.e. the average degree of sellers' market power, to be sufficiently high. Based on these findings, the upper graph in Figure 1 displays a model simulation of inflation's impact on price dispersion for an environment in which sellers' market power is high. Furthermore, Becker and Nautz (2010) point out that with decreasing search costs, i.e. lower price mark-ups, the U-shape of the inflation-RPV relationship becomes progressively flatter and inflation has less of an impact on price dispersion.

With lower search costs the proportion of buyers observing only one price quote decreases. Therefore, an increase in inflation has a smaller impact on search intensity and price dispersion responds less to inflation. In case of very low search costs, i.e. low mark-ups, inflation has no effect on price dispersion and the classic dichotomy holds. To visualize these effects, the middle and lower graph in Figure 1 display simulation results for moderate and low mark-ups, respectively. Compared to the high mark-up simulation, decreasing mark-ups shift the inflation-RPV nexus downwards. More importantly, the curvature of the relationship dampens out.

These theoretical implications lead to the first empirically testable Hypothesis:

Hypothesis 1: *Consider the monetary search model of Head and Kumar (2005). Provided that the average degree of sellers' market power, i.e. the average price mark-up, is sufficiently high, the relationship between inflation and RPV is U-shaped around a positive rate of inflation. With increasing competition, i.e. lower price mark-ups, the U-shaped relationship between inflation and RPV gets progressively flatter and the impact of inflation on the dispersion of prices declines.*

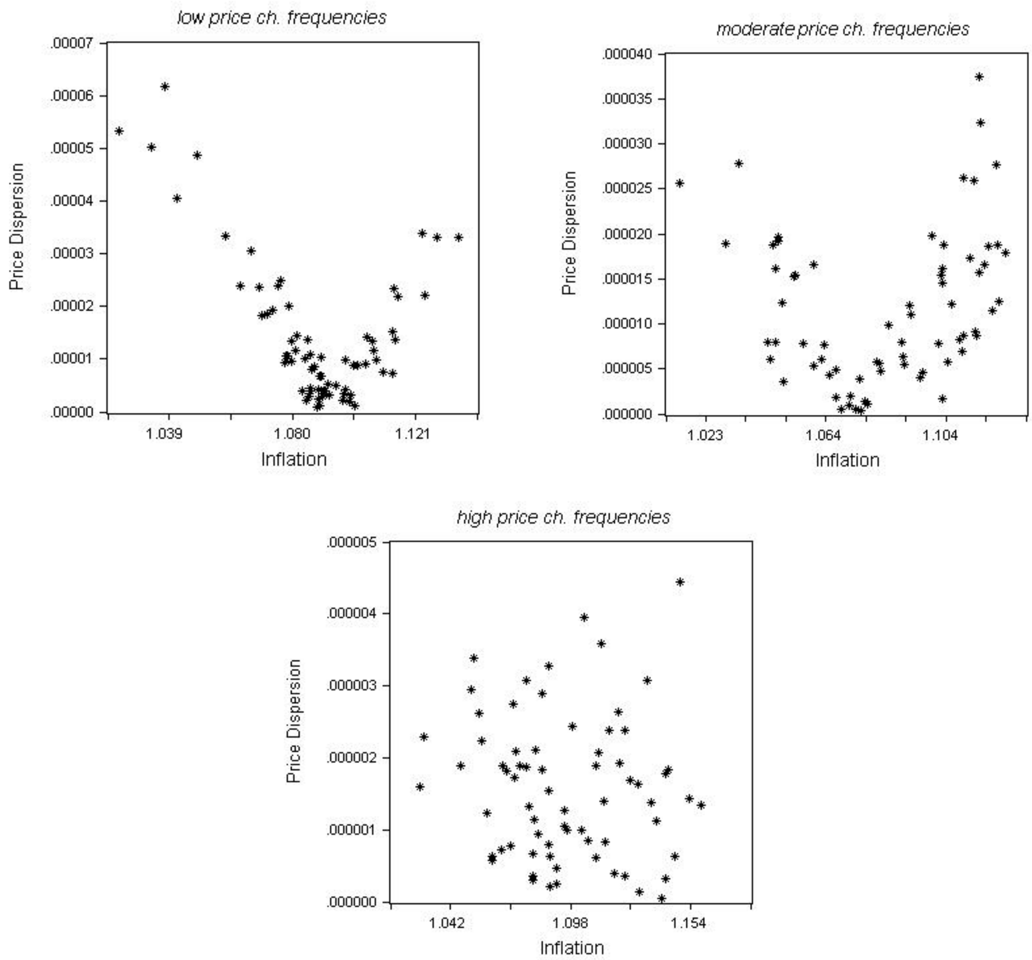
Calvo-Pricing with Sectoral Heterogeneity and the Role of Price Rigidities

Choi (2010) considers a Calvo model of sticky prices within a setting of sectoral heterogeneity. In particular, he assumes that the degree of price stickiness varies across sectors. Under these circumstances, sectors with relatively flexible prices respond much more strongly to an external shock than do sectors with relatively sticky prices and price dispersion necessarily occurs. According to Choi (2010), the relationship between inflation and price variability in such a Calvo-pricing model is again non-linearly U-shaped. Here, the non-linearity can be explained as follows: Since under the Calvo-assumption agents can not adjust prices each period, they have to form expectations about future price developments. Now suppose that there exists an inflation level which is widely perceived by the public, e.g. the targeted level for inflation targeting central banks or the implicit level of target set by the European Central Bank or the Federal Reserve. If actual inflation is around this target level, agents expectations proved to be correct and there is no need to adjust prices. Under these circumstances, price dispersion is low as every sectors perceives this and takes into account when forming prices. However, if the actual level of inflation is deviating from this perceived target level (in either direction), price dispersion is rising as explained above. Since it is not inflation per se, but the deviation from the expected level of inflation that increases RPV, the relationship between RPV and inflation is U-shaped around this level.

Furthermore, Choi (2010) points out that the nature of the inflation-RPV nexus critically hinges on the average degree of price rigidity. For sectors in which the average degree of price rigidity is high, the relationship is U-shaped, but this link weakens when price adjustment is highly flexible. The degree of price rigidity therefore exerts an important influence on the relationship between inflation and RPV. That the real effects of inflation depend on the Calvo-parameter is an unsurprising result, since the Calvo-environment is the driving force of any real effects in such a model setup. Consequentially, real effects are more pronounced for higher rigidity measures.

Figure 2 presents different model simulations for varying levels of price rigidities. In line with Choi (2010), the relationship between inflation and RPV is U-shaped for sectors in which the average degree of price rigidity is high, i.e. the frequency of price changes is low (see upper left panel). The remaining panels depict the inflation-RPV nexus for moderate and high price changes frequencies. With moderate price adjustment, the non-linear effect of inflation is less pronounced. Furthermore as displayed in the lower panel, the U-shaped relationship disappears completely in the highly flexible price adjustment environment.

Figure 2: The Choi Calvo-Type Model



Notes: Figure plots price dispersion versus inflation for varying levels of price change frequencies: i) low price change frequencies (upper left plot) ii) moderate price change frequencies (upper right plot) and iii) high price change frequencies (lower plot). See Choi (2010) for more details on the simulation exercise.

The implications of the Choi Calvo-type model can be summarized as follows:

Hypothesis 2: *Consider the Calvo-type model of Choi (2010). Provided that the average degree of price rigidity is sufficiently high, i.e. the average price change frequency is sufficiently low, the relationship between inflation and RPV is U-shaped. With more flexible prices, i.e. higher price change frequency, the U-shaped relationship gets less pronounced and the impact of inflation on the dispersion of prices declines.*

2.2 Empirical Evidence

Based on the predictions of classic menu-cost and misperception models, early empirical work on the relationship between inflation and price dispersion typically focuses on linear regressions of RPV/RIV on inflation. In line with theory, most empirical contributions find a significant positive impact of inflation (see Parsley, 1996, Grier and Perry, 1996, Debelle and Lamont, 1997, Aarstol, 1999, and Jaramillo, 1999), but there are notable exceptions. According to Lastrapes (2006), for example, the relationship between U.S. inflation and price dispersion breaks down in the mid-1980s, whereas Reinsdorf (1994) demonstrates that the relationship is negative during the disinflationary period of the early 1980s. A first attempt to analyze the European inflation-RPV nexus is provided by Fielding and Mizen (2000), who use price index data from 10 EU countries over the period 1986 to 1993. They find evidence of a negative relationship between inflation and RPV and conclude that the law of one price tends to hold more strongly with higher inflation.[5] Similar results are provided by Silver and Ioannidis (2001) for the European inflation-RIV relationship.

Lending support to monetary search and Calvo-pricing models, more recent empirical evidence suggests that the relationship between inflation and RPV/RIV is nonlinear. In particular, several studies find that the effect of inflation on price dispersion

[5]Note that Fielding and Mizen (2000) base their RPV measure on price index data. However, price index numbers convey no meaningful information for comparing relative prices at a point in time and therefore their results should be viewed with caution.

varies between high and low inflation periods and between countries with different inflationary contexts (Caglayan and Filiztekin, 2003, Caraballo, Dabús, and Usabiaga, 2006, Becker and Nautz, 2009, and Choi, 2010). Bick and Nautz (2008) apply panel threshold models and find evidence of threshold effects in the U.S. inflation-RIV linkage. Similar results are obtained by Becker and Nautz (2010) and Nautz and Scharff (2011) using European data. Becker and Nautz (2010) also find evidence in favor of a varying inflation-RIV nexus across country groups. In line with monetary search theory, they show that in a less integrated market, such as the EU-27 economy, where search costs are high, the relationship between inflation and price dispersion is non-linearly U-shaped, whereas for the highly integrated Euro-area market, inflation has no effect on price dispersion.

3 Data

3.1 Measuring Price Dispersion

The data used in this study comprise Price Level Indices (PLIs) for 12 Euro-area countries over the period 1996 to 2008.[6] Following the United Nations "Classification of Individual Consumption According to Purpose" (COICOP) scheme, 38 four-digit COICOP subcategories are considered (see Table 3 in the Appendix). PLIs make it possible to compare prices in relation to the Euro-area average. An index higher than 100 means that the country is relatively expensive compared to the Euro-area average; an index lower than 100 means that the country is relatively inexpensive. For example, a PLI of 105 for Germany indicates that prices in Germany are about 5 percent higher compared to the Euro-area average. Note that Eurostat publishes annual averages of PLIs such that only a limited amount of data on PLIs is available. To obtain reliable regressions results, this study employs monthly inflation data to generate monthly PLIs

[6]These countries are Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, and Spain.

(see Appendix A1 for details).[7]

Based on the enlarged data set, this study follows the lead of other authors (e.g. Parsley, 1996, or Fielding and Mizen, 2000) and defines *intramarket* relative price variability in subcategory i at time period t as:[8]

$$RPV_{it} = \left[\sum_{j=1}^{N} w_{jt} (R_{ijt} - R_{it})^2 \right]^{0.5}, \qquad (1)$$

where the relative product price of country j in subcategory i at period t is computed as $R_{ijt} = ln(PLI_{ijt}) - ln(PLI_{EU})$ and the cross sectional average relative price for product category i is $R_{it} = \sum_{j=1}^{N} w_{jt} R_{ijt}$. w_{jt} is the weight of country j at time t in the overall HICP index ($\sum_{j=1}^{N} w_{jt} = 1$) and N refers to the number of countries under consideration. Due to data constraints, the empirical literature usually employs price index data and proxies relative price variability (RPV) via relative inflation variability (RIV).[9] From the theoretical side, however, RPV is the relevant concept (see e.g. Danziger, 1987, and Woodford, 2003).

Inflation measures are based on monthly seasonally adjusted price index data from the Harmonized Index of Consumer Prices (HICP) provided by the Eurostat database. The price index data also include observations of the 38 four-digit COICOP subcategories, for 12 Euro-area countries over the period 01/1996 to 12/2008. In line with the

[7] Annual PLIs are utilized in previous studies of price convergence in the EU (see e.g. Allington et al., 2005, Wolszczak-Derlacz, 2008, and Dreger et al., 2009).

[8] Many empirical contributions analyze the impact of inflation on *inter*market relative price variability (RPV), see e.g. Debelle and Lamont (1997), Jaramillo (1999), and Becker and Nautz (2009). *Inter*market RPV is typically defined as the standard deviation of individual product prices around the average price in a given city or country. By contrast, the *intra*market side (deviations of individual product specific prices with respect to the average individual product price across cities or countries) seems to be under-researched. Exceptions include Lach and Tsiddon (1992), Reinsdorf (1994), Parsley (1996), Fielding and Mizen (2000), and Caglayan et al. (2008). In the following empirical study, the focus shall be on price variability in Europe within the *intra*market side because the monetary search and Calvo-type models are specifically designed to account for price dispersion within a given market.

[9] *Intramarket* relative inflation variability is typically defined as:

$RIV_{it} = \left[\sum_{j=1}^{N} w_{jt} (\pi_{ijt} - \pi_{it})^2 \right]^{0.5}$,

where π_{ijt} is the rate of change in the price index of the ith subcategory in country j at time period t and π_{it} is the average rate of change in product category i's price index ($\pi_{it} = \sum_{j=1}^{N} w_{jt} \pi_{ijt}$).

empirical literature, the average rate of change in the price index of the ith subcategory at time period t is defined as $\pi_{it} = \sum_{j=1}^{N} w_{jt}\pi_{ijt}$, where π_{ijt} is the rate of change in the price index of the ith subcategory in country j at time period t.

3.2 Price Mark-Ups and Price-Rigidities in Europe

Recent theoretical models on the relationship between inflation and price dispersion highlight the importance of sellers' market power and the degree of price rigidity for real effects of inflation (see Section 2). To identify different inflation-RPV linkages, this paper concentrates on a number of highly disaggregated product sectors with varying levels of price mark-ups and price change frequencies.

Empirical research abounds with micro and macro evidence of significant heterogeneity of price mark-ups and price stickiness across different product sectors in the Euro-area. Christopoulou and Vermeulen (2008) provide estimates of price-marginal cost ratios or mark-ups for 50 sectors in eight Euro-area countries. Applying the methodology developed by Roeger (1995) on the EU KLEMS database, they show that Euro-area mark-ups differ significantly across sectors, with services having higher mark-ups on average than manufacturing. An important body of work on price adjustment in Europe is carried out by the Inflation Persistence Network of the European Central Bank. Álvarez et al. (2006) and Dhyne et al. (2006) summarize the conclusions of a number of papers dealing with the frequency of price adjustment in consumer prices for the countries of the Euro-area. Based on the analysis of a common sample of 50 products, both papers present details of Euro-area price-rigidity and conclude that there is a tremendous amount of heterogeneity across sectors. Specifically, price changes occur frequently for energy (oil products) and unprocessed food, while they are relatively infrequent for non-energy industrial goods and services.

Table 3 in the Appendix links the 38 four-digit COICOP (CP) subcategories for which PLI data are available and the estimates on Euro-area mark-ups and price change

Table 1: Mark-ups and Price-change frequencies in Europe

	Mark-up (in %)	Price-fr. (in %)
Mean	36.0	16.4
Standard Deviation	20.1	23.4
Minimum	11.0 [CP 01.12]	3.4 [CP 07.23]
Maximum	79.0 [CP 03.14]	80.4 [CP 07.22]
Product Groups	38	38

Notes: This Table presents summary statistics on mark-ups and price-change frequencies used in this study. Price-fr. indicates the average percentage of consumer prices which change in a given month. For further explanations see Table 3 in the Appendix.

frequencies provided by the studies discussed above.[10] Overall, the product group ”Maintenance and repair of personal transport equipment” [CP 07.23] has the lowest degree of price change frequency (3.4%) and ”Fuels and lubricants for personal transport equipment” [CP 07.22] the highest (80.4%), see Table 1. Average price change frequency equals 16%. Considering sellers' market power, the range of mark-ups varies between 11% for ”Meat” [CP 01.12] and 79% for ”Cleaning, repair and hire of clothing” [CP 03.14], with an average mark-up of 36%. Interestingly, for the product groups considered here, mark-ups and price rigidities are nearly uncorrelated (the correlation coefficient equals -0.19). For instance, products with low price change frequency and high mark-ups appear as often as products with low price change frequency and low

[10]The linkage of the PLI subcategories and the estimates presented in Álvarez et al. (2006), Dhyne et al. (2006), and Christopoulou and Vermeulen (2008) is based on the CP classification scheme. For example, the result on Euro-area price change frequency for ”Lettuce” (CP 01.17.1) presented by Dhyne et al. (2006) is used to proxy price rigidity in the four-digit subcategory ”Vegetables” (CP 01.17.0).

mark-ups.

3.3 The European Integration Process and its Effect on Price Dispersion

Over the past two decades, markets within the European Union have become progressively more integrated as internal barriers to trade have been dismantled. Two crucial steps in this process were the completion of the Single Market Program (SMP) in 1992 and the start of Economic and Monetary Union (EMU) in 1999. The first removed the important physical, administrative, and technical barriers to integration and stimulated competition. The second increased price transparency through a common currency and eliminated exchange rate variations between the 11 (later 17) members of the Eurozone. The European Commission (1996) argued that ”increased price transparency will enhance competition and whet consumer appetites for foreign goods; price discrimination between different national markets [in the EU] will be reduced.” Additionally, the European Commission (1999) hypothesized that when the Euro was actually realized, it would ”squeeze price dispersion in EU markets.”

A number of empirical studies analyze the impact of European market integration on price convergence. Most of them conclude that price dispersion significantly declined during the last decades. There is no clear consensus, however, on whether the major step toward convergence occurred after the introduction of the Euro or even before. Foad (2005) finds evidence for a slightly reduced level of price dispersion after 1999. Allington et al. (2005) conclude that ”the process of convergence in the Eurozone triggered by EMU appears in the form of a structural break in the time trend of price dispersion.” Contrarily, several authors including Lutz (2003), Engel and Rogers (2004), and Rogers (2007) present evidence of a significant reduction in price dispersion throughout the decade of the 1990s, but find little evidence of further decline since 1999. Moreover, using smooth transition analysis, Fielding and Mizen (2000) find transition effects in European price dispersion over the period 1986 to 1993.

These studies clearly identify structural changes in the level of European price dispersion. As a consequence and in contrast to the large inflation-RIV literature in which long-run trends are filtered out via simple first differencing, this paper explicitly accounts for changes in the deterministic components of the RPV series by employing a smooth transition model. The empirical results indicate that for all product groups the deterministic process of the price dispersion series can be accurately described by a smooth transition process, i.e. once the deterministic component is removed, the de-trended series exhibit mean-reverting behavior (see Appendix A2).[11] Below, the de-trended series are used to analyze the relationship between inflation and RPV.

4 The Inflation-RPV Nexus in Europe

4.1 The Empirical Model

Consider the panel autoregressive distributed lag (PARDL) model:

$$RPV_{it} = \omega_i + \sum_{k=1}^{p} \rho_{ik} \cdot RPV_{i,t-k} + \sum_{k=0}^{q} \phi_{ik1} \cdot \pi_{i,t-k} + \sum_{k=0}^{r} \phi_{ik2} \cdot \pi^2_{i,t-k} + \epsilon_{it}, \qquad (2)$$

where the measures of price dispersion (RPV) and inflation (π) correspond to the definitions in Section 3 which sum over all countries j, to give RPV and inflation measures for individual product groups i at time t; $t = l, l+1, \ldots, T$ and $l = max(p,q,r)$. ω_i denotes a fixed effects type intercept and ρ_{ik}, ϕ_{ik1} and ϕ_{ik2} denote slope coefficients. The empirical inflation-price dispersion literature often assumes independently distributed residuals across the different product sectors, compare e.g. Fielding and Mizen (2000). A more reasonable assumption is that product groups are cross-correlated due to similar market characteristics and common influences such as common macroeconomic shocks. Neglecting such dependencies yields inefficient parameter estimates and likely results in size distortions of conventional tests of significance. A convenient way to incorporate cross-sectional dependence in the frame-

[11] Furthermore, classical ADF tests indicate that all inflation measures are stationary. Results of these ADF tests are not presented here, but are available on request.

work presented here is to model such dependencies by a factor error structure. Under this assumption, the errors of Equation (2) are given by $\epsilon_{it} = \boldsymbol{\lambda}_i^{'} \cdot \boldsymbol{f}_t + e_{it}$, where $\boldsymbol{f}_t$ is an unobserved common effect, $\boldsymbol{\lambda}_i^{'}$ is a vector of slope coefficients and e_{it} are independently distributed product-specific errors. To capture the common effects, the empirical analysis employs the common correlated effects augmentation proposed by Pesaran (2006), which approximates the common factor vector by cross-sectional averages of the dependent variable and the regressors.

The error-correction representation of Equation (2), separating short- and long-run dynamics, is given by:

$$\Delta RPV_{it} = \omega_i + \alpha_i \cdot [RPV_{i,t-1} - \theta_{i1} \cdot \pi_{i,t-1} - \theta_{i2} \cdot \pi_{i,t-1}^2] + \boldsymbol{\psi}_i^{'} \cdot \boldsymbol{h}_{it} + \epsilon_{it}, \tag{3}$$

where

$$\theta_{i1} = -\beta_{i1}/\alpha_i, \quad \theta_{i2} = -\beta_{i2}/\alpha_i, \quad \alpha_i = \sum_{k=1}^{p} \rho_{ik} - 1, \quad \beta_{i1} = \sum_{k=0}^{q} \phi_{ik1}, \quad \beta_{i2} = \sum_{k=0}^{r} \phi_{ik2},$$

$\boldsymbol{h}_{it}$ includes the lagged differences of the variables and $\boldsymbol{\psi}_i^{'}$ the corresponding parameters.

According to Equation (3), the long-run relationship between inflation and price dispersion for each product group i is given by:[12]

$$RPV_{it} = \theta_{i1} \cdot \pi_{it} + \theta_{i2} \cdot \pi_{it}^2 + \eta_{it}, \tag{4}$$

where η_{it} is $I(0)$. The parameters θ_{i1} and θ_{i2} detect the long-run effect of the level of inflation and inflation-squared on price dispersion. Inclusion of inflation-squared is motivated by recent theoretical contributions suggesting that the relationship between inflation and RPV is non-linearly U-shaped, see e.g. Choi (2010). Accordingly, the

[12] The existence of a long-run relationship between inflation and price dispersion critically depends on the stationarity properties of the RPV series. The results of the smooth transition analysis indicate that the price dispersion series are mean-reverting processes around deterministic components that experience transitions (see Appendix A2). This ensures that the speed of adjustment coefficient, α_i, is smaller than zero and there exists a long-run relationship between inflation and RPV. Note that with the model given by Equation (3), the distinction between short- and long-run dynamics is purely data-driven.

estimates of θ_{i2} are expected to be positive. Given a U-shaped function ($\theta_{i2} > 0$), the vertex of the inflation-RPV nexus is positive if $\theta_{i1} < 0$ but negative if $\theta_{i1} > 0$.[13] Since theory predicts a U-shaped inflation-RPV linkage around a positive vertex, the estimates of θ_{i1} are expected to be negative.

Equally important, recent theory posits that the effect of inflation on RPV varies across different product groups. According to the Head and Kumar monetary search model, the inflation-RPV nexus depends on sellers' market power. U-shaped effects should be found for product sectors characterized by high mark-ups, but the relationship should break down in a very competitive sector [see *Hypothesis 1*]. In contrast, the Choi Calvo-pricing model predicts that the degree of price rigidity significantly affects the relationship between inflation and RPV. According to this model, sectors with sticky prices should exhibit a U-shaped profile, whereas the distorting impact of inflation should disappear in the presence of highly flexible prices [see *Hypothesis 2*]. To discover whether this is indeed the case, the empirical analysis presented below explicitly accounts for sectoral heterogeneity.

4.2 Estimation Results

Pooling of Product Groups - the Pooled Mean Group Estimator

In a first step, the products are grouped together according to similar market characteristics. For example, *Panel I* consists of five product subcategories for which mark-ups are high and prices are sticky, i.e. the frequency of price changes is low.[14] Given the theoretical predictions, it is now plausible to assume a homogenous long-run

[13]The minimum point of the quadratic function in Equation (4) equals $\frac{-\theta_{i1}}{2\theta_{i2}}$. Consequently, the vertex is positive if $\theta_{i1} < 0$ and $\theta_{i2} > 0$, while negative if $\theta_{i1} > 0$ and $\theta_{i2} > 0$.

[14]Each panel includes products with similar mark-ups and price change frequencies. The sorting scheme differentiates between high, moderate, and low mark-ups/price change frequencies such that in total nine product panels are considered. The sorting scheme is based on Euro-area averages. Following Christopoulou and Vermeulen (2008), the average mark-up for Euro-area countries is 37%. Accordingly, moderate mark-ups range between 20% and 50%. The frequency of Euro-area price changes averages 15%, see Dhyne et al. (2006). So, moderate price frequencies are classified to lie between 10% and 20%.

inflation-RPV relationship across the different products within each panel. In particular, the Pesaran et al. (1999) pooled mean-group (PMG) estimator is obtained from imposing $\theta_{i1} = \theta_1$ and $\theta_{i2} = \theta_2$ on Equation (3) and maximizing the implied joint conditional log-likelihood function.[15]

The estimation results for the nine different product panels are shown in Table 2. As expected, there is a considerable amount of heterogeneity across the different classes of products. The size and significance of $\widehat{\theta}_1$ and $\widehat{\theta}_2$, which measure the long-run effects of inflation and inflation-squared, depend on the product panel under consideration. In some panels inflation has no impact on price dispersion; in others, inflation significantly affects RPV. Given significant effects, the impact of inflation on price dispersion is U-shaped (Panel I, II, IV, and V), positive (Panel III and VIII), or negative (Panel VI). In light of the theoretical predictions, a comparison of Panel I and Panel IX is particularly interesting. In line with monetary search and Calvo-type models, the relationship between inflation and RPV is U-shaped around a positive vertex for a market characterized by a high degree of sellers' market power and sticky prices (Panel I). Moreover, and as theory predicts, the real effects of inflation disappear in a highly competitive market with flexible prices (Panel IX).

The results of the Likelihood Ratio test-statistics, however, indicate that the long-run homogeneity restriction of the PMG model does not hold for all product panels. Additionally, the classification of different products into panel data sets having similar market characteristics depends on the underlying sorting scheme. In fact, it is debatable whether mark-ups/price change frequencies need to be classified as high, moderate, or low. Based on these considerations, the analysis below employs an alternative estimation approach that avoids imposing such an a priori structure on the data. Furthermore and in contrast to the results presented in this subsection, the analysis presented below will be able to discriminate directly between the two theoretical predictions.

[15]Note that in contrast to classic panel estimators, the short-run dynamics are still modeled as heterogenous across products.

Table 2: Relative Price Variability and Inflation in Europe
Pooling of Product Groups

$$\Delta RPV_{it} = \omega_i + \alpha_i \cdot [RPV_{i,t-1} - \theta_1 \cdot \pi_{i,t-1} - \theta_2 \cdot \pi^2_{i,t-1}] + \boldsymbol{\psi}_i' \cdot \boldsymbol{h}_{it} + \epsilon_{it}$$

Product Panel	M_j	$\widehat{\theta}_1$	$\widehat{\theta}_2$	$H_0: \theta_{11} = \ldots = \theta_{M1}$	$H_0: \theta_{12} = \ldots = \theta_{M2}$
Panel I *high mark-ups* *low price fr.*	5	-1.413^{***} (0.389)	26.84^{***} (7.274)	7.932 [0.16]	18.75 [0.00]
Panel II *high mark-ups* *moderate price fr.*	4	-0.407 (0.379)	12.74^{**} (6.434)	4.607 [0.33]	6.270 [0.18]
Panel III *high mark-ups* *high price fr.*	2	0.517^{**} (0.535)	16.08 (24.54)	1.645 [0.44]	1.992 [0.37]
Panel IV *moderate mark-ups* *low price fr.*	9	-0.154^{***} (0.032)	4.080^{*} (2.267)	26.39 [0.00]	35.21 [0.00]
Panel V *moderate mark-ups* *moderate price fr.*	1	-0.108 (0.117)	12.14^{*} (6.576)	...	...
Panel VI *moderate mark-ups* *high price fr.*	2	-0.297^{***} (0.091)	-1.672 (2.233)	3.794 [0.15]	3.130 [0.21]
Panel VII *low mark-ups* *low price fr.*	9	0.093 (0.219)	5.054 (26.58)	34.55 [0.00]	28.47 [0.00]
Panel VIII *low mark-ups* *moderate price fr.*	2	0.215^{***} (0.081)	2.201 (1.483)	2.410 [0.30]	11.15 [0.00]
Panel IX *low mark-ups* *high price fr.*	4	-0.235 (0.191)	1.425 (2.065)	4.201 [0.38]	10.72 [0.03]

Notes: Each panel consists of products with similar mark-ups and price change frequencies. M_j refers to the number of products in each panel ($\sum_{j=1}^{9} M_j = 38$). To estimate the common factors, the correlated effects augmentation proposed by Pesaran (2006) is used. The optimal lag-lengths (p, q, and r) are selected according to the AIC. Tests of homogeneity of the long-run slope coefficients are based on Likelihood-Ratio test statistics. Heteroskedasticity and autocorrelation robust standard errors in parentheses. p-values in brackets. *, **,*** indicate significance at the 10%, 5%, and 1% significance level. Sample: 1996.02-2008.12. See Section 4.1 for further explanations.

Parameter Conditioning - the Conditional Pooled Mean Group Estimator

The recently developed Conditional Pooled Mean Group (CPMG) model offers a flexible framework for analyzing the effect of varying market characteristics on the long-run inflation-RPV nexus, see Binder and Offermanns (2007) and Binder et al. (2010). In this framework, the long-run multipliers on inflation, θ_1 and θ_2, are allowed to vary depending on the level of mark-ups (μ_i) and the degree of price change frequency (λ_i) in a given product group i. Consider the error correction representation of the PARDL from Section 4.1 in which the parameters on inflation and inflation-squared are conditioned to depend on μ_i and λ_i:

$$\begin{aligned} \Delta RPV_{it} &= \omega_i + \alpha_i \cdot [RPV_{i,t-1} - \theta_1(\mu_i, \lambda_i) \cdot \pi_{i,t-1} - \theta_2(\mu_i, \lambda_i) \cdot \pi^2_{i,t-1}] \\ &\quad + \boldsymbol{\psi}_i^{'} \cdot \boldsymbol{h}_{it} + \epsilon_{it}. \end{aligned} \tag{5}$$

With this form of conditioning, the long-run dynamics are homogenous only for products sharing the same conditioning environments. Introducing the weak conditional pooling restrictions that products sharing the same values of the conditioning variables also share the same long-run multipliers, $\theta_{i1}(\mu_i, \lambda_i) = \theta_1(\mu_i, \lambda_i)$ and $\theta_{i2}(\mu_i, \lambda_i) = \theta_2(\mu_i, \lambda_i)$, is obviously noticeably weaker than the unconditional slope coefficient pooling restriction of conventional fixed effects panel data models, and also significantly weaker than the unconditional long-run pooling restriction of the pooled mean group model of Pesaran et al. (1999). In conducting the estimation and making inferences, this study uses the CPMG set-up of Binder et al. (2010), in which the unknown functionals $\theta_1(\cdot)$ and $\theta_2(\cdot)$ are approximated by a Chebyshev polynomial in the set of conditioning variables.[16] Under this set-up, an immediate approach to estimating Equation (5) would be to construct a Quasi Maximum Likelihood Estimator taking into account the cross-product conditional long-run pooling restrictions. The analysis presented here, however, uses the computationally less burdensome two-step proce-

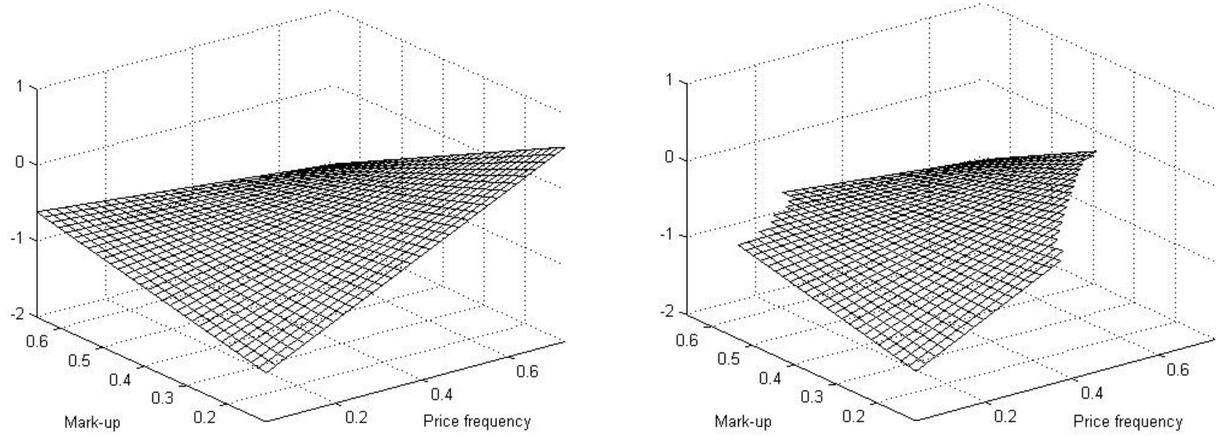
[16]For reasons of parsimony, only maximum Chebyshev polynomial orders of order two are considered. Indeed, information criteria detect the optimal polynomial order to be of order one.

dure suggested by Binder and Offermanns (2007). Once the conditioning polynomial coefficients have been estimated, an estimate of the approximated functional can be graphed for the complete panel domain of the conditioning variables.

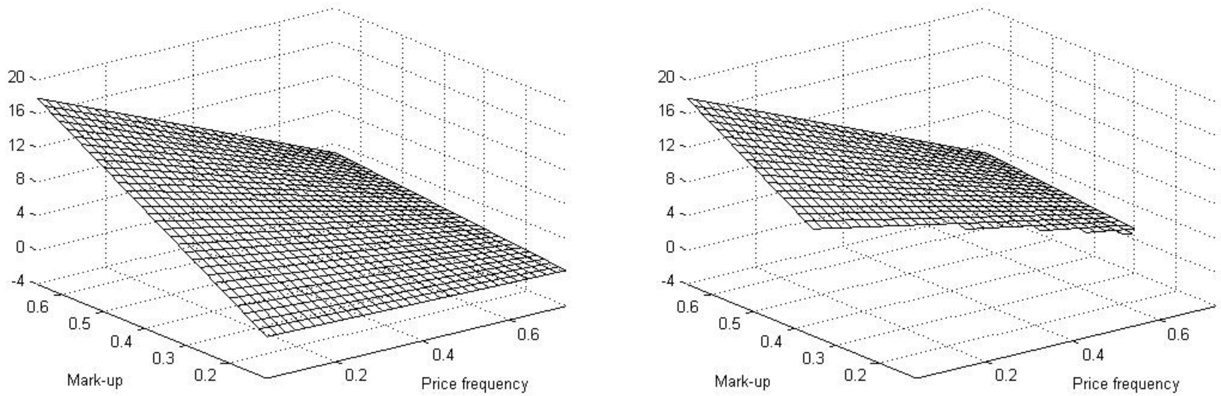
The two upper panels of Figure 3 show the estimated functional $\widehat{\theta}_1(\mu_i, \lambda_i)$, while $\widehat{\theta}_2(\mu_i, \lambda_i)$ is displayed in the two bottom panels. Compared to the left-hand panels in which the estimated functionals are plotted for the complete panel domain, all insignificant grid points are dropped in the right-hand panels. First, examination of the two left-hand panels illustrates that $\widehat{\theta}_1(\cdot) < 0$ and $\widehat{\theta}_2(\cdot) > 0$ for almost all given combinations of mark-ups and price change frequencies. Accordingly, the inflation-RPV nexus is U-shaped around a positive vertex. Second, the magnitude of the parameter estimates, i.e. the curvature as well as the vertex of the U-shaped relationship, varies with changing market conditions. The plot for $\widehat{\theta}_2(\cdot)$ implies that given an environment of very high mark-ups and sticky prices, changes in inflation induce relatively large movements in price dispersion, whereas the effect of inflation decreases for more competitive markets and/or higher price change frequency. In markets characterized by low mark-ups and highly flexible prices, both the functionals on inflation and inflation-squared become insignificant, see the two right-hand panels. As a result, the relationship between inflation and RPV is heavily dependent on market characteristics. Particularly and in line with the results of the PMG model, inflation has no effect on price dispersion in highly competitive markets with flexible prices. More interesting, as the lower-right plot indicates, sellers' market power is more important for inflation's impact on RPV than is the degree of price stickiness. The significance of $\widehat{\theta}_2(\cdot)$ is not affected by changes in price frequency; however, the impact of inflation-squared becomes insignificant for mark-ups smaller than approximately 30%. The occurrence of a non-linear inflation-RPV profile depends only on sellers' market power. For mark-ups higher than 30%, the relationship between inflation and price dispersion is U-shaped, whereas the non-linearity vanishes for smaller mark-up values.

Figure 3: The Role of Market Power and Price Rigidity for the Relationship between Inflation and RPV

Estimation Results for the Coefficient on Inflation, $\widehat{\theta}_1(\mu_i, \lambda_i)$



Estimation Results for the Coefficient on Inflation-Squared, $\widehat{\theta}_2(\mu_i, \lambda_i)$



Notes: The upper left-hand panel plots the estimated functional $\widehat{\theta}_1(\mu_i, \lambda_i)$ in Equation (5). The horizontal axes display the level of mark-ups and degree of price change frequency. The estimate of the long-run multiplier of inflation on price dispersion for given combinations of mark-ups and price change frequencies is displayed on the vertical axis. The graph in the upper right-hand panel is the analog of that in the upper left-hand panel, with the exception that insignificant grid points are dropped from the surface of multiplier values. The two lower panels plot the estimated functional $\widehat{\theta}_2(\mu_i, \lambda_i)$ for given combinations of mark-ups and price change frequencies.

In accordance with Becker and Nautz (2010), these results strongly support the prediction made by the Head and Kumar monetary search model that the inflation-RPV nexus will be U-shaped provided that mark-ups are sufficiently high. With increasing competition, the U-shaped inflation-RPV relationship becomes progressively flatter and the impact of inflation on price dispersion declines. Furthermore, when mark-ups fall below a critical threshold, inflation ceases to have any effect on price dispersion. In contrast, empirical support for Choi's Calvo-type model is limited: a U-shaped inflation-RPV profile is found for sectors with sticky prices and for sectors with highly flexible prices.

5 Concluding Remarks

Variability in relative prices is known to be a major channel through which inflation can induce welfare costs. In contrast to earlier research, recent evidence suggests that the relationship between inflation and price dispersion is non-linear. According to monetary search (Head and Kumar, 2005) and Calvo-type models (Choi, 2010), the inflation-RPV linkage is U-shaped, implying an optimal rate of inflation above zero. Interestingly, while sellers' market power affects the linkage between inflation and RPV in the monetary search framework, Calvo-type models predict that the impact of inflation on RPV varies with the degree of price rigidity. This paper uses a new set of European price data that exhibits a great amount of heterogeneity in price mark-ups and price stickiness to contrast the implications of monetary search theory with those of Calvo-type models.

The empirical results confirm that the impact of inflation on price dispersion depends on market characteristics. In line with the predictions of the Head and Kumar monetary search model, the inflation-RPV nexus is U-shaped around a positive vertex for markets exhibiting high mark-ups. With increasing competition, the U-shaped profile becomes progressively flatter and inflation has less of an impact on price dispersion.

When mark-ups fall below 30%, the non-linear U-shaped effect of inflation on RPV disappears. In contrast, no evidence was found to support the contentions of Choi's Calvo-type model that the inflation-RPV nexus depends on the degree of price stickiness. U-shaped effects of inflation are present for sectors with sticky and for those with highly flexible prices.

The literature on the relationship between inflation and price dispersion typically centers around a discussion of a linear vs. a non-linear linkage. That the inflation-RPV nexus might vary across markets is an idea that has received very little attention. This paper is designed to change this current state of affairs and suggests to add a new dimension to the recent debate. In addition to focusing on the shape of the inflation-RPV profile, it is important to discriminate between different product markets since the impact of inflation varies with market characteristics. Given that empirical work focuses on very different product markets, a *market-varying* inflation-RPV nexus might to some extent reconcile the mixed empirical evidence on the shape of the nexus. Moreover, and in contrast to European data, micro evidence on the U.S. product market points to significant heterogeneity not only across sectors, but also over time. For instance, several studies conclude that the degree of price rigidity varies systematically over inflation regimes (see e.g. Kiley, 2000, and Nakamura and Steinsson, 2008). It will be left to future research to explore whether changes in the degree of price rigidity resulted from changes of inflation process can lead to a *time-varying* pattern of the inflation-RPV nexus.

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Appendix

A1 Derivation of Monthly Price Level Index Data

The annual PLIs are computed as a ratio of the respective annual PPP exchange rate over the annual average of the respective nominal exchange rate ($NX^a_{j/EU}$). PPP series are constructed by comparing price level data of similar goods and services for country j (P^a_j) with its counterpart for the Euro-area economy (P^a_{EU}). Accordingly, annual PLI for country j is defined as:

$$PLI^a_{j/EU} = \frac{PPP^a_{j/EU}}{NX^a_{j/EU}} * 100 = \frac{\frac{P^a_j}{P^a_{EU}}}{NX^a_{j/EU}} * 100 \tag{6}$$

The prices of consumer goods and services are collected by Eurostat in cooperation with the national statistical agencies for the Eurostat-OECD comparison program every three years. Data are gathered for all goods and services at six collection dates, one every half year (using a rolling benchmark approach). Prices in between the three-year collections are extrapolated with the respective monthly consumer price index in order to arrive at a set of annual average prices (see Eurostat-OECD, 2006, pp. 38 et seq.). The methodology of computing monthly PPP data and, thereby, also monthly PLIs is based on this extrapolation scheme. Using monthly inflation rates for country j and the Euro-area economy, the methodology simply inverts Eurostat's extrapolation procedure.

Annual PPP for country j can be written as:

$$PPP^a_{j/EU} = \frac{P^a_j}{P^a_{EU}} = \frac{\frac{1}{12}\left[P^{Jan}_j + P^{Feb}_j + P^{Mar}_j + ... + P^{Dec}_j\right]}{\frac{1}{12}\left[P^{Jan}_{EU} + P^{Feb}_{EU} + P^{Mar}_{EU} + ... + P^{Dec}_{EU}\right]} \tag{7}$$

In a first step, PPP for counry j in January is calculated according to:

$$\begin{aligned}
PPP^{a}_{j/EU} &= \frac{P_j^{Jan} + P_j^{Jan}(1+\Pi_j^{Jan}) + ... + P_j^{Jan}(1+\Pi_j^{Jan})(1+\Pi_j^{Feb})...(1+\Pi_j^{Nov})}{P_{EU}^{Jan} + P_{EU}^{Jan}(1+\Pi_{EU}^{Jan}) + ... + P_{EU}^{Jan}(1+\Pi_{EU}^{Jan})(1+\Pi_{EU}^{Feb})...(1+\Pi_{EU}^{Nov})} \\
&= \frac{P_j^{Jan}\left[1 + (1+\Pi_j^{Jan}) + ... + (1+\Pi_j^{Jan})(1+\Pi_j^{Feb})...(1+\Pi_j^{Nov})\right]}{P_{EU}^{Jan}\left[1 + (1+\Pi_{EU}^{Jan}) + ... + (1+\Pi_{EU}^{Jan})(1+\Pi_{EU}^{Feb})...(1+\Pi_{EU}^{Nov})\right]} \\
&= PPP^{Jan}_{j/EU} \underbrace{\frac{1 + (1+\Pi_j^{Jan}) + ... + (1+\Pi_j^{Jan})(1+\Pi_j^{Feb})...(1+\Pi_j^{Nov})}{1 + (1+\Pi_{EU}^{Jan}) + ... + (1+\Pi_{EU}^{Jan})(1+\Pi_{EU}^{Feb})...(1+\Pi_{EU}^{Nov})}}_{\Pi}
\end{aligned}$$

$$\Rightarrow \; PPP^{Jan}_{j/EU} = \frac{PPP^{a}_{j/EU}}{\Pi}$$

where e.g. inflation in January is defined as $\Pi^{Jan} = ln(HICP^{Feb}) - ln(HICP^{Jan})$.

Secondly, monthly PPP data for the rest of the year is given by:

$$\begin{aligned}
PPP^{Feb}_{j/EU} &= \frac{P_j^{Feb}}{P_{EU}^{Feb}} = \frac{P_j^{Jan}(1+\Pi_j^{Jan})}{P_{EU}^{Jan}(1+\Pi_{EU}^{Jan})} = PPP^{Jan}_{j/EU}\frac{(1+\Pi_j^{Jan})}{(1+\Pi_{EU}^{Jan})} \\
PPP^{Mar}_{j/EU} &= \frac{P_j^{Mar}}{P_{EU}^{Mar}} = \frac{P_j^{Jan}(1+\Pi_j^{Jan})(1+\Pi_j^{Feb})}{P_{EU}^{Jan}(1+\Pi_{EU}^{Jan})(1+\Pi_{EU}^{Feb})} \\
&= PPP^{Jan}_{j/EU}\frac{(1+\Pi_j^{Jan})(1+\Pi_j^{Feb})}{(1+\Pi_{EU}^{Jan})(1+\Pi_{EU}^{Feb})} \\
&. \\
&. \\
PPP^{Dec}_{j/EU} &= PPP^{Jan}_{j/EU}\frac{(1+\Pi_j^{Jan})...(1+\Pi_j^{Nov})}{(1+\Pi_{EU}^{Jan})...(1+\Pi_{EU}^{Nov})}
\end{aligned}$$

Finally, monthly PLI for country j can be computed according to:

$$PLI^{m}_{j/EU} = \frac{PPP^{m}_{j/EU}}{NX^{m}_{j/EU}} * 100, \tag{8}$$

where $NX^{m}_{j/EU}$ represents the monthly average of the respective nominal exchange rate.

A2 De-Trending RPV via Smooth Transition Analysis

The suggestion that a smooth transition could be used as a means of representing a structural change arising from deterministic factors was originally proposed by Bacon and Watts (1971). It has the appealing feature that the transition in the series from one trend path to another is gradual, but with limiting cases allowing non-transition or a discrete break in trend. Leybourne et al. (1998) consider the following logistic smooth transition model:

$$y_t = \alpha_1 + \beta_1 t + \alpha_2 S(\gamma, \tau) + \beta_2 t S(\gamma, \tau) + \epsilon_t, \tag{9}$$

where $S(\gamma, \tau) = \{1 + exp\left[-\gamma(t - \tau T)\right]\}^{-1}$ is the logistic smooth transition function and T is the sample size. The parameters τ and γ determine the timing and the speed of the transition process, respectively. Under the assumption that ϵ_t is a zero-mean I(0) process, y_t in Equation (9) is stationary around a mean that changes gradually from initial value α_1 to final value $\alpha_1 + \alpha_2$. In addition, the time-trend also changes form β_1 to $\beta_1 + \beta_2$. The procedure introduced by Leybourne et al. (1998) tests the stationarity of the residuals from Equation (9) around a smooth logistic intercept and trend against the null of a unit-root process. The first step of the test procedure is to compute non-linear least square estimates of the deterministic components of Equation (9) and derive the resulting residuals. Using these residuals, an ADF statistic can be computed. The critical values for the unit root test are tabulated in Leybourne et al. (1998).

The empirical results indicate that the null of non-stationarity can be rejected for all RPV series.[17] Accordingly, the deterministic process of the price dispersion series can be accurately described by a smooth transition process. Having calculated the smooth transition and tested for unit roots, the deterministic component of the price dispersion series is removed by subtracting the smooth transition process. In Section 4, the de-trended series are used to analyze the relationship between inflation and RPV.

[17]For brevity, the results of estimating a smooth transition model for the 38 RPV series are not presented, but are available on request.

Table 3: Selected Two- and Four-Digit Subcategories

two-digit subcategories			four-digit subcategories				
COICOP	Name	Weight (in %)	COICOP	Name	Weight (in %)	Mark-up (in %)	Price-fr. (in %)
01	Food and non-alcoholic beverages	15.5	01.12	Meat	3.8	11.0	20.8
			01.13	Fish and seafood	1.1	11.0	41.9
			01.14	Milk, cheese and eggs	2.2	51.0	11.1
			01.16	Fruit	1.1	11.0	46.2
			01.17	Vegetables	1.5	11.0	76.8
			01.18	Sugar, jam, honey, chocolate and confectionery	1.0	11.0	9.6
			01.21	Coffee, tea and cocoa	0.4	51.0	22.3
			01.22	Mineral waters, soft drinks, fruit and vegetable juices	0.9	51.0	11.8
					$\sum$ 12.0		
02	Alcoholic beverages, tobacco and narcotics	4.1	02.11	Spirits	0.3	51.0	21.0
			02.13	Beer	0.5	51.0	14.4
					$\sum$ 0.8		
03	Clothing and footwear	7.4	03.12	Garments	5.5	16.0	7.6
			03.14	Cleaning, repair and hire of clothing	0.2	79.0	4.3
			03.21	Shoes and other footwear	1.4	12.0	9.2
					$\sum$ 7.1		

Table 3 continued

two-digit subcategories			four-digit subcategories				
COICOP	Name	Weight (in %)	COICOP	Name	Weight (in %)	Mark-up (in %)	Price-fr. (in %)
04	Housing, water, electricity, gas and other fuels	15.1	04.13	Materials for the maintenance and repair of the dwelling	0.6	17.0	6.5
			04.53	Liquid fuels	0.8	38.0	72.9
					$\sum 1.4$		
05	Furnishings, household eq. and routine maintenance of the house	7.7	05.11	Furniture and furnishings	2.6	17.0	9.0
			05.13	Repair of furniture, furnishings and floor coverings	0.1	62.0	5.5
			05.21	Household textiles	0.6	16.0	7.1
			05.32	small electric household appliances	1.1	14.0	7.8
			05.33	Repair of household appliances	0.1	73.0	5.5
			05.52	small tools and miscellaneous accessories	0.5	14.0	5.5
			05.62	Domestic services and household services	0.9	57.0	4.0
					$\sum 5.9$		
06	Health	4.2		——			

Table 3 continued

two-digit subcategories			four-digit subcategories				
COICOP	Name	Weight (in %)	COICOP	Name	Weight (in %)	Mark-up (in %)	Price-fr. (in %)
07	Transport	15.3	07.21	Spare parts and accessories for personal transport equipment	1.0	11.0	13.7
			07.22	Fuels and lubricants for personal transport equipment	3.9	48.0	80.4
			07.23	Maintenance and repair of personal transport equipment	2.6	48.0	3.4
			07.24	Other services in respect of personal transport equipment	1.0	48.0	7.9
			07.32	Passenger transport by road road	0.5	36.0	5.3
					$\sum$ 9.0		
08	Communications	2.2	08.21	Telephone and telefax	0.2	45.0	14.5
09	Recreation and culture	9.5	09.11	Equipment for the reception, recording and reproduction of sound and pictures	0.5	21.0	13.2
			09.31	Games, toys and hobbies	0.4	49.0	7.8
			09.32	Equipment for sport, camping and open-air recreation	0.3	49.0	5.2
			09.34	Pets and related products	0.5	49.0	9.8
			09.42	Cultural services	1.4	21.0	4.8
					$\sum$ 3.2		

Table 3 continued

two-digit subcategories			four-digit subcategories				
COICOP	Name	Weight (in %)	COICOP	Name	Weight (in %)	Mark-up (in %)	Price-fr. (in %)
10	Education	0.9		———			
11	Restaurants and hotels	9.3	11.11	Restaurants, cafés and the like	6.9	30.0	3.9
			11.21	Accommodation services	1.7	30.0	7.8
					$\sum 8.6$		
12	Miscellaneous goods and services	8.2	12.11	Hairdressing salons and personal grooming establishments	1.1	66.0	4.2
			12.13	Other appliances, articles and products for personal care	1.5	50.0	11.8
			12.32	Other personal effects	0.6	42.0	8.2
					$\sum 3.1$		

Notes: This Table displays the 38 four-digit Price Level Index (PLI) product subcategories used in this study. Weights refer to the HICP-COICOP item weights in the year 2005. Price-fr. indicates the average percentage of consumer prices which change in a given month. The linkage of the 38 four-digit COICOP subcategories and the estimates on Euro-area mark-ups and price change frequencies given by Álvarez et al. (2006), Dhyne et al. (2006), and Christopoulou and Vermeulen (2008) is based on the COICOP classification scheme. For example, the result on Euro-area price change frequency for ”Lettuce” (COICOP 01.17.1) presented by Dhyne et al. (2006) is used to proxy price-rigidity in the four-digit subcategory ”Vegetables” (COICOP 01.17.0).

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This research was supported by the Deutsche Forschungsgemeinschaft through the SFB 649 "Economic Risk".