The Non-Linear Relationship between Inflation and Relative Price Variability

Inaugural-Dissertation zur Erlangung des akademischen Grades eines Doktors der Wirtschaftswissenschaften des Fachbereichs Wirtschaftswissenschaft der Freien Universität Berlin

vorgelegt von

Sascha S. Becker

aus Frankfurt am Main

August 2010

Erstgutachter: Prof. Dr. Dieter Nautz

Zweitgutachter: Prof. Dr. Christian Offermanns

Tag der Disputation: 14. Dezember 2010

Acknowledgments

I would first like to express my deep gratitude to my adviser, Dieter Nautz, for all of his extremely useful advice, guidance and dedication in supporting me to pursue my research. During all these years he was always available and devoted a great amount of his time to supervising my thesis, for which I would like to thank him. The discussions with him very much inspired me and essentially contributed to my clarification and understanding. Second, I would like to thank Christian Offermanns who has kindly agreed to be my second supervisor. Third, I very much welcomed and profited from the stimulating research environment at the Goethe University Frankfurt and the Free University Berlin. My thesis has greatly benefited from the classes offered and from the discussions in the research seminars. A number of people have commented on my papers. I would particularly like to thank Alexander Bick and Jorgo Georgiadis for their helpful comments and suggestions concerning my research as well as the active and stimulating private discussions. It was an awesome time. Finally, I would like to thank my colleagues at the Chair of Applied Macroeconomics and the Chair of Econometrics for the wonderful and inspiring time we had together in the past years.

Sascha Becker

Contents

List of Figures

List of Tables

Overview

According to the European Central Bank (2009) price stability is important because it "...reduces uncertainty about general price movements and thereby improves the transparency of relative prices..." In economic theory, this statement is motivated by the relationship between the general inflation rate and the distribution of relative prices as a possible channel for welfare costs of inflation. If inflation causes a suboptimal adjustment of goods prices due to price adjustment costs or imperfect information, then inflation manipulates relative price variability (RPV), distorts the information content of prices, and impedes the efficient allocation of resources.

For a long time, it has been widely believed that inflation monotonically increases RPV. Recent empirical evidence, however, suggest that the inflation-RPV nexus is non-linear 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.

Identifying the correct functional form of the relationship bears a crucial implication for monetary policy. If the true relationship is positive, monetary authorities can reduce RPV simply by lowering inflation via disinflationary policy, whereas this is no longer the case if the relation is non-linear. A proper understanding of the inflation-RPV nexus is therefore of great importance for policy making. To this end, this dissertation sheds more light on the existence of non-linearities in the relation between inflation and the variability of relative prices.

The dissertation consists of three chapters:

Chapter 1 reexamines the empirical relationship between U.S. inflation and RPV to give information about the role of expected inflation during the recent low-inflation period.

Many empirical studies on the inflation-RPV nexus do not account for the different effects of expected and unexpected inflation emphasized by the theoretical literature. An early attempt to account for the implications of economic theories relating inflation and RPV is provided by Aarstol (1999). Using U.S. price data from 1973 to 1997, he finds that both expected and unexpected inflation significantly increase RPV. Yet recent theoretical contributions question the stability of the empirical relationship between inflation and RPV. In particular, the monetary search model introduced by Head and Kumar (2005) suggests that the influence of expected inflation on RPV may have changed during the recent low inflation period. In order to investigate the empirical relevance of this prediction, the focus of this chapter is on the (changing) role of expected inflation for the U.S. inflation-RPV nexus.

Adopting the empirical framework of Aarstol (1999), our results show that the effect of expected inflation on RPV becomes insignificant if the sample includes the recent low inflation period. The instability of the relationship between inflation and RPV can be confirmed for different price indices, disaggregation levels, and RPV measures. Furthermore, we employ endogenous break-point tests to identify the timing and to test for the significance of a structural break. In line with recent evidence obtained for Germany (Nautz and Scharff, 2005) and the Euro-area (Nautz and Scharff, 2010), our results indicate that the influence of expected inflation on RPV has already disappeared since the early 1990s, when U.S. monetary policy made interest rates more responsive to inflation and, thereby, stabilized inflation expectations on a lower level, see e.g. Judd and Trehan (1995) and Mankiw (2001).

This chapter is based on a paper (joint work with Dieter Nautz) which is already published in the *Southern Economic Journal* (76, pp. 146-164).

Chapter 2 employs the Head and Kumar (2005) framework to shed more light on the functional relationship between inflation and RPV.

Solving the monetary search model numerically, we show that the impact of inflation on price dispersion and welfare crucially depends on the level of search costs. In particular, two testable implications of the model are derived: First, provided that search costs are sufficiently high, the relationship between inflation and price dispersion is predicted to be asymmetrically U-shaped. Second, for decreasing search costs the U-shaped relationship gets progressively flatter and inflation has less of an impact on RPV. Using monthly HICP-data from a panel of 27 EU countries, we furthermore test the empirical content of both predictions. Assuming that search costs decrease when markets become more integrated, the inflation-RPV nexus is estimated for two subgroups of EU countries, i.e. the highly integrated Euro-area and the less integrated EU 27 economy

Our empirical results show that the impact of inflation on price dispersion is non-linear and crucially depends on the level of goods market integration. Particularly, the evidence supports both predictions of the monetary search model. On the one hand, the empirical relationship between inflation and RPV is asymmetrically U-shaped in the less integrated EU-27 economy suggesting an optimal annual inflation rate of about 3%. On the other hand, the impact of inflation on price dispersion is only small and insignificant for the highly integrated Euro-area markets where search costs are low.

This chapter is based on a working paper which is also joint work with Dieter Nautz.

Chapter 3 uses a new set of sectoral price-level data from a panel of European countries to contrast the implications of recent monetary search theory with those of recent Calvo-type models.

As mentioned above, monetary search and Calvo-type models (see Head and Kumar, 2005, and Choi, 2010) predict the inflation-price dispersion nexus to be U-shaped. Interestingly, these two models make very different predictions about the economics behind the U-shaped profile. While the level of search costs, i.e.

the degree of 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. To capture such dependencies, this chapter 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 empirical concept is based on i) different levels of product aggregation and ii) different estimation strategies. On the one hand, this chapter uses 12 two-digit and 38 four-digit product subcategories. The results of the latter disaggregation scheme are of particular interest since the categorization into product markets with varying mark-ups or price change frequencies is more accurate for higher product disaggregation. On the other hand, 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-RPV linkage. In this framework, the long-run effect of inflation is allowed to vary depending on the level of mark-ups and the degree of price rigidity in a given market.

The empirical results confirm that the impact of inflation depends on market characteristics. In line with the predictions of monetary search models, 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 is found to support the contentions of Calvo-type models that the relationship between inflation and RPV 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.

Zusammenfassung

Für die Europäischen Zentralbank (2009) ist Preisstabilität von Bedeutung, da diese "... Unsicherheiten über die allgemeine Preisentwicklung verringert und somit die Transparenz der relativen Preise verbessert ..." In der ökonomischen Theorie wird diese Aussage durch den Zusammenhang zwischen der allgemeinen Inflationsrate und der Verteilung der relativen Preise begründet. Reale Effekte von Inflation können demnach auftreten, falls Inflation eine suboptimale Anpassung der Güterpreise verursacht, somit die relative Preisvariabilität (RPV) manipuliert, den Informationsgehalt nominaler Preise verzerrt und folglich eine effiziente Verteilung der Ressourcen verhindert.

Lange Zeit wurde angenommen, dass der Zusammenhang zwischen Inflation und RPV positiv sei. Aktuelle empirische Arbeiten deuten dagegen auf einen nicht-linearen Zusammenhang hin, vgl. Fielding und Mizen (2008) und Bick und Nautz (2008). Aus theoretischer Sicht prognostizieren neuere Search- und Calvo-Modelle (Head und Kumar, 2005, und Choi, 2010) eine U-förmige Verknüpfung von Inflation und Preisdispersion und implizieren dadurch eine positive optimale Inflationsrate.

Eine genaue Identifizierung des funktionalen Zusammenhangs zwischen Inflation und RPV ist für geldpolitische Entscheidungen enorm wichtig. Unter der Annahme eines positiven Zusammenhangs können Zentralbanken RPV durch eine disinflationäre Geldpolitik reduzieren, wohingegen solch ein Vorgehen für eine nicht-lineare Verknüpfung unangebracht ist. Basierend auf diesen Überlegungen erforscht die zugrundeliegende Dissertation das Auftreten von Nicht-Linearitäten in dem Zusammenhang zwischen Inflation und der Variabilität der relativen Preise.

Die Dissertation umfasst drei Kapitel:

Kapitel 1 untersucht den Zusammenhang zwischen Inflation und RPV in den Vereinigten Staaten. Hierbei wird im speziellen die Rolle der erwarteten Inflation in der aktuellen Inflationsperiode analysiert.

Viele empirische Studien über die Verknüpfung von Inflation und Preisdispersion vernachlässigen unterschiedliche Effekte von erwarteter und unerwarteter Inflation. Ein erster Versuch diesen theoretischen Implikationen gerecht zu werden, stammt von Aarstol (1999). Unter der Verwendung von U.S. Preisdaten für den Zeitraum von 1973 bis 1997 zeigt er, dass sowohl erwartete als auch unerwartete Inflation einen signifikanten positiven Einfluss auf RPV ausüben. Neuere theoretische Arbeiten bezweifeln jedoch die Stabilität dieser Zusammenhänge: das monetäre Search-Modell, eingeführt von Head und Kumar (2005), deutet darauf hin, dass sich der Einfluss von erwarteter Inflation angesichts der derzeit niedrigen Inflationsraten verändert haben könnte. Aus diesem Grund beschäftigt sich dieses Kapitel mit einer möglichen Veränderung des U.S. Inflation-RPV Zusammenhangs hinsichtlich erwarteter Inflation.

Basierend auf dem empirischen Ansatz von Aarstol (1999) zeigen unsere Resultate, dass der Effekt von antizipierter Inflation insignifikant wird, sobald die Regressionsanalyse die aktuelle Inflationsperiode berücksichtigt. Diese Instabilität in dem Zusammenhang zwischen Inflation und RPV kann für verschiedene Preisindizes, Disaggregationsstufen und RPV-Maße bestätigt werden. Zudem wenden wir im Rahmen dieser empirischen Studie endogene Tests auf Strukturbruch an um den genauen Zeitpunkt sowie die Signifikanz des Strukturbruchs zu untersuchen. In Übereinstimmung mit aktuellen Arbeiten für Deutschland (Nautz und Scharff, 2005) und den Euroraum (Nautz und Scharff, 2010) weisen die Ergebnisse dieser Analyse darauf hin, dass der Einfluss von erwarteter Inflation auf RPV bereits in den frühen 1990er Jahren verschwand. Zu diesem Zeitpunkt unternahm die U.S. Geldpolitik einen Kurswechsel, indem sie die Zinssätze stärker an die Inflation koppelte und somit die Inflationserwartungen auf einem niedrigeren Niveau stabilisierte, vgl. Judd und Trehan (1995) und Mankiw (2001).

Der diesem Kapitel zugrundeliegende Aufsatz, welcher in Zusammenarbeit mit Dieter Nautz entstanden ist, ist bereits in der Fachzeitschrift *Southern Economic Journal* (76, S. 146-164) veröffentlicht worden.

Kapitel 2 bedient sich des Modellansatzes von Head und Kumar (2005) um den funktionalen Zusammenhang zwischen Inflation und RPV einer genaueren Untersuchung zu unterziehen.

Aufbauend auf dem monetären Search-Modell zeigen wir in verschiedenen Simulationsstudien, dass der Einfluss von Inflation auf die Preisvariabilität sowie die Wohlfahrt fundamental von der Höhe der Suchkosten abhängt. Im speziellen werden hierbei zwei prüfbare Implikationen des Modells hergeleitet: 1) der Zusammenhang zwischen Inflation und RPV ist asymmetrisch U-förmig, gegeben die Suchkosten sind ausreichend hoch; 2) für niedrigere Suchkosten wird der U-förmige Zusammenhang zunehmend flacher und Inflation hat einen weniger starken Einfluss auf RPV. Des Weiteren werden diese theoretischen Implikationen in einem empirischen Teil mittels HICP-Daten aller 27 EU-Mitgliedsstaaten getestet. Unter der Annahme, dass Suchkosten negativ mit dem Grad der Marktintegration verbunden sind, wird die Verknüpfung von Inflation und RPV für verschiedene europäische Märkte mit unterschiedlicher Marktintegration analysiert (Euroraum vs. EU-27).

Unsere empirischen Ergebnisse deuten darauf hin, dass der Einfluss von Inflation auf die Preisvariabilität nicht-linear ist und zudem entscheidend von dem Grad der Marktintegration abhängt. Den theoretischen Implikationen entsprechend, ist der empirische Zusammenhang zwischen Inflation und RPV für die weniger stark integrierte EU-27 Ökonomie asymmetrisch U-förmig. Ebenso in Übereinstimmung mit der Theorie ist der Effekt von Inflation auf RPV klein und insignifikant für den stark integrierten Euroraum.

Der diesem Kapitel zugrundeliegende Aufsatz resultiert ebenfalls aus einer Zusammenarbeit mit Dieter Nautz.

Kapitel 3 verwendet einen neu verfügbaren Datensatz bestehend aus sektoralen europäischen Preisniveaudaten um die theoretischen Implikationen von monetären Search-Modellen denen von Calvo-Modellen gegenüberzustellen.

Wie bereits erwähnt, deuten aktuelle monetäre Search- und Calvo-Modelle (Head und Kumar, 2005 und Choi, 2010) auf einen nicht-linearen U-förmigen Inflation-RPV Zusammenhang hin. Interessanterweise unterscheiden sich diese Modelle stark hinsichtlich ihrer ökonomischen Grundsätze. Während im Search-Modell die Höhe der Suchkosten, d.h. die Marktmacht der Firmen, den Zusammenhang zwischen Inflation und RPV beeinflusst, prognostizieren Calvo-Modelle, dass der Zusammenhang signifikant vom Grad der Preisrigidität abhängt. Um solche Abhängigkeiten zu identifizieren, konzentriert sich dieser Teil der Dissertation auf unterschiedliche Produktmärkte, welche ein großes Maß an Heterogenität bezüglich der Wettbewerbssituation und der Preisflexibilität aufweisen und untersucht die Verknüpfung von Inflation und RPV in den verschiedenen Märkten. Das empirische Konzept beruht hier im speziellen auf unterschiedlichen i) Produktdisaggregationsstufen und ii) Schätzstrategien. Zum einen benutzt die empirische Studie 12 zweistellige und 38 vierstellige Aggregationsniveaus. Die Resultate der vierstelligen Stufe sind dabei von besonderer Bedeutung, da die Einteilung in Produktgruppen mit unterschiedlichen Wettbewerbsverhältnissen und Preisrigiditäten umso genauer ist, je höher die Stufe der Disaggregation. Zum anderen werden das *pooled mean group* Modell (Pesaran et al., 1999) sowie das erst kürzlich eingeführte *conditional pooled mean group* Modell (Binder et al., 2010) angewandt. Das *conditional pooled mean group* Modell bietet einen sehr flexiblen Rahmen um den Einfluss von Inflation auf die Preisvariabilität zu untersuchen. Mit Hilfe dieses Modells ist es möglich den Langzeiteffekt von Inflation in Abhängigkeit von der Markmacht der Firmen und dem Grad der Preisrigidität in einem bestimmten Produktsektor zu modellieren.

Die empirischen Ergebnisse bestätigen, dass der Zusammenhang zwischen Inflation und RPV von Marktcharakteristika abhängt. In Übereinstimmung mit den Vorhersagen des monetären Search-Modells ist der Effekt von Inflation U-förmig für weniger kompetitive Märkte. Mit ansteigender Konkurrenz wird die U-förmige Verknüpfung flacher und der Einfluss von Inflation nimmt ab; für Mark-Up Werte unter 30% verschwindet der nicht-lineare Effekt vollends. Im Gegensatz dazu wird keine Evidenz für die Prognose des Calvo-Modells gefunden. U-förmige Effekte von Inflation treten sowohl für Sektoren mit flexiblen Preisen als auch für Sektoren mit inflexiblen Preisen auf.

1 Inflation and Relative Price Variability: New Evidence for the United States

1.1 Introduction

Various economic theories predict that inflation increases relative price variability (RPV) and, thus, impedes the efficient allocation of resources. In fact, recent macroeconomic models put much emphasis on the distorting impact of inflation on relative prices, yet the empirical relationship between inflation and RPV seems under-researched.[1] In particular, recent theoretical and empirical contributions suggest that the impact of expected inflation on RPV may depend on the level of inflation. This paper reexamines the empirical relationship between U.S. inflation and RPV in order to shed more light on the role of expected inflation during the recent low-inflation period.

Since the seminal study by Parks (1978), the empirical evidence on inflation's impact on RPV has been mixed and elusive. While most studies (see e.g., Jaramillo 1999) find a significant positive impact of inflation on RPV, the relationship has broken down according to Lastrapes (2006), while Reinsdorf (1994) concludes that RPV decreases with inflation. Bick and Nautz (2008) partly reconcile this contra-

[1] For example, standard new Keynesian dynamic stochastic general equilibrium models support price stability as an outcome of optimal monetary policy only because inflation increases RPV, see Woodford (2003).

dicting evidence by allowing for inflation thresholds where the marginal impact of inflation on RPV varies with the inflation regime.

Many empirical studies on the inflation-RPV nexus do not account for the different effects of expected and unexpected inflation emphasized by the theoretical literature. For example, menu-cost models imply that RPV is only increased by expected inflation. An early attempt to account for the implications of economic theories relating inflation and RPV is provided by Aarstol (1999). Using U.S. producer price data from 1973 to 1997, he finds that both expected and unexpected inflation significantly increase RPV. Yet recent theoretical contributions question the stability of the empirical relationship between inflation and RPV. In particular, the monetary search model introduced by Head and Kumar (2005) suggests that the influence of *expected inflation* on RPV may have changed during the recent low inflation period. In order to investigate the empirical relevance of this prediction, the focus of our empirical analysis is on the (changing) role of expected inflation for the U.S. inflation-RPV nexus. However, to ensure that our results concerning expected inflation are not driven by further instabilities in the empirical relation between inflation and RPV, we will also account for breaks in the role of unexpected inflation and inflation uncertainty.

Adopting the empirical framework of Aarstol (1999), we find that the effect of expected inflation on RPV becomes insignificant if the sample includes the recent low inflation period. The instability of the relationship between inflation and RPV can be confirmed for different price indices, disaggregation levels, and RPV measures. In order to shed more light on the changing role of expected inflation for RPV, we employ endogenous break-point tests to identify the timing and to test for the significance of a structural break. In line with recent evidence obtained for Germany (Nautz and Scharff, 2005) and the Euro area (Nautz and Scharff, 2010), our results indicate that the influence of expected inflation on RPV has already disappeared since the early 1990s, when U.S. monetary policy made interest rates more responsive to inflation and, thereby, stabilized inflation expectations on a lower level, see e.g. Judd and Trehan (1995) and Mankiw (2001).

The paper is organized as follows. Section 1.2 reviews theory and empirical evidence on the relationship between inflation and RPV. Section 1.3 provides first results suggesting a changing role of expected inflation for the U.S. inflation-RPV nexus. Section 1.4 uses endogenous breakpoint tests to assess the timing and significance of the structural break in the relationship between expected inflation and RPV, where we controlled for possible changes in the effects of unexpected inflation and inflation uncertainty on RPV. Section 1.5 provides some concluding remarks.

1.2 Inflation and Relative Price Variability: Theory and Evidence

1.2.1 Theoretical Literature

The theoretical literature on the relation between inflation and RPV consists mainly of three types of models: menu cost models, signal extraction models, and monetary search models. Interestingly, the implications of these models concerning the role of expected and unexpected inflation are very different.

Menu Cost Models

Menu cost models assume that nominal price changes are subject to price adjustment costs, see e.g. Sheshinski and Weiss (1977), Rotemberg (1983) or Benabou (1992). In this case, it can be shown that firms set prices discontinuously according to an (S, s) pricing rule. Because of inflation, the firm's real price begins at S and then falls to s over time. At that point, the firm raises its nominal price so that the real price once again equals S. In case of deflation, a firm decreases its nominal price accordingly. Since the width of the (S, s) band depends on the size of its menu costs, firm-specific menu costs lead to staggered price setting, distorted relative prices, and an inefficient increase of RPV. The crucial point is that only the anticipated part of inflation affects the width of the (S, s) band. Therefore, increases in expected inflation amplify the distorting effect of menu costs on relative prices. Due to the symmetry in firms' pricing strategy, menu cost models typically imply that RPV is increasing in the absolute value of expected inflation.

Signal Extraction Models

Signal extraction models share the assumption that inflation is not always anticipated correctly. As a consequence, firms and households confuse absolute and relative price changes. For example, according to Lucas (1973), Barro (1976), and Hercowitz (1981), higher inflation uncertainty makes aggregate demand shocks harder to predict. Solving the implied signal extraction problem, firms adjust output less in response to *all* shocks, including idiosyncratic real demand shocks. As a result, increases in unexpected inflation and inflation uncertainty will raise RPV.

Monetary Search Models

Monetary search models emphasize that buyers have only incomplete information about the prices offered by different sellers. In these models, the overall effect of inflation on RPV is not always obvious, see e.g. Reinsdorf (1994) and Peterson and Shi (2004). On the one hand, higher expected inflation lowers the value of fiat money which increases sellers' market power and, thereby, the dispersion of prices. On the other hand, higher expected inflation also raises the gains of search, which lowers sellers' market power and, thus, relative price variability. As inflation rises, the RPV increasing effect will eventually dominate. Yet there will be a region within which small changes in expected inflation have little effect on RPV. Head and Kumar (2005) showed that expected inflation may increase RPV only if it exceeds a critical value.

1.2.2 Empirical Literature

The early empirical evidence on the relation between inflation and RPV is typically based on linear regressions of RPV on inflation. In line with menu cost and signal extraction models, most empirical contributions find a significant positive coefficient of expected inflation, unexpected inflation, or inflation uncertainty, see e.g. Parsley (1996), Grier and Perry (1996), Debelle and Lamont (1997), Aarstol (1999), and Jaramillo (1999). Yet there are notable exceptions. In particular, according to Lastrapes (2006) the relationship between U.S. inflation and RPV broke down in the mid-eighties, while Reinsdorf (1994) demonstrates that the relation is even negative during the disinflationary early 1980s. Similarly, Fielding and Mizen (2000) and Silver and Ioannidis (2001) show for several European countries that RPV decreases in inflation.

In accordance with the implications of monetary search models, more recent evidence suggests that the relation between inflation and RPV might be more complex. In particular, several studies have found that the impact of inflation on RPV is different for high and low inflation periods and countries with different inflationary contexts, see e.g. Caglayan and Filiztekin (2003) and Caraballo, Dabús and Usabiaga (2006). Using non-parametric methods, Fielding and Mizen (2008) find that the U.S. inflation-RPV linkage is non-linear. Nautz and Scharff (2010) apply panel threshold models to price data of Euro area countries. In line with Head and Kumar (2005), they find evidence in favor of threshold effects in the European link between expected inflation and RPV. Similar threshold effects are found by Bick and Nautz (2008) using price data from U.S. cities, although they do not differentiate between expected and unexpected inflation. Finally, analyzing price observations from bazaars, convenience stores, and supermarkets in Turkey, Caglayan, Filiztekin and Rauh (2008) show that the relationship between RPV and expected inflation confirms the predictions of monetary search models. In particular, expected inflation increases RPV only if it exceeds a certain threshold.

Given the overall decline of U.S. inflation and inflation expectations over the past decades, the focus of our analysis is on the impact of expected inflation on RPV in the United States. In light of the recent theoretical and empirical literature, a changing role of expected inflation should be reflected in a structural break of the traditional inflation-RPV nexus.

1.3 The Empirical Relation between Inflation and RPV

1.3.1 Data and Variables

Our benchmark measures of inflation (π^{PPI}) and relative price variability (RPV) use monthly price data of the U.S. Producer Price Index (PPI). At the two-digit disaggregation level, the corresponding RPV measure, RPV_{PPI-2}, is based on the prices of the complete set of 15 subcategories. In order to check the robustness of our results, we additionally employ four alternative inflation and RPV measures typically applied in the empirical literature. Specifically, we consider RPV_{Core} as a second RPV measure, where food and energy prices are excluded to control for supply shocks. More precisely, we eliminated the prices of "farm products", "processed foods and feeds", and "fuels and related products and power", that is, 3 out of the 15 PPI subcomponents, compare e.g. Aarstol (1999). Our results should not depend on the aggregation level of the price index. Therefore, the third RPV measure, RPV_{PPI-3}, is based on the three-digit PPI disaggregation level, that is, on the prices of 77 subcategories. Fourth, we consider $RPV_{Abs} = \sqrt{RPV_{PPI-2}}$ since it should not be important whether one measures RPV by the variance or the standard deviation of relative prices. And, finally, we define inflation (π^{CPI}) and RPV (RPV_{CPI-2}) with respect to the 8 subcategories of the 2-digit Consumer Price Index (CPI) to guarantee that the following empirical results are robust with respect to the choice of the price index. The definitions of the various RPV measures are summarized in Table 1.1.

Following e.g. Aarstol (1999), we define each RPV measure via the *unweighted* variance of subcategory-specific inflation rates around the corresponding rate of inflation.[2] It is worth noting, however, that the use of weighted RPV measures that account for the importance of subcomponents in the price index does not affect our main results. More detailed information on the price indices and the corresponding subcategories is presented in the Appendix, see Tables 1.5 and 1.6.

[2] $\pi_{it} = ln(P_{it}/P_{it-1})$ is the inflation rate and P_{it} is the price index of the ith subcategory in period t. π_t is the aggregate inflation rate.

All data runs from January 1973 to December 2007 and is provided by the Bureau of Labor Statistics. Unit root tests clearly indicate that all inflation and RPV measures are stationary.[3]

Table 1.1: RPV Measures

Variable	Measure	Data
RPV_{PPI-2}	$\frac{1}{15}\sum_{i=1}^{15}(\pi_{it}-\pi_t)^2$	$PPI\ 2-digit$ $15\ subcategories$
RPV_{Core}	$\frac{1}{12}\sum_{i=1}^{12}(\pi_{it}-\pi_t)^2$	$PPI\ 2-digit$ $12\ subcategories$
RPV_{PPI-3}	$\frac{1}{77}\sum_{i=1}^{77}(\pi_{it}-\pi_t)^2$	$PPI\ 3-digit$ $77\ subcategories$
RPV_{Abs}	$\sqrt{\frac{1}{15}\sum_{i=1}^{15}(\pi_{it}-\pi_t)^2}$	$PPI\ 2-digit$ $15\ subcategories$
RPV_{CPI-2}	$\frac{1}{8}\sum_{i=1}^{8}(\pi_{it}-\pi_t)^2$	$CPI\ 2-digit$ $8\ subcategories$

Notes: Price data provided by the Bureau of Labor Statistics. The variable RPV_{CPI-2} accounts for the change in the composition of the CPI subcategories in 01/1998.

1.3.2 Inflation Forecasts

The theories on the relation between inflation and RPV presented in Section 1.2 highlight the different roles of expected inflation, unexpected inflation, and inflation uncertainty. It is a general problem of any such decomposition that the empirical results might depend on the accuracy of the expected inflation measure. Many measures of inflation expectations exist, including the forecasts of professional economists, results from consumer surveys, or information extracted from financial markets. Despite the increasing importance and quality of this kind of data, survey data is not available over the whole sample period and on a monthly basis. In particular, there are no surveys on expectations about PPI

[3] Results of ADF and KPSS tests are not presented but are available on request.

inflation. In view of these problems, we follow the bulk of the empirical literature and base our measure of expected inflation on a time series representation of inflation. Note, however, that beating the forecasting performance of univariate time series models of inflation is not an easy task, particularly over a monthly forecast horizon, see e.g. Elliott and Timmermann (2008).

Allowing for time-varying inflation uncertainty ($CVAR$), the forecast equations for overall U.S. producer price inflation (π^{PPI}) and consumer price inflation (π^{CPI}) are specified as GARCH models, where the corresponding mean equations follow an ARMA process.[4] Expected inflation (EI) is derived as the one-period-ahead inflation forecast while unexpected inflation (UI) is the resulting forecast error ($UI = \pi - EI$). The Garch equations provide us with time series for inflation uncertainty ($CVAR$). Using Maximum-Likelihood estimation, we applied a standard information criterion (BIC) to determine the optimal lag structure. Detailed results of the estimated inflation forecast equations are shown in the Appendix, see Table 1.7. It is worth noting that alternative specification strategies for obtaining the inflation forecast equations lead to very similar results. In particular, using inflation forecasts based on a simple AR(12) mean model will not affect the following outcomes.

Aarstol (1999) finds that the impact of unexpected inflation on RPV depends on the sign of the inflation forecast error. In order to control for this effect, we define positive unexpected inflation as $UIP = UI$ if $UI \geq 0$ and $UIP = 0$ otherwise and negative unexpected inflation UIN accordingly.

1.3.3 The (Changing) Impact of Expected Inflation on RPV

After these preliminaries, let us now estimate the impact of expected inflation (EI), unexpected inflation (UIP, UIN), and inflation uncertainty ($CVAR$) on RPV. Using the various inflation and RPV measures, we estimate the relationship between inflation and RPV based on two specifications, typically applied in the empirical literature. Following e.g. Aarstol (1999), Equation (1.1) contains

[4] Preliminary investigations indicate that the forecast errors of the best-fitting ARMA model are heteroscedastic.

squared terms of inflation and is applied to the four RPV measures based on the variance of relative prices (RPV_{PPI-2}, RPV_{Core}, RPV_{CPI-2}, and RPV_{PPI-3}):

$$RPV_t = \gamma_0 + \gamma_1 EI_t^2 + \gamma_2 UIP_t^2 + \gamma_3 UIN_t^2 + \gamma_4 CVAR_t + v_t \tag{1.1}$$

Accordingly, Equation (1.2) which explains the standard deviation of relative prices, RPV_{Abs}, includes the absolute value of the inflation terms:

$$RPV_t = \gamma_0 + \gamma_1 |EI_t| + \gamma_2 UIP_t + \gamma_3 |UIN_t| + \gamma_4 \sqrt{CVAR_t} + u_t \tag{1.2}$$

Table 1.2 summarizes the results for the U.S. inflation-RPV nexus for all RPV measures. For sake of comparability, the upper part of the Table presents the estimates for the sample period used by Aarstol (1999), ranging from 01/1973 until 05/1997. Since he used the 2-digit PPI index, the results shown in the first row exactly replicate his findings. Specifically, there is a significant positive impact of expected inflation (γ_1) on RPV. According to Wald tests of parameter equality, the effect of unexpected inflation (γ_2, γ_3) depends on the sign of the inflation forecast error. And, finally, the coefficient of inflation uncertainty (γ_4) is significant and plausibly signed. During the first sample period, most of these conclusions remain valid with respect to different RPV and inflation measures. Although the absolute size of the inflation coefficients changes with the underlying RPV measure, the relative size of the inflation coefficients and their statistical significance remain merely unaffected. The only exception refers to the coefficient of inflation uncertainty, where the evidence is more elusive.

The overall impression of structural stability of the U.S. inflation-RPV linkage changes, however, if the sample period is extended by more recent data (01/1973 - 12/2007), see the middle part of the Table. In particular, both magnitude and significance of the impact of expected inflation on RPV have decreased regardless of the underlying measures of inflation and RPV. The evidence in favor of a structural break stirred by a changing role of expected inflation gets even more striking, if the inflation-RPV equations are estimated for the recent period separately, see the lower part of Table 1.2.

Table 1.2 indicates that the impact of expected inflation on RPV has become insignificant in the United States over the past years. The implied instability

Table 1.2: The Changing Impact of Expected Inflation on RPV

$$RPV_t = \gamma_0 + \gamma_1 EI_t^2 + \gamma_2 UIP_t^2 + \gamma_3 UIN_t^2 + \gamma_4 CVAR_t + v_t$$

Sample 01/1973-05/1997

	$\hat{\gamma}_1$	$\hat{\gamma}_2$	$\hat{\gamma}_3$	$\hat{\gamma}_4$
RPV_{PPI-2}	0.897*** (5.40)	1.276*** (9.78)	0.210 (1.40)	0.316** (1.84)
RPV_{Abs}	0.254** (2.10)	0.844*** (6.23)	0.594*** (3.88)	0.805 (1.62)
RPV_{PPI-3}	3.897*** (3.53)	5.520*** (11.77)	0.668** (2.07)	1.455** (2.12)
RPV_{Core}	0.445** (2.46)	0.867*** (12.58)	0.166* (1.91)	0.226 (1.50)
RPV_{CPI-2}	0.118* (1.97)	0.647*** (3.58)	0.578*** (3.21)	0.202 (0.74)

Sample 01/1973-12/2007

	$\hat{\gamma}_1$	$\hat{\gamma}_2$	$\hat{\gamma}_3$	$\hat{\gamma}_4$
RPV_{PPI-2}	0.161 (0.35)	1.438*** (20.59)	0.949*** (5.00)	0.171 (1.17)
RPV_{Abs}	0.233* (1.76)	0.911*** (10.19)	0.737*** (8.54)	0.515 (1.37)
RPV_{PPI-3}	2.294** (2.31)	5.541*** (13.49)	1.112*** (5.75)	1.221** (2.48)
RPV_{Core}	0.324 (1.33)	0.886*** (16.32)	0.429*** (6.64)	0.119 (1.36)
RPV_{CPI-2}	−0.012 (−0.21)	0.935*** (6.88)	0.932*** (5.02)	0.282 (1.03)

Sample 06/1997-12/2007

	$\hat{\gamma}_1$	$\hat{\gamma}_2$	$\hat{\gamma}_3$	$\hat{\gamma}_4$
RPV_{PPI-2}	0.107 (0.15)	1.638*** (6.21)	1.189*** (17.24)	0.087 (0.61)
RPV_{Abs}	0.189 (1.15)	0.996*** (10.10)	0.833*** (12.08)	0.129 (0.25)
RPV_{PPI-3}	2.041 (1.26)	5.248*** (3.81)	1.102*** (4.46)	−0.384 (−0.54)
RPV_{Core}	0.318 (0.86)	0.927*** (10.96)	0.528*** (10.78)	−0.008 (−0.15)
RPV_{CPI-2}	−0.207 (−0.58)	1.611*** (9.85)	1.513*** (5.92)	0.306 (0.68)

Notes: Estimation results of RPV equations (1.1) and (1.2) using different inflation and RPV measures for various sample periods. The inflation forecast equations implying expected (EI), unexpected (UIP, UIN) inflation, and inflation uncertainty ($CVAR$) are shown in Table 1.7. t-statistics (Newey-West standard errors) in parentheses. *, **, *** indicate significance at the 10%, 5%, and 1% significance level.

of the inflation-RPV nexus may explain the breakdown of the traditional linear relation between RPV and U.S. inflation found by Lastrapes (2006). However, before we have a closer look at the changing role of expected inflation, two remarks are in order. First, it is worth mentioning that Equations (1.1) and (1.2) involve generated regressors such that the appropriateness of an ordinary least squares (OLS) estimation and the validity of standard t-statistics is not obvious. Pagan (1984) has shown that OLS estimation is consistent and does not necessarily lead to efficiency losses if generated regressors (EI) as well as forecast errors (UIP and UIN) enter the equation. The only problem concerns the OLS-generated t-statistic of the coefficient of EI (γ_1) which tends to be overstated. Since the acceptance of the relevant null hypothesis (no influence of expected inflation) with the overstated t-statistic must lead to the acceptance with the correct one, only those EI coefficients require further investigation for which the null hypothesis is rejected. Therefore, we reinvestigated the significance of EI in the early sample period (01/1973-05/1997) by using Pagan's corrected t-statistics. In line with Silver and Ioannidis (2001), however, the corrected t-statistics had no quantitative effect on the significance of expected inflation, see Table 1.8 in the Appendix.

Second, Table 1.2 further suggests that the vanishing influence of expected inflation might not be the only source of instability in the relation between inflation and RPV. Therefore, we have to ensure that the results concerning the changing role of expected inflation are not driven by further instabilities. To that aim, the following endogenous breakpoint analysis of the empirical relation between expected inflation and RPV will also control for the effect of instabilities in the role of unexpected inflation and inflation uncertainty, see Section 1.4.3.

In the United States, average inflation has significantly decreased over the past two decades. Therefore, in line with the predictions of the monetary search model introduced by Head and Kumar (2005), our empirical results may indicate that the impact of expected inflation on RPV has been reduced because inflation expectations have been stabilized on a low level. This interpretation of our empirical results obtained for recent U.S. data would be in line with evidence for Germany and the Euro area, two textbook examples for low-inflation currency areas, see Nautz and Scharff (2005, 2010). Finally, note that our findings are compatible with the thresholds effects of U.S. inflation established by Bick and Nautz (2008) and the non-linear relationship between expected inflation and RPV found by Fielding and Mizen (2008).

1.4 Structural Break Tests for the U.S. Inflation-RPV Nexus

1.4.1 Endogenous Break-Point Tests

This Section sheds more light on the changing role of expected inflation for the inflation-RPV nexus. In particular, we investigate the timing and the significance of the structural instability in the relationship between expected inflation and RPV using endogenous break-point tests. Specifically, we apply the testing procedure by Andrews (1993) and Andrews and Ploberger (1994), which is designed to detect a structural break even if the break-point is unknown.

The endogenous break-point tests are implemented as follows: Having defined a sequence of dummy variables, $D(j)$, that equal 0 if $t < j$ and 1 otherwise, we estimate for each j a break-augmented RPV equation that allows a shift in the marginal impact of expected inflation at date j. For example, for the four variance-based RPV measures we obtain the following test equations:[5]

$$RPV_t = \gamma_0 + \delta_j D(j) EI_t^2 + \gamma_1 EI_t^2 + \gamma_2 UIP_t^2 + \gamma_3 UIN_t^2 + \gamma_4 CVAR_t + v_t \quad (1.4)$$

In a first step, we derive for each $j \in [T_1, T_2]$ the Likelihood ratio statistic, $LR(j)$, corresponding to the null hypothesis that δ_j, the coefficient of the dummy variable, is zero. In a second step, we compute the test statistics *ave-LR* and *sup-LR* for the unknown break-point defined as the average and the maximum of all $LR(j)$-statistics, respectively. The date j that corresponds to *sup-LR* serves as the estimate of the break date.

[5] Accordingly, in case of $RPV = RPV_{Abs}$ the test equations are obtained as

$$RPV_t = \gamma_0 + \delta_j D(j)|EI_t| + \gamma_1 |EI_t| + \gamma_2 UIP_t + \gamma_3 |UIN_t| + \gamma_4 \sqrt{CVAR_t} + u_t \quad (1.3)$$

Andrews (1993) showed that the asymptotic distributions of the test statistics are nonstandard and depend on the number of coefficients that are allowed to break and on the fraction of the sample that is examined.[6] Below, we use the approximate asymptotic p-values provided by Hansen (1997).

1.4.2 Test Results on the Changing Role of Expected Inflation

Table 1.3 summarizes the test results obtained for the various measures of inflation and RPV. With the exception of RPV_{Abs}, the LR-statistics clearly indicate a structural break in the impact of expected inflation on RPV. The estimated break dates implied by the maximum of the LR-statistics are 08/1990 for RPV_{PPI-2} and RPV_{Abs} and 09/1990 for RPV_{CPI-2}. According to the *sup*-LR statistics, the breaks for the other two RPV measures, RPV_{PPI-3} and RPV_{Core}, occur in 12/1992 and 06/1995, that is, about two and five years later.

However, a closer inspection of the underlying sequence of LR-test statistics reveals that even for these RPV measures the instability of the inflation RPV nexus has already started around 12/1990, very close to the break date estimates of the other RPV measures, compare Figure 1.1 in the Appendix. In both cases, RPV_{PPI-3} and RPV_{Core}, the enormous jump in the LR-test values at the end of 1990 strongly suggest that the instability in the relation between expected inflation and RPV has started before the LR-statistics eventually reached their maximum. This break date is confirmed by the Chow-type breakpoint-tests $LR^{12/1990}$ (also presented in Table 1.3) which for both RPV measures clearly indicate that the relation between expected inflation and RPV was already unstable in 12/1990.

Next, we revisit the inflation-RPV equation for all RPV measures taking into account the insights of the endogenous breakpoint tests. Assuming the breakpoint in 1990, as suggested by the behavior of LR-statistics, we reestimate the RPV

[6] Note that the distributions become degenerate as the first period tested approaches the beginning of the equation sample, or the end period approaches the end of the equation sample. To compensate for this behavior it is generally suggested that the start/end of the equation sample should not be included in the testing procedure. In accordance with Andrews (1993), the sample range where breaks are considered is defined by $T_1 = 1/3 * T$ and $T_2 = 2/3 * T$. Therefore, possible break dates range from 09/1984 to 04/1996.

Table 1.3: Test for Unknown Break-Point in the U.S. Inflation-RPV Nexus
The Case of Expected Inflation

H_0 : No break in the role of expected inflation for RPV

Model	Statistic		Value	Prob.
RPV_{PPI-2}	*ave*-LR statistic		10.56	0.00
	sup-LR statistic	(08/1990)	11.36	0.00
RPV_{Abs}	*ave*-LR statistic		2.07	0.14
	sup-LR statistic	(08/1990)	2.41	0.47
RPV_{PPI-3}	*ave*-LR statistic		11.15	0.00
	sup-LR statistic	(06/1995)	12.22	0.00
	$LR^{12/1990}$ statistic		11.54	0.00
RPV_{Core}	*ave*-LR statistic		8.62	0.00
	sup-LR statistic	(12/1992)	8.83	0.01
	$LR^{12/1990}$ statistic		8.74	0.00
RPV_{CPI-2}	*ave*-LR statistic		5.05	0.00
	sup-LR statistic	(09/1990)	7.23	0.04

Notes: Tests are based on equations (1.3) and (1.4). p-values of *ave*-LR and *sup*-LR according to Hansen (1997), estimated break date in parentheses. Feasible range of break points is 09/1984-04/1996. $LR^{12/1990}$ refers to a standard Chow breakpoint-test.

equation for the two resulting sample periods. For the early sub-sample, the results presented in Table 1.4 confirm the significant impact of expected inflation on RPV established by Aarstol (1999) and others.[7] However, the results look very different for the more recent subperiod. The former significant impact of expected inflation on RPV has disappeared in the recent low inflation period, independent of the price index, the disaggregation level, and the RPV measure.

1.4.3 Sensitivity Analysis: The Role of Further Instabilities in the Inflation-RPV Nexus

The evidence in favor of a structural break in the relation between expected inflation and RPV might be affected by further instabilities in the empirical inflation-RPV nexus. In fact, according to Table 1.4, there seem to be considerable movements in the coefficients of both unexpected inflation and inflation uncertainty that may distort the estimated relation between expected inflation and RPV. Therefore, this Section reexamines the stability of the EI-RPV relationship taking into account possible breaks in the coefficients of unexpected inflation and inflation uncertainty.

1.4.3.1 Testing for Further Instabilities in the Inflation-RPV Nexus

In a first step, we test for the presence of additional structural breaks in the inflation-RPV nexus related to unexpected inflation or inflation uncertainty. In a second step, in case of a significant break in one of the coefficients of UIP, UIN or $CVAR$, we rerun the endogenous break-point test for the relation between expected inflation and RPV based on an augmented test equation that takes this further instability into account. If the augmented test equation confirms the changing role of expected inflation, we can be confident that the vanishing impact of expected inflation on RPV is a robust result and not a statistical artefact stirred by the instability of other variables.

[7] Note that this result is not driven by the generated regressor problem because using corrected t-statistics does not affect the significance of $\hat{\gamma}_1$, see Section 1.3.3.

Table 1.4: The Inflation-RPV Nexus in the United States

before the break

	$\hat{\gamma}_1$	$\hat{\gamma}_2$	$\hat{\gamma}_3$	$\hat{\gamma}_4$
RPV_{PPI-2} 01/1973–07/1990	0.902** (2.34)	1.349*** (13.67)	0.178 (1.06)	0.307 (1.43)
RPV_{Abs} 01/1973–07/1990	0.374** (2.11)	0.771*** (4.08)	0.472*** (2.68)	0.932* (1.82)
RPV_{PPi-3} 01/1973–11/1990	3.823*** (2.97)	5.385*** (9.84)	0.673 (1.37)	1.254* (1.91)
RPV_{Core} 01/1973–11/1990	0.557*** (2.74)	0.905*** (12.23)	0.145 (1.46)	0.207 (1.28)
RPV_{CPI-2} 01/1973–08/1990	0.109** (2.01)	0.667*** (3.60)	0.597*** (3.09)	0.157 (0.65)

after the break

	$\hat{\gamma}_1$	$\hat{\gamma}_2$	$\hat{\gamma}_3$	$\hat{\gamma}_4$
RPV_{PPi-2} 08/1990–12/2007	−0.102 (−0.17)	1.859*** (5.96)	1.215*** (18.00)	0.102 (0.78)
RPV_{Abs} 08/1990–12/2007	0.078 (0.56)	1.054*** (9.97)	0.864*** (14.08)	−0.056 (−0.12)
RPV_{PPi-3} 12/1990–12/2007	1.794 (0.85)	5.648*** (6.41)	1.138*** (4.87)	0.627 (0.86)
RPV_{Core} 12/1990–12/2007	0.351 (0.78)	0.932*** (11.37)	0.537*** (10.73)	0.005 (0.11)
RPV_{CPI-2} 09/1990–12/2007	−0.094 (−0.50)	1.468*** (8.34)	1.362*** (5.39)	0.520 (1.12)

Notes: t-statistics (Newey-West standard errors) in parentheses. *, **, *** indicate significance at the 10%, 5% and 1% significance level. See Table 1.2 for further explanations.

For example, the test for an additional break in the RPV equation corresponding to a changing role of inflation uncertainty is based on the following test equation:[8]

$$\begin{aligned} RPV_t &= \gamma_0 + \delta_0 D_{90} EI_t^2 + \gamma_1 EI_t^2 + \gamma_2 UIP_t^2 + \gamma_3 UIN_t^2 \\ &\quad + \delta_j D(j) CVAR_t + \gamma_4 CVAR_t + v_t, \end{aligned} \tag{1.5}$$

where the step dummy variable, D_{90}, is defined in accordance with the changing coefficient of expected inflation, see Table 1.4.

Table 1.9 summarizes the test results for the various empirical specifications of the inflation-RPV nexus. Overall, the results confirm the conclusion of modest instability in unexpected inflation and inflation uncertainty already suggested by the estimation results obtained for the different sample periods, see Table 1.4. In accordance with Table 1.4, the evidence in favor of a structural break is strongest for the variable UIN, that is, for the impact of negative unexpected inflation.

1.4.3.2 The Changing Role of Expected Inflation in the Presence of Further Instabilities

Let us now investigate how the results on the changing role of expected inflation are affected by these additional breaks in the relation between inflation and RPV. To that aim, we augment the original test equations for the $EI - RPV$ relationship, (1.3) and (1.4), by the break dummies that were found to be significant for unexpected inflation or inflation uncertainty. For example, in case of the RPV measure RPV_{PPI-2}, we found significant breaks in the coefficients of UIP and UIN in 08/1990 and 08/1985, respectively, while the coefficient of $CVAR$ remained stable over the whole sample period, see Table 1.9. As a consequence, the augmented test equation for RPV_{PPI-2} is obtained as:

$$\begin{aligned} RPV_t^{PPI-2} &= \gamma_0 + \delta_j D(j) EI_t^2 + \gamma_1 EI_t^2 + \rho_1 D_{07/90} UIP_t^2 + \gamma_2 UIP_t^2 \\ &\quad + \rho_2 D_{07/85} UIN_t^2 + \gamma_3 UIN_t^2 + \gamma_4 CVAR_t + v_t, \end{aligned} \tag{1.6}$$

where $D_{07/90}$ and $D_{07/85}$ are the step dummy variables indicating the corresponding break dates of UIP and UIN.

[8] In the case of $RPV = RPV_{Abs}$, test equations are obtained by replacing all squared terms by the corresponding absolute values and the $CVAR$ term by its square root.

The results for the augmented breakpoint tests do not differ qualitatively from those of the previous Section, see Table 1.10 in the Appendix. Therefore, irrespective of further, less-theory related structural breaks in the inflation-RPV nexus due to unexpected inflation and inflation uncertainty, the results confirm the evidence in favor of a changing role of expected inflation for RPV. In particular, in line with our previous results, the various breaks in the impact of EI can be all dated around 1991. Moreover, confirming the results of Table 1.4, pre- and after-break estimations of the augmented inflation-RPV equations reveal that for all RPV and inflation measures the impact of expected inflation is significant before the break but small and insignificant thereafter.[9]

1.5 Concluding Remarks

This paper provided new evidence on the empirical relationship between inflation and RPV in the United States. Reconciling the mixed results offered by earlier contributions, we found that the impact of expected inflation on RPV has declined significantly since the 1990s. Endogenous break-point tests confirmed the timing and statistical significance of the changing role of expected inflation for RPV regardless of the inflation and RPV measure.

Our results support the implications of recent monetary search models which predict that the inflation-RPV nexus depends on the level of expected inflation, see Head and Kumar (2005) and Caglayan et al. (2008). In accordance with the evidence obtained by Nautz and Scharff (2005, 2010) for Germany and the Euro area, our results suggest that the impact of expected inflation on RPV broke down in the United States because inflation expectations had been stabilized on a low level.

According to recent macroeconomic theory, the impact of expected inflation on RPV is a major channel for real effects of inflation, see e.g. Woodford (2003). The current study demonstrated that the empirical analysis of the relation be-

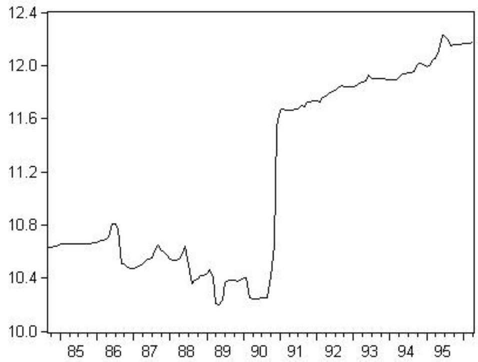
[9] For brevity, the results of the augmented pre- and after-break regressions, which are very similar to those shown in Table 1.4, are not presented but are available on request.

tween inflation and RPV can be largely improved by paying more attention to the predictions of theoretical models. In addition to the different role of expected and unexpected inflation implied by well-established menu cost and signal extraction models, our results suggest that recent monetary search models provide particularly useful insights on the functional form of the inflation-RPV nexus.

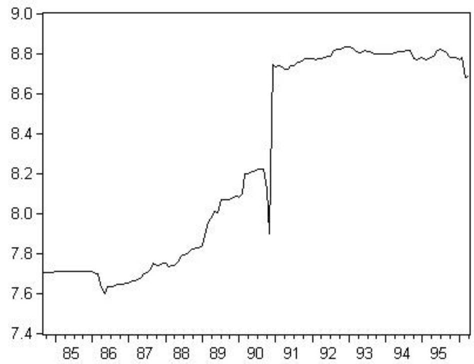
1.6 Appendix

1.6.1 Figures

Figure 1.1: Break in the Inflation-RPV Nexus: *LR*-Test Statistics
Test sample: 09/1984-04/1996



(a) $RPV_{3-digit}$



(b) RPV_{Core}

Notes: $LR(j)$-test statistics correspond to the null of no break in the impact of expected inflation on RPV in period j. For both RPV measures, the Figure illustrate a sharp increase of the test statistics at 12/1990, see Table 1.3.

1.6.2 Tables

Table 1.5: Subcategories of the U.S. Consumer Price Index (Two-Digit)

Subcategory
Food and beverages
Housing
Apparel
Transportation
Medical care
Recreation
Education and communication
Other goods and services

Source: Bureau of Labor Statistics. Series ID's: CUSR0000SAA-CUSR0000SAT. Note that in 01/1998 the subcategory "Entertainment" was replaced by the subcategories "Recreation" and "Education and Communication".

Table 1.6: Subcategories of the U.S. Producer Price Index (Two-Digit and Three-Digit)

two-digit	*three-digit*	
Farm products	Fruits and melons, fresh/dry vegs. and nuts	Grains
	Slaughter livestock	Slaughter poultry
	Chicken eggs	Hay, hayseeds and oilseeds
	Plant and animal fibers	Fluid milk
Processed foods and feeds	Cereal and bakery products	Meats, poultry, and fish
	Processed fruits and vegetables	Beverages and beverage materials
	Fats and oils	Prepared animal feeds
	Sugar and confectionery	Dairy products
	Miscellaneous processed foods	
Textile products and apparel		
Hides, skins, leathers and related products	Hides and skins, incl. cattle	Leather
	Footwear	Other leather and related products
Fuels and related products and power	Coal	Gas fuels
	Petroleum and coal products, n.e.c.	Petroleum products, refined
	Electric power	
Chemical and allied products	Industrial chemicals	Plastic resins and materials
	Fats and oils, inedible	Agricultural chemicals and chemical products
	Drugs and pharmaceuticals	Other chemicals and allied products
Rubber and plastic products	Rubber and rubber products	Plastic products
Lumber and wood products	Lumber	Millwork
	Plywood	Other wood products
Pulp, paper and allied products	Pulp, paper, and prod., ex. bldg. paper	Building paper and building board mill prods.

Table 1.6 continued

two-digit	*three-digit*	
Metal and metal products	Iron and steel	Nonferrous metals
	Hardware	Plumbing fixtures and fittings
	Fabricated structural metal products	Heating equipment
	Metal containers	Miscellaneous metal products
Machinery and equipment	Agricultural machinery and equipment	Construction machinery and equipment
	General purpose machinery and equipment	Special industry machinery and equipment
	Metalworking machinery and equipment	Electrical machinery and equipment
	Miscellaneous machinery	
Furniture and household durables	Household furniture	Commercial furniture
	Household appliances	Home electronic equipment
	Floor coverings	Other household durable goods
Nonmetallic mineral products	Glass	Concrete ingredients and related products
	Clay construction products ex. refractories	Refractories
	Gypsum products	Glass containers
	Concrete products	Asphalt felts and coatings
	Other nonmetallic minerals	
Transportation equipment	Motor vehicles and equipment	Railroad equipment
Miscellaneous products	Toys, sporting goods, small arms, etc.	Tobacco products, incl. stemmed and redried
	Photographic equipment and supplies	Notions
	Other miscellaneous products	

Source: Bureau of Labor Statistics. Series ID's (two-digit): WPU01-WPU15. Series ID's (three-digit): WPU011-WPU159.

Table 1.7: The Inflation Forecast Equations (01/1973-12/2007)

Producer Price Index

$$\pi_t^{PPI} = \underset{(3.60)}{0.02} + \underset{(7.33)}{0.38}\pi_{t-1}^{PPI} - \underset{(-1.93)}{0.11}\pi_{t-2}^{PPI} + \underset{(2.98)}{0.12}\pi_{t-6}^{PPI} + \underset{(4.00)}{0.14}\pi_{t-10}^{PPI} + \underset{(4.40)}{0.26}v_{t-3} + \underset{(2.76)}{0.10}v_{t-12} + v_t$$

$$\sigma_{v,t}^2 = \underset{(2.04)}{0.00001} + \underset{(6.21)}{0.246}v_{t-1}^2 + \underset{(22.67)}{0.763}\sigma_{v,t-1}^2$$

adjusted $R^2 = 0.23$ $Q(12) = 5.42$ [0.49] $ARCH(12) = 7.65$ [0.81]

Consumer Price Index

$$\pi_t^{CPI} = \underset{(2.80)}{0.02} + \underset{(28.37)}{0.81}\pi_{t-1}^{CPI} + \underset{(3.44)}{0.09}\pi_{t-9}^{CPI} - \underset{(-3.38)}{0.67}\pi_{t-12}^{CPI} - \underset{(-9.44)}{0.61}u_{t-1} + \underset{(5.77)}{0.30}u_{t-2} - \underset{(-6.34)}{0.14}u_{t-12} + u_t$$

$$\sigma_{u,t}^2 = \underset{(2.29)}{0.000002} + \underset{(3.72)}{0.111}u_{t-1}^2 + \underset{(22.55)}{0.857}\sigma_{u,t-1}^2$$

adjusted $R^2 = 0.30$ $Q(12) = 4.23$ [0.64] $ARCH(12) = 5.50$ [0.93]

Notes: For both equations, the optimal lag structure is determined using Bayesian Information Criteria (BIC). Alternative specification strategies lead to very similar estimates of expected inflation (EI, UI) and inflation uncertainty ($CVAR$). $Q(12)$ denotes the Ljung-Box statistic testing for serial correlation in the residuals; $ARCH(12)$ denotes the LM-statistic testing for ARCH effects. p-values are given in brackets. t-statistics in parentheses.

Table 1.8: The Impact of Expected Inflation on RPV
(the Role of the Generated Regressor Problem)

Sample 01/1973-05/1997

	$\hat{\gamma}_1$
RPV_{PPI-2}	0.897***
	(5.40)
	[4.11]
RPV_{Abs}	0.254*
	(2.10)
	[1.91]
RPV_{PPI-3}	3.897***
	(3.53)
	[3.04]
RPV_{Core}	0.445**
	(2.46)
	[1.98]
RPV_{CPI-2}	0.118*
	(1.97)
	[1.82]

Notes: The results of this Table demonstrate that the significant impact of expected inflation on RPV found by Aarstol (1999) and others is not an artefact of the generated regressor problem, see Pagan (1984). Numbers in parentheses are t-statistics ignoring that expected inflation is a generated regressor as in Table 1.2. Numbers in brackets are t-statistics corrected for the generated regressor problem, see e.g. Silver and Ioannidis (2001). *, **, *** indicate significance at the 10%, 5%, and 1% level (based on the corrected t-statistics). See Table 1.2 for further explanations.

Table 1.9: Test for Unknown Break-Point in the U.S. Inflation-RPV Nexus
The Case of Unexpected Inflation and Inflation Uncertainty

Model	H_0 : No break in the coef. on UIP (γ_2)		H_0 : No break in the coef. on UIN (γ_3)		H_0 : No break in the coef. on $CVAR$ (γ_4)	
	ave-LR	*sup-LR*	*ave-LR*	*sup-LR*	*ave-LR*	*sup-LR*
RPV_{PPI-2}	3.48 [0.05]	6.67 [0.06] (08/1990)	12.48 [0.00]	23.08 [0.00] (08/1985)	0.04 [1.00]	0.23 [1.00]
RPV_{Abs}	1.13 [0.28]	3.65 [0.23]	4.89 [0.02]	12.37 [0.00] (08/1985)	0.34 [0.66]	0.68 [0.94]
RPV_{PPI-3}	0.16 [0.89]	0.36 [1.00]	0.31 [0.70]	0.60 [0.96]	0.43 [0.59]	1.10 [0.77]
RPV_{Core}	0.02 [1.00]	0.10 [1.00]	11.96 [0.00]	19.33 [0.00] (04/1985)	2.03 [0.15]	4.47 [0.16]
RPV_{CPI-2}	14.43 [0.00]	25.97 [0.00] (07/1994)	16.65 [0.00]	26.45 [0.00] (03/1986)	11.01 [0.00]	15.25 [0.00] (03/1986)

Notes: Test equations assume a break in the coefficient of expected inflation as it is indicated by the results of the endogenous break-point tests, see Table 1.3 and Equation (1.5). P-values of the *ave-LR* and *sup-LR* statistics according to Hansen (1997) in brackets, estimated break date in parentheses. Feasible range of break-points is 09/1984-04/1996. See Section 1.4.3 for further explanations.

Table 1.10: Test for Unknown Break-Point in the *EI-RPV* Relationship (Accounting for Structural Breaks of UIP, UIN, and $CVAR$)

H_0 : No break in the role of expected inflation for RPV

Model	Statistic		Value	Prob.
RPV_{PPI-2}	*ave*-LR statistic		5.17	0.01
	sup-LR statistic	(11/1990)	8.05	0.02
RPV_{Abs}	*ave*-LR statistic		1.39	0.23
	sup-LR statistic	(11/1990)	2.33	0.51
RPV_{PPI-3}	*ave*-LR statistic		11.15	0.00
	sup-LR statistic	(06/1995)	12.22	0.00
	$LR^{12/1990}$ statistic		11.54	0.00
RPV_{Core}	*ave*-LR statistic		6.10	0.00
	sup-LR statistic	(12/1990)	8.61	0.02
RPV_{CPI-2}	*ave*-LR statistic		9.02	0.00
	sup-LR statistic	(03/1991)	12.46	0.00

Notes: P-values of *ave-LR* and *sup-LR* according to Hansen (1997), estimated break date in parentheses. Feasible range of break-points is 09/1984-04/1996. $LR^{12/1990}$ refers to a standard Chow breakpoint-test. See Section 1.4.3 for further explanations.

2 Inflation, Price Dispersion, and Market Integration through the Lens of a Monetary Search Model

2.1 Introduction

In macroeconomic theory, the impact of inflation on price dispersion is a major channel of real effects of inflation. According to 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 the efficient allocation of resources. Both types of models imply a monotonous inflation-RPV relationship in which inflation always lowers welfare. As a consequence, the early empirical evidence is typically based on linear regressions of RPV on the rate of inflation (see e.g. Debelle and Lamont, 1997, and Jaramillo, 1999).

Recent monetary search models predict that the impact of inflation on price dispersion and welfare is more complex. In particular, Head and Kumar (2005) show that both, the inflation-RPV and the inflation-welfare nexus, are V-shaped implying that the optimal rate of inflation is above zero. This paper uses the Head and Kumar (2005) framework to shed more light on the functional relationship between inflation and RPV. Solving the monetary search model numerically reveals two further implications. Firstly, RPV should react stronger to inflation when inflation is low. Secondly, when search costs decrease, the curvature of the asymmetrically V-shaped inflation-RPV relationship flattens and price dispersion responds less to inflation. So far, these implications for the inflation-RPV nexus have not been tested empirically. Assuming that search costs decrease when markets become more integrated, the empirical part of the paper fills this gap by estimating the relationship between inflation and RPV for sub-groups of European countries with different degrees of goods market integration.

Contradicting the predictions of standard menu-cost or misperception models, recent empirical evidence suggests that the relation between inflation and RPV is non-linear, see e.g. Fielding and Mizen (2008), Bick and Nautz (2008), and Choi (2010). A first attempt to explicitly test the implications of the Head and Kumar (2005) model is given by Caglayan et al. (2008). Using price observations from bazaars, convenience stores, and supermarkets in Turkey, they find a symmetric V-shaped relationship between inflation and RPV, but do not explore the role of market integration.

Monetary search models are designed for countries with low or moderate inflation rates (see Head and Kumar, 2005, p.535). Therefore, members of the European Union (EU) are natural candidates for an empirical test of these models. Although European integration has made considerably progress on average, notable differences in goods market integration across Europe have remained. The following analysis compares two groups of countries. The first group contains the highly integrated Euro-area countries where a common currency contributes to keep search costs low. The second group contains the rather heterogenous group of all 27 EU member states where markets are less integrated and, thus, search costs should be significantly higher compared to Euro-area countries, see Engel and Rogers (2004) and Parsley and Wei (2008).

Our empirical results show that the impact of inflation on price dispersion is non-linear and crucially depends on the level of goods market integration. In particular, the evidence supports both predictions of the monetary search model. On the one hand, the empirical relation between inflation and price dispersion is asymmetrically V-shaped in the less integrated EU-27 economy suggesting an optimal annual inflation rate of about 3%. On the other hand, the impact of inflation on price dispersion is only small and insignificant for the highly integrated Euro-area markets where search costs are low.

The paper is organized as follows. Section 2.2 briefly reviews the Head and Kumar (2005) monetary search model and derives testable implications for the empirical relationship between inflation and RPV. Section 2.3 introduces the data and specifies the price variability and inflation measures. Section 2.4 presents the empirical results obtained for the inflation-RPV nexus of the EU27 and the Euro-area countries. Section 2.5 investigates the inflation-RPV nexus accounting for important policy events that may have increased European market integration over time. Specifically, we consider the effects of the introduction of the Euro as a physical currency in 2002 and the role of the EU enlargement in 2004 for the empirical inflation-RPV relationship. Section 2.6 offers some concluding remarks.

2.2 The Monetary Search Model

2.2.1 Inflation, Price Dispersion, and Welfare

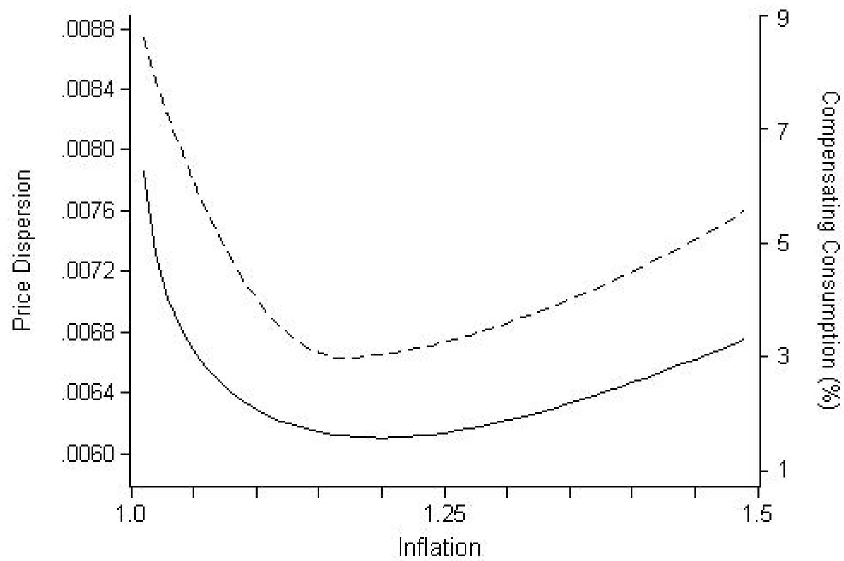
The Head and Kumar (2005) monetary search model emphasizes that buyers have only incomplete information about the prices offered by different sellers.[1] In this model, the impact of inflation on price dispersion and welfare is determined by two opposing effects. On the one hand, higher expected inflation lowers the value of fiat money, which increases demand for goods and, thereby, sellers' market power. Since market power differs across sellers, higher expected inflation leads to higher price dispersion. On the other hand, higher expected inflation also raises the gains of search which adds two further dimensions to its effect on welfare. First, the search induced by inflation is costly. And second, because it induces search, inflation increases buyers' information and, thereby, weakens sellers' market power.

[1] Adopting the monetary exchange framework proposed by Shi (1999), Head and Kumar (2005) extend the nonsequential price setting model of Burdett and Judd (1983) in order to link inflation and the optimal search strategy. 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.

Therefore, inflation may have also welfare-improving effects by reducing the dispersion of prices. As a result, the sign of the overall effect of inflation on price dispersion and welfare depends on the level of inflation.

In the following, we derive two further theoretical implications on the functional relationship between inflation and price dispersion by solving the monetary search model numerically for a plausible set of parameter values typically used in calibrated macroeconomic models, see Head and Kumar (2005) and Head et al. (2010). It is worth emphasizing that both results hold for a very broad range of parameter values, see Appendix A1 for a more detailed presentation of the model and the simulation exercise.

Figure 2.1: Inflation, Price Dispersion, and Welfare



Notes: The figure shows the impact of expected inflation on price dispersion and welfare as predicted by the Head and Kumar (2005) monetary search model. Price Dispersion (solid line - left scale); Compensating Consumption (%) (dashed line - right scale). For more details, see Appendix A1.

Figure 2.1 displays the benchmark simulation for inflation's impact on welfare and price dispersion. The welfare cost of inflation is measured by the quantity of consumption required to give a representative household the same utility as she would receive in the optimum (without asymmetric information) as a percentage of optimum consumption.[2] The figure shows that at low inflation rates the reduction of market power resulting from increased search intensity in response to an increase in inflation is sufficient to decrease price dispersion and to raise welfare (i.e. welfare costs decrease). However, when inflation exceeds a critical value, the welfare distorting effect of inflation eventually dominates.

As a result, the relationship between expected inflation and price dispersion can be captured by a V-shaped specification where the vertex occurs at positive levels of inflation. Note that the welfare maximizing inflation rate Π^*, which is determined by the minimum of the welfare cost curve, is positive and located below but very close to the vertex of the inflation-RPV nexus. Accordingly, this vertex may serve as a proxy for Π^*.

Figure 2.1 further shows that the relationship between inflation and price dispersion is asymmetric. The economics behind this asymmetry can be explained as follows. At low levels of inflation, a relatively large fraction of buyers observe only a single price. 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 in inflation have relatively large effects on search intensity and, thereby, on price dispersion. As the rate of inflation rises, the share of buyers observing only one price decreases. Therefore, any further increase in inflation has a smaller effect on search intensity and price dispersion.

In the Appendix, we show that asymmetrically V-shaped effects of inflation require that search costs are sufficiently high. Since the level of search costs should be negatively related to the degree of market integration, this leads to our first empirically testable implication of the monetary search model:

Hypothesis 1: *Consider the monetary search model of Head and Kumar (2005). Provided that the degree of market integration in an economy is sufficiently low, i.e. search costs are sufficiently high, the relationship between expected*

[2] Craig and Rocheteau (2008) relate the measure of the welfare cost of inflation obtained from a monetary search model to the traditional measures based on the "welfare triangle" methodology of Lucas (2000).

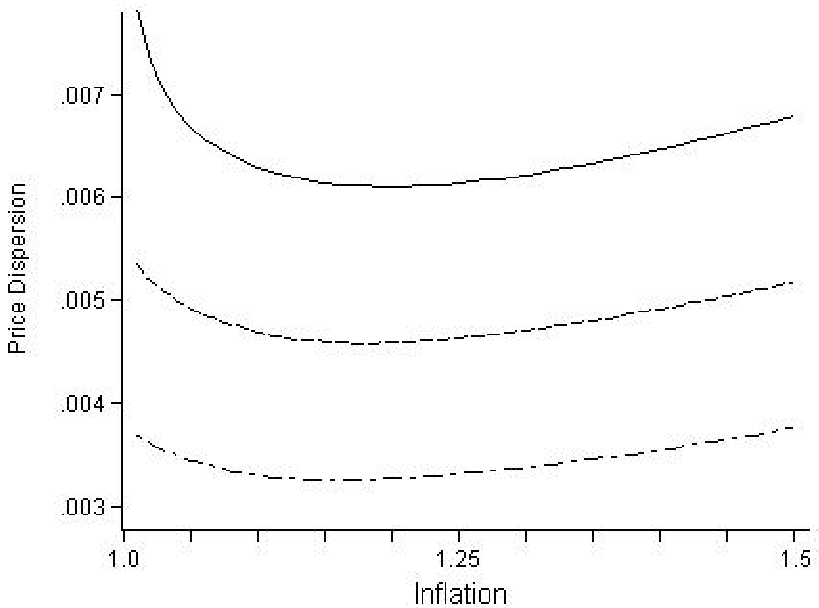
inflation and RPV is asymmetrically V-shaped with a non-zero optimal rate of inflation.

A first attempt to test this hypothesis is given by Caglayan et al. (2008) who found, however, a *symmetric* V-shaped relationship between price dispersion and expected inflation in Turkey.

2.2.2 Search Costs and Market Integration

In the benchmark simulation presented above, search costs have been calibrated to achieve an average mark-up of prices over marginal costs of 10%, compare Gali et al. (2001) and Head et al. (2010). However, due to the ongoing market integration in Europe, mark-ups may have declined over the recent years.

Figure 2.2: The Inflation-RPV Nexus and the Role of Search Costs



Notes: Figure plots price dispersion versus inflation for varying levels of search costs: i) high search costs (upper graph) ii) moderate search costs (middle graph) and iii) low search costs (lower graph). See Appendix A1 and Figure 2.1 for more details.

To shed more light on the role of search costs for the real effects of inflation, we computed additional model simulations with varying levels of search costs.

The upper graph in Figure 2.2 displays the asymmetric V-shaped relationship between inflation and RPV for the benchmark simulation where search costs are high. The two remaining graphs present simulation results for moderate and low search costs, respectively. Compared to the benchmark, decreasing search costs shift the inflation-RPV nexus downwards. More importantly, the curvature of the relationship gets progressively flatter: 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.

We summarize this implication of the Head and Kumar (2005) monetary search model as follows:

Hypothesis 2: *With increasing market integration, i.e. decreasing search costs, the V-shaped relationship between expected inflation and RPV gets progressively flatter and the impact of inflation on the dispersion of prices declines.*

In the limiting case, when search costs are zero, inflation has no impact on price dispersion.[3]

2.2.3 Market Integration in the European Union

According to the predictions of Head and Kumar (2005) and the hypotheses stated above, market integration crucially affects the relationship between inflation and price dispersion. In the following, both hypotheses will be tested using panel data from two subgroups of EU member states characterized by different levels of market integration.

For Euro-area countries, on the one hand, much progress on the issue of market integration and price transparency has been made with the Single Market Program of 1992 and the introduction of the Euro in 1999. Using price data across different Euro-area countries, Engel and Rogers (2004) find evidence for

[3] When search costs fall below a critical threshold value, all buyers optimally observe more than one price quote. The only possible price distribution is then concentrated at the marginal cost price and price dispersion equals zero. Accordingly, if search costs are extremely low, the distorting effect of inflation on price dispersion vanishes and the classical dichotomy holds.

an advanced integration of Eurozone consumer markets caused by the efforts to reduce economic barriers initiated in the 1990s. Parsley and Wei (2008) show that market integration among the countries in the Eurozone is uniformly higher compared to non-Euro countries. Therefore, the Euro-area should represent a highly integrated market where search costs are low. On the other hand, the EU 27 economy consists of a very heterogeneous group of countries and exhibits a lower degree of market integration.[4]

2.3 Data and Measurement

Many empirical contributions analyze the impact of inflation on *inter*market 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 the rates of inflation of various products of goods and services around the average inflation rate in a given city or country. By contrast, the *intra*market side (deviations of individual product specific inflation rates with respect to the product average inflation rate across cities or countries) seems to be underresearched.[5] In the following empirical study, the focus shall be on price variability in Europe within the *intra*market side because search models are specifically designed to account for price dispersion within a given market.

We use monthly data for various subcategories of the Harmonized Index of Consumer Prices (HICP) provided by the Eurostat database. The data set runs from January 1996 to August 2008. It includes observations of the twelve major HICP

[4] Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal and Spain are grouped together in Euro-area, whereas the EU-27 group consists of the Euro-area countries plus Bulgaria, Czech Republic, Denmark, Estonia, Cyprus, Latvia, Lithuania, Hungary, Malta, Poland, Romania, Slovenia, Slovakia, Sweden and United Kingdom. Although Slovenia, Cyprus and Malta adopted the Euro in 2007 and 2008, respectively, we do not include them into the Euro-area group, because our sample already starts in 1996. This implicates that Slovenia, Cyprus and Malta did not participate in the EMU for the major part of our sample period. Alternatively, one can split the countries into a Euro-area group and a non-Euro group. The qualitative results presented in this paper do not depend on this splitting scheme.

[5] Exceptions include Lach and Tsiddon (1992), Reinsdorf (1994), Parsley (1996), Fielding and Mizen (2000), and Caglayan et al. (2008).

subcategories for all 27 EU member states.[6] Following the empirical literature, *intra*market relative price variability is defined as:

$$RPV_{it} = \left[\sum_{j=1}^{N} w_{jt}(\pi_{ijt} - \pi_{it})^2 \right]^{0.5} , \tag{2.1}$$

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 ($\pi_{it} = \sum_{j=1}^{N} w_{jt}\pi_{ijt}$). 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.

Overall HICP inflation is denoted by $\Pi_t = \sum_{j=1}^{N} w_{jt}\Pi_{jt}$, where Π_{jt} is overall inflation in country j in time period t. Table 2.4 in Appendix A2 presents some summary statistics on the RPV and inflation measures, see also Figures 2.3 and 2.4. Panel Unit root tests indicate that all inflation and RPV measures are stationary.[7]

Theories on the relation between inflation and RPV emphasize the different roles of expected and unexpected inflation. In line with the empirical literature, we base our measures of expected inflation on a time series representation of inflation. Specifically, we estimate an AR(12) model for π_{it} and Π_t.[8] Expected inflation is derived as the one period-ahead inflation forecast while unexpected inflation is the resulting forecast error. Note that beating the forecasting performance of univariate time series models of inflation is not an easy task, particularly over a monthly forecast horizon, see e.g. Elliott and Timmermann (2008).

---

[6] These HICP subcategories are: food and non-alcoholic beverages (CP01); alcoholic beverages, tobacco and narcotics (CP02); clothing and footwear (CP03); housing, water, electricity, gas and other fuels (CP04); furnishing, household equipment and routine maintenance of the house (CP05); health (CP06); transport (CP07); communication (CP08); recreation and culture (CP09); education (CP10); restaurants and hotels (CP11); miscellaneous goods and services (CP12). Data series are seasonally adjusted using the Census X11 procedure.

[7] Results of the Panel Unit Root tests are not presented but are available on request.

[8] Additionally to the autoregressive parts, the π_{it} forecast model also contains past values of overall HICP inflation (up to 3 lags).

2.4 Inflation, Price Dispersion, and the Role of Market Integration

2.4.1 The Empirical Model

This Section empirically tests implications of market integration on the inflation-RPV nexus derived from the Head and Kumar monetary search model. Since expected inflation in the Head and Kumar model stems from growth in the stock of fiat money, our analysis focuses on overall expected inflation (Π^e). To control for the predictions of menu-cost and signal extraction models, we follow the empirical literature on the *intra*market inflation-RPV relationship (see e.g. Lach and Tsiddon, 1992) and include the absolute values of expected (π_i^e) and unexpected ($\pi_i - \pi_i^e$) product specific inflation into our regression model. The panel equation contains a product fixed effect (α_i) and monthly time dummies (λ_t):[9]

$$RPV_{it} = \alpha_i + \lambda_t + \beta_1|\pi_{it}^e| + \beta_2|(\pi_{it} - \pi_{it}^e)| + \beta_3|\Pi_t^e - a| + \beta_4 D_t|\Pi_t^e - a| + \epsilon_{it} \quad (2.2)$$

According to Hypothesis 1, the relationship between overall expected inflation and price dispersion can be captured via a V-shaped specification where the vertex occurs at positive levels of expected HICP inflation. Following Caglayan et al. (2008), we therefore include $|\Pi_t^e - a|$ (with $a \geq 0$) into our regression model. For $a > 0$ the vertex of the V-shaped inflation-RPV relation shifts away from the origin towards positive values of expected overall inflation. The equation is estimated by means of minimizing the sum of squared residuals using a grid search procedure for a.[10]

Hypothesis 1 furthermore states that the impact of expected inflation on RPV is asymmetric. The asymmetry is captured by the term $D_t|\Pi_t^e - a|$ where D_t is a dummy variable which equals one when $\Pi_t < a$ and zero otherwise. For levels of

[9] Including lagged price dispersion or a measure of overall unexpected inflation ($\Pi - \Pi^e$) to Equation (2.2) does not affect our results.

[10] The starting point of our grid search is $a = 0$. Subsequently, we increase a in increments of 0.00025 up to $a = 0.0075$. Note that the average values of monthly overall inflation for our two country samples are 0.001723 and 0.002703 (0.021 and 0.032 in annual terms), respectively (see Table 2.4). So, $a = 0.0075$ seems to be a reasonable endpoint.

inflation below a the slope of the V-shaped inflation-RPV nexus equals $\beta_3 + \beta_4$, whereas for inflation rates above a the marginal impact of inflation on RPV is given by β_3. Since theory predicts that the response of RPV to expected inflation is stronger for values of inflation below the vertex, we would expect β_4 to be greater than zero.

According to Hypothesis 2, higher market integration flattens the V-shaped relationship between inflation and RPV. We therefore expect that the size and significance of the estimated coefficients for β_3 and β_4 should decrease with the degree of market integration. Whereas both coefficients should be close to zero for highly integrated markets like the Euro-area, they should be positively signed and significant for less integrated markets like the EU27 economy.

2.4.2 Inflation and Price Dispersion in a Less Integrated Market

The estimation results for the EU 27 economy are shown in the first column of Table 2.1. In line with menu-cost and misperception models, we find a significant positive effect of expected and unexpected product specific inflation on price dispersion, i.e. $\widehat{\beta}_1$, $\widehat{\beta}_2 > 0$. More interestingly, however, for the huge, and probably less integrated EU 27 market both coefficients on overall inflation, $\widehat{\beta}_3$ and $\widehat{\beta}_4$, are highly significant and plausibly signed. The estimated vertex a in the inflation-RPV nexus is greater than zero resulting in a right shift of the V-shaped inflation-RPV nexus. The null hypothesis $a = 0$ is rejected at the 1% significance level. Thus, in line with Hypothesis 1, the estimated relationship between inflation and price dispersion is asymmetrically V-shaped around a positive vertex. The estimated vertex, $\widehat{a} = 0.0025$, implies that the optimal annual inflation rate for the EU-27 economy should be about 3% .

2.4.3 Inflation and Price Dispersion in a Highly Integrated Market

The second column of Table 2.1 presents the estimation results for the Euro-area panel, a textbook example for a highly integrated market. According to

Table 2.1: Inflation and Relative Price Variability in the European Union
An Empirical Test of the Head and Kumar Monetary Search Model

$$RPV_{it} = \alpha_i + \lambda_t + \beta_1|\pi^e_{it}| + \beta_2|(\pi_{it} - \pi^e_{it})| + \beta_3|\Pi^e_t - a| + \beta_4 D_t|\Pi^e_t - a| + \epsilon_{it}$$

	$EU-27$	$Euro-area$
$\widehat{\beta}_1$	1.616^{**} (0.183)	0.333^{**} (0.022)
$\widehat{\beta}_2$	0.560^{**} (0.041)	0.283^{**} (0.004)
$\widehat{\beta}_3$	0.343^{**} (0.082)	0.023 (0.029)
$\widehat{\beta}_4$	0.543^{**} (0.251)	0.132 (0.131)
$\widehat{a}$	0.00250	0
$H_0:\ a = 0$	7.891 [0.00]	–
Obs	1632	1632
Product Groups	12	12
Countries	27	12

Notes: Expected and unexpected inflation series are based on an AR forecast model (see Section 2.3). Heteroskedasticity-consistent standard errors in parentheses, p-values in brackets. D_t is a dummy variable equal to 1 when $\Pi^e_t < a$ and zero otherwise. *, ** indicate significance at the 5% and 1% significance level. Following Hansen (1999), a bootstrap procedure was used to obtain p-values for testing H_0: a=0. Sample: 05/1997-08/2008.

Hypothesis 2, a flatter, almost negligible, inflation-RPV relationship for the highly integrated Euro-area market is predicted by monetary search theory. In fact, compared to the results obtained for the EU 27 panel, the estimated coefficients of overall inflation , $\widehat{\beta}_3 = 0.023$ and $\widehat{\beta}_4 = 0.132$, are substantially smaller and far from being significant. In the same vein, the estimated a that determines the vertex of the V-shaped inflation-RPV relationship equals zero in the Euro-area.

2.5 Changes in the Level of Market Integration over Time

The results presented in the previous Section indicate the importance of the degree of market integration for the relationship between inflation and price dispersion in Europe. Apparently, there is little room for discussion whether Euro-area countries are more integrated compared to all EU-27 member states. Yet there might have been changes in the level of European market integration over time. This Section accounts for possible variations in the degrees of market integration within a country group by splitting the sample periods according to major political changes.

2.5.1 The Effect of the 2004 EU Enlargement

On the first of May 2004, the European Union saw its biggest enlargement to date when ten countries joined the EU. This may have had significant consequences for market integration within the acceding countries. To analyze the effect of the 2004 EU enlargement on market integration and, thereby, on the relationship between inflation and price dispersion, we introduce a new country panel, called *acc-2004*, which includes all countries involved in the 2004 EU enlargement. Thus, *acc-2004* consists of Czech Republic, Estonia, Cyprus, Latvia, Lithuania, Hungary, Malta, Poland, Slovenia, and Slovakia. Since the accession of those countries into the EU single market should have significantly fostered market integration, the effect of inflation on price dispersion should have decreased accordingly.

Table 2.2: Inflation and Relative Price Variability: The EU Enlargement in 2004

$$RPV_{it} = \alpha_i + \lambda_t + \beta_1|\pi^e_{it}| + \beta_2|(\pi_{it} - \pi^e_{it})| + \beta_3|\Pi^e_t - a| + \beta_4 D_t|\Pi^e_t - a| + \epsilon_{it}$$

	05/1997-04/2004	05/2004-08/2008
$\widehat{\beta}_1$	1.104** (0.146)	0.327* (0.148)
$\widehat{\beta}_2$	0.458** (0.157)	0.262** (0.016)
$\widehat{\beta}_3$	0.341** (0.102)	0.154 (0.116)
$\widehat{\beta}_4$	0.308** (0.078)	0.226 (0.334)
$\widehat{a}$	0.00575	0.00335
$H_0: a = 0$	7.363 [0.01]	0.759 [0.53]
Obs	1008	624
Product Groups	12	12
Countries	10	10

Notes: Estimation results are based on acceding countries only. See Table 2.1 for further explanations.

The results for the pre- and post-05/2004 regressions of the acceding countries panel are shown in Table 2.2. Again, in line with menu cost and misperception models the impact of expected and unexpected product specific inflation is highly significant. This holds for the pre- and post-2004 period. However, there are striking differences with respect to overall expected inflation. In line with Hypothesis 1, we find evidence of a significant asymmetric V-shaped relation between overall expected inflation and RPV in the pre-2004 regression. The estimated optimal inflation rate is close to 6.9% in annual terms which clearly exceeds the optimal inflation rate estimated for the complete panel of 27 EU countries.[11]

In line with expectations, the results indicate that the effect of inflation on price dispersion has actually decreased during the post-2004 period. The estimated slope coefficients are both smaller $\widehat{\beta}_3 = 0.154 < 0.341$ and $\widehat{\beta}_4 = 0.226 < 0.308$ than their pre-2004 counterparts and insignificant. Moreover, the null hypothesis $a = 0$ can not be rejected for the post-2004 period. Therefore, the V-shaped inflation-RPV relationship got flatter as markets of the EU acceding countries have been more integrated in the post-2004 period. Put differently, the results reflect that the EU-enlargement did improve market integration in the acceding countries in a significant way.

2.5.2 The Introduction of the Euro

Within the Euro-area group, the introduction of the Euro might have influenced market integration and, thus, the real effects of inflation. In this Section, we will analyze if the common currency had a significant impact on the relationship between inflation and price dispersion. In monetary search models search costs are certainly more affected by all price quotes given in a common currency instead of a currency in non-physical form where price comparisons come at the cost of using fixed exchange rates. Therefore, we split the sample period into the pre-Euro part (05/1997-12/2001) and the post-Euro part (01/2002-08/2008).

Table 2.3 indicates that the introduction of the Euro in 2002 had no impact on the relationship between inflation and RPV. While the effects of expected and unexpected product specific inflation are significant different from zero, overall expected inflation has no impact on RPV. In accordance with Table 2.1, this holds for both, the pre- and post-Euro samples. Similarly, the shift of the V-shaped inflation-RPV nexus is not statistically different from zero in both sub-samples. Even before the Euro was introduced no significant V-shaped relationship can be

[11] Higher optimal inflation rates in the acceding countries group which primarily consists of less developed Central and Eastern European countries might be explained by higher productivity growth rates, see e.g. Égert et al. (2003).

found. These results are in line with Engel and Rogers (2004) and Parsley and Wei (2008) who find no evidence for a significant change in the integration of Eurozone consumer markets after the introduction of the Euro. They conclude that market integration in Europe occurred already throughout the decade of the 1990s.

Table 2.3: Inflation and Relative Price Variability: The Introduction of the Euro

$$RPV_{it} = \alpha_i + \lambda_t + \beta_1|\pi^e_{it}| + \beta_2|(\pi_{it} - \pi^e_{it})| + \beta_3|\Pi^e_t - a| + \beta_4 D_t|\Pi^e_t - a| + \epsilon_{it}$$

	05/1997-12/2001	01/2002-08/2008
$\widehat{\beta}_1$	0.175** (0.040)	0.382** (0.029)
$\widehat{\beta}_2$	0.139** (0.028)	0.280** (0.051)
$\widehat{\beta}_3$	0.155 (0.127)	0.066 (0.058)
$\widehat{\beta}_4$	−0.531 (0.900)	0.193 (0.161)
$\widehat{a}$	0.0015	0.001
$H_0: \ a = 0$	1.691 [0.24]	1.425 [0.31]
Obs	672	960
Product Groups	12	12
Countries	12	12

Notes: Estimation results are based on Euro-area countries only. See Table 2.1 for further explanations.

2.6 Concluding Remarks

In contrast to classical menu-cost or misperception models, the recent literature predicts that the relationship between inflation and the variability of relative prices is non-linear. Advancing on Head and Kumar (2005), we show that the impact of inflation on price dispersion and welfare crucially depends on the level of search costs. In particular, two testable implications of the model are derived: First, the relationship between inflation and price dispersion is predicted to be asymmetrically V-shaped. Second, for decreasing search costs the V-shaped relationship gets progressively flatter. We use monthly HICP-data of a panel of 27 EU countries to test the empirical content of both predictions. Assuming that search costs should be negatively related to the level of market integration, the inflation-RPV nexus is estimated for two subgroups of EU countries, i.e. the highly integrated Euro-area and the less integrated EU 27 economy.

Our empirical results confirm both theoretical predictions for the role of inflation regarding different levels of market integration. On the one hand, the relation between RPV and HICP inflation is V-shaped for the less integrated EU27 market, where the vertex occurs at positive values of inflation. On the other hand, we find that the impact of inflation on RPV gets negligible for the highly integrated markets of the Euro-area. These results proved to be robust with respect to alternative splits of the sample, accounting for a particular role of acceding countries in the EU enlargement of 2004 and the introduction of the Euro as a physical currency.

The relationship between inflation and relative price variability has important implications for the welfare cost of inflation. While the earlier literature typically predicts a monotonically increasing effect of inflation on price dispersion, recent evidence suggests that the relationship is actually V-shaped implying e.g. a positive optimal rate of inflation. Yet the economics behind the non-linearity are still unclear. Choi (2010), for example, shows that a V-shaped relationship between inflation and relative price variability can be generated in a Calvo model of sticky prices with heterogenous sectors. Provided that price rigidity varies with trend inflation, this approach may even explain a time-varying pattern of the inflation-

RPV nexus. The current paper shows that similar results can be obtained from monetary search theory shedding new light on the role of market integration on the welfare cost of inflation.

2.7 Appendix

2.7.1 A1 The Monetary Search Model

2.7.1.1 A1.1 Basic Model Setup

The Head and Kumar (2005) monetary search economy consists of $H \geq 3$ different types of households, with a continuum of identical sellers and buyers in each household and a continuum of identical households in each type. A type h household produces good h and derives utility only from consumption of good $h+1$, modulo H. Exchange is facilitated by the existence of fiat money. At the beginning of each period households receive a lump-sum transfer of new units of fiat money from the government that has no other purpose than to increase the stock of money at gross rate γ. Members of a representative type h who are sellers produce good h at marginal costs ϕ. In contrast, buyers of this representative household observe random number of price quotes and may purchase good $h+1$ at the lowest price observed. Let q_{kt} denote the measure of the household's buyers who observe $k \in \{1, 2, ..., K\}$ price quotes in period t. For each price quote observed, the household pays a search cost of μ units. Thus, household's total disutility of search in period t is equal to $\mu \sum_{k=1}^{K} kq_{kt}$.[12] Overall, a representative household maximizes the expected discounted sum of utility from consumption minus total production and search costs over an infinite horizon:

$$U = E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left[(u(c_t) - \phi y_t - \mu(2 - q_t)) \right] \right\}, \tag{2.3}$$

where β is a discount factor, c_t is consumption of the preferred good in time period t and y_t is total production in period t.

Restricting the analysis to symmetric and stationary monetary equilibria (SME's), buyers' reservation levels are endogenous and depend on the marginal value of fiat

[12] Without loss of generality, we will assume in the following that $K = 2$ (see also Head and Kumar, 2005, Corollary 2). This causes buyers to observe either one price quote with probability q_t or two prices with probability $1 - q_t$. Hence, total search costs in period t are equal to $\mu(2 - q_t)$.

money. Furthermore, all households choose the same probability for their buyers to observe different numbers of price quotes, the same distribution of posted prices, and all have the same consumption, money holdings, and valuation of money. It is also important to note that if the SME is characterized by some buyers observing one price while others observe two, then the distribution of prices will exhibit price dispersion necessarily (Head and Kumar, 2005, p. 542). Moreover, in this model the relationship between inflation and RPV is determined by two opposing effects resulting in an asymmetrically V-shaped inflation-RPV nexus (see Section 2.2).[13]

2.7.1.2 A1.2 The Importance of Search Costs

According to Head and Kumar (2005) and Head et al. (2010) the household's optimal choice of q is given by

$$q^* = \begin{cases} 0 & if \quad \mu < \mu_L \equiv u^{'}(c_2)[c_2 - c_1] \\ \frac{[u^{'-1}(\frac{\mu}{c_2-c_1}) - c_2]}{c_1 - c_2} & if \quad \mu_L \leq \mu \leq \mu_H \\ 1 & if \quad \mu > \mu_H \equiv u^{'}(c_1)[c_2 - c_1] \end{cases} \tag{2.4}$$

where c_1 and c_2 are the expected purchases of buyers observing one and two price quotes, respectively, and μ_L and μ_H are state contingent cut-off levels for search costs.

Equation (2.4) illustrates the importance of search costs for the household's search strategy and ultimately for the existence of an equilibrium with price dispersion. More specifically, an SME with price dispersion only exists if search costs lie in a certain interval ($\mu_L \leq \mu \leq \mu_H$). When search costs fall below a critical threshold value ($\mu < \mu_L$), the household behaves optimally by setting the probability of observing only one price quote equal to zero. In this scenario, sellers' market power erodes, the price distribution is concentrated around the marginal cost price and the real effects of inflation vanish. Furthermore, with very high search costs ($\mu > \mu_H$) the household has no incentive to have any of its buyers observe

[13] Head et al. (2010) study the extend to which real and nominal prices adjust to fluctuations in productivity and the money growth rate in a similar but stochastic environment.

a second price quote, $q^* = 1$. Here, the sellers' act as monopolists and the price is equal to the buyer's reservation level.

2.7.1.3 A1.3 Results from a Simulation Study

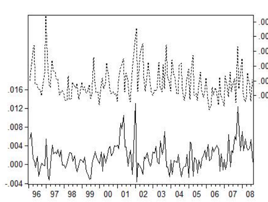
Following Gali et al. (2001), Head and Kumar (2005), and Head et al. (2010), we use a log utility function and set the discount factor, β, equal to 0.9. To achieve an average mark-up of prices over marginal costs of 10%, we set $\phi = 0.1$ and $\mu = 0.029$. Furthermore, we allow γ, which determines the growth rate of the money stock and the rate of inflation to range between 1 and 1.5. The solid line in Figure 2.1 and the upper graph of Figure 2.2 depict the V-shaped relationship between inflation and price dispersion for this benchmark scenario.

The middle and lower graph in Figure 2.2 demonstrate how lower search costs affect the inflation-RPV nexus. Compared to the benchmark simulation search costs are set equal to 0.024 (mark-up = 5.2%) and 0.019 (mark-up = 3.1%), respectively, which causes the inflation-RPV relationship to get progressively flatter. Decreasing the level of search cots even further ($\mu \leq 0.011$) results in a breakdown of the non-linear inflation-RPV linkage. In this case, price dispersion equals zero for any level of inflation.

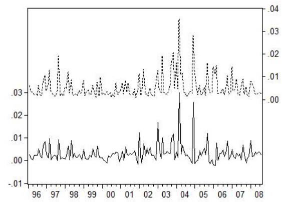
In line with Head and Kumar (2005), for a high search cost market RPV is V-shaped in expected overall inflation with the vertex occurring at positive levels of the inflation measure. The level of search costs determines the curvature of the inflation-RPV nexus. With lower search costs, price dispersion responds less to inflation. In the limiting case, if search cost fall below a certain threshold value, the real effects of inflation on RPV vanish and the classical dichotomy holds.

2.7.2 A2 Figures and Tables

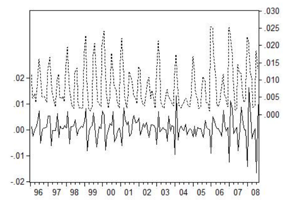
Figure 2.3: Product Specific Inflation and RPV (Euro-area)



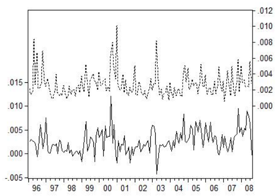
(a) CP01



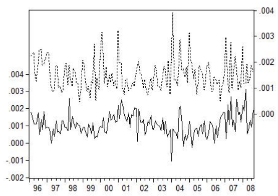
(b) CP02



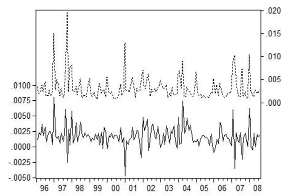
(c) CP03



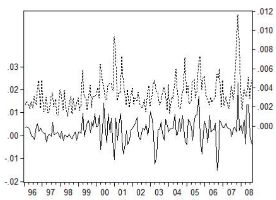
(d) CP04



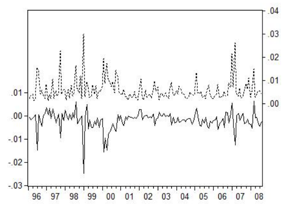
(e) CP05



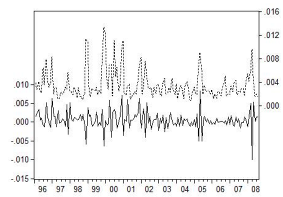
(f) CP06



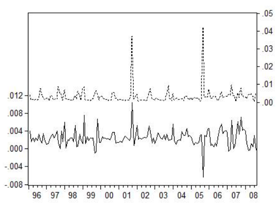
(g) CP07



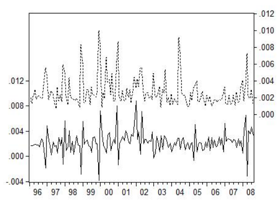
(h) CP08



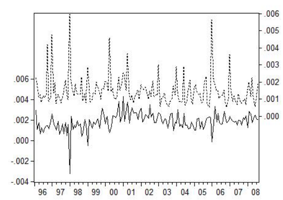
(i) CP09



(j) CP10



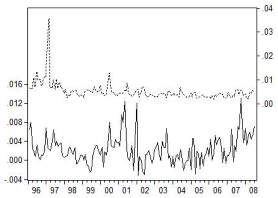
(k) CP11



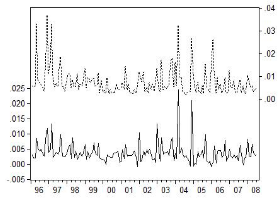
(l) CP12

Notes: Monthly HICP product specific inflation rates (left scale). Monthly product specific RPV (right scale). 1996.02-2008.08.

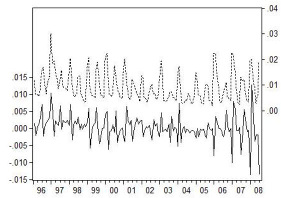
Figure 2.4: Product Specific Inflation and RPV (EU-27)



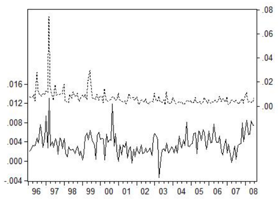
(a) CP01



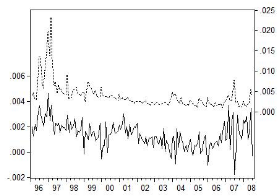
(b) CP02



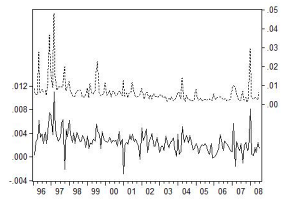
(c) CP03



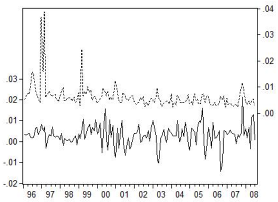
(d) CP04



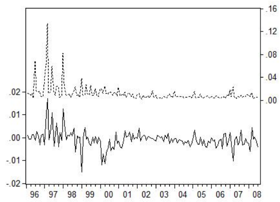
(e) CP05



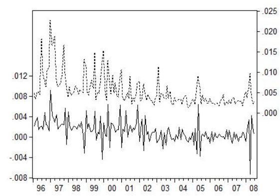
(f) CP06



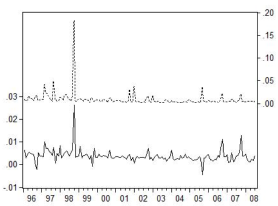
(g) CP07



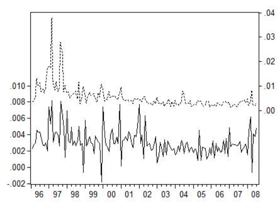
(h) CP08



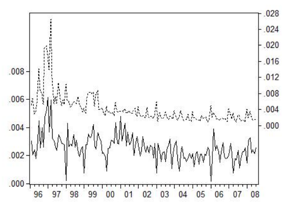
(i) CP09



(j) CP10



(k) CP11



(l) CP12

Notes: Monthly HICP product specific inflation rates (left scale). Monthly product specific RPV (right scale). 1996.02-2008.08.

Table 2.4: Summary Statistics

	Mean	Standard Deviation	Minimum	Maximum	Countries	Product Groups	Obs
Euro-area							
Π_t	0.001723	0.002573	-0.005985	0.009748	12	12	151
RPV_{it}	0.003763	0.004623	0.000460	0.097040	12	12	1812
EU-27							
Π_t	0.002703	0.003162	-0.004868	0.025044	27	12	151
RPV_{it}	0.006790	0.008490	0.000845	0.182809	27	12	1812

Notes: Monthly overall HICP inflation is denoted by Π_t and RPV_{it} measures monthly product specific relative price variability (see Section 2.3 for further explanations). Sample: 1996.02-2008.08.

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

3.1 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-linear 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, Head et al., 2010, 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 empirical concept is based on i) different levels of product aggregation and ii) different estimation strategies. On the one hand, this study uses 12 two-digit and 38 four-digit product subcategories. The results of the latter disaggregation scheme are of particular interest since the categorization into product markets with varying mark-ups or price change frequencies is more accurate for higher product disaggregation. On the other hand, 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 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. Using rates of change furthermore helps in taking care of possible non-stationarity problems in price levels by filtering out long-run trends via first differencing. However, as noted by Danziger (1987) and Beaulieu and Mattey (1999), RPV is more relevant from a theoretical point of view. Danziger (1987) points out that the RIV methodology is not appropriate for evaluating the empirical relevance of classic menu-cost theory and, therefore, empirical results on the inflation-RIV nexus must be interpreted with caution.

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 (PPPs) 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 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.

Especially for the Euro-area, quantitative results could be strongly dependent on the dispersion measure used.[3] Moreover, the deterministic components of the

---

[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.

[3] 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. Hence, the RPV measure should exhibit a clear downward trend while RIV remains high.

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.

The estimation results strongly suggest that the relationship between inflation and price dispersion depends on market characteristics. 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 recent monetary search models (Head and Kumar, 2005). No evidence, however, is found 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 recent Calvo-type models (Choi, 2010).

The paper is organized as follows. Section 3.2 reviews recent theoretical and empirical contributions on the relationship between inflation and price dispersion. Section 3.3 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 3.4 introduces the empirical model and presents results on the European inflation-price dispersion relationship using different levels of product aggregation as well as different estimation strategies. Concluding remarks are offered in Section 3.5.

3.2 The Non-Linear Inflation-RPV Nexus

3.2.1 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 monotonous inflation-RPV relationship in which inflation always lowers welfare. In contrast, recent monetary search and Calvo-type models predict the relationship to be non-linearly U-shaped, with an optimal rate of inflation above zero. Interestingly, monetary search theory suggests a critical dependence of the real effects of inflation on sellers' market power, whereas in Calvo-type models the degree of price stickiness significantly affects the inflation-price dispersion nexus.

Monetary Search Theory and the Role of Market Power

Monetary search models emphasize that buyers have incomplete information about prices offered by different sellers. In these models, the overall effect of inflation on RPV is not always obvious. According to Head and Kumar (2005) and Head et al. (2010), higher inflation, on the one hand, lowers the value of fiat money, which increases sellers' market power and, thereby, the dispersion of prices. On the other hand, an increase in price dispersion also increases the benefits of searching, 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. Becker and Nautz (2010) point out that the inflation-RPV relationship suggested by the Head and Kumar model is heavily dependent on the level of search costs, i.e. the level of sellers' market power. U-shaped effects of inflation are present provided that overall sellers' market power is sufficiently high. However, with increasing competition, i.e. lower price mark-ups, the U-shape of the inflation-RPV relationship becomes progressively flatter and the impact of inflation on price dispersion declines. In case of very low mark-ups, inflation has no effect on price dispersion and the classic dichotomy holds.

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

Consider a Calvo model of sticky prices within a setting of sectoral heterogeneity. In particular, assume 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 simulation results presented by Choi (2010), the relationship between inflation and price variability in such a Calvo-pricing model is non-linear. The nature of the inflation-RPV nexus, however, critically hinges on the degree of price rigidity. For sectors in which the average degree of price rigidity is high, the relationship is again U-shaped with a vertex occurring at positive levels of inflation, 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.

3.2.2 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.[4] 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 non-linear. In particular, several studies find that the effect of inflation on price dispersion varies between high and low inflation periods and between countries with different inflationary contexts (Caglayan and Filiztekin, 2003, Caraballo, Dabús, and Usabiaga, 2006, and Becker and Nautz, 2009). 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 Nautz and Scharff (2010) and Becker and Nautz (2010) 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 mark-ups are high, the relationship between inflation and price dispersion is non-linearly U-shaped, whereas for the highly integrated Euro-area, inflation has no effect on price dispersion. Choi (2010) shows that the relationship between inflation and RIV in the Unites States is not stable, but varies significantly over time in a way coinciding with regime changes in inflation or monetary policy. The relationship is nearly positive during the period of high inflation in the 1970s and the early 1980s, whereas it becomes U-shaped after the great moderation period.

[4] 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.

3.3 Data

3.3.1 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.[5] Following the United Nations "Classification of Individual Consumption According to Purpose" (COICOP) scheme, the 12 major two-digit COICOP subcategories, as well as 38 four-digit COICOP subcategories, are considered (see Table 3.5 in the Appendix). PLIs make it possible to compare prices in relation to the Euro-area average ($PLI_{EU} = 100$). 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 (see Appendix A1 for details).[6]

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:

$$RPV_{it} = \left[\left(\sum_{j=1}^{N} w_{jt}(R_{ijt} - R_{it}) \right)^2 \right]^{0.5}, \qquad (3.1)$$

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

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

[6] 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).

literature usually employs price index data and proxies relative price variability (RPV) via relative inflation variability (RIV).[7] 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 12 major two-digit COICOP subcategories, as well as 38 four-digit COICOP subcategories, for 12 Euro-area countries over the period 01/1996 to 12/2008. In line with the 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.

3.3.2 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 3.2). 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

[7] *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 ($\pi_{it} = \sum_{j=1}^{N} w_{jt}\pi_{ijt}$).

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 3.5 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 frequencies provided by the studies discussed above.[8] Note that heterogeneity of price mark-ups and price stickiness is not only important *across* the two-digit product categories – there is also a substantial degree of heterogeneity *within* each two-digit subcategory. For example, the two-digit product group "Food and non-alcoholic beverages" consists of products with very different degrees of price rigidity: on average, 77% of consumer prices for "Vegetables" are changed in a given month, whereas only 10% of prices in the category "Sugar, jam, honey, chocolate and confectionery" change.

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 3.1. 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

[8] 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 appear as often as products with low price change frequency and low mark-ups.

Table 3.1: Mark-Ups and Price-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 3.5 in the Appendix.

3.3.3 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 in 1992 and the start of Economic and Monetary Union (EMU) in 1999. The first removed the remaining 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 16) 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 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 the majority of 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).[9] Below, the de-trended series are used to analyze the relationship between inflation and RPV.

3.4 The Inflation-RPV Nexus in Europe

3.4.1 The Empirical Model

Consider the panel autoregressive distributed lag (PARDL) model:

$$RPV_{it} = \omega_i + \sum_{k=1}^{p} \rho_{ik} \cdot RPV_{i,t-k} + \sum_{k=0}^{q} \phi_{ik1} \cdot \pi_{i,t-k} + \sum_{k=0}^{r} \phi_{ik2} \cdot \pi^2_{i,t-k} + \epsilon_{it}, \quad (3.2)$$

where the measures of price dispersion (RPV) and inflation (π) correspond to the definitions in Section 3.3 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 framework presented here is to model such dependencies by a factor error structure. Under this assumption, the errors of Equation (3.2) 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.

[9] 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.

The error-correction representation of Equation (3.2), separating short- and long-run dynamics, is given by:

$$\Delta RPV_{it} = \omega_i + \alpha_i \cdot [RPV_{i,t-1} - \theta_{i1} \cdot \pi_{i,t-1} - \theta_{i2} \cdot \pi^2_{i,t-1}] + \boldsymbol{\psi}_i^{'} \cdot \boldsymbol{h}_{it} + \epsilon_{it}, \quad (3.3)$$

where

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

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

According to Equation (3.3), the long-run relationship between inflation and price dispersion for each product group i is given by:[10]

$$RPV_{it} = \theta_{i1} \cdot \pi_{it} + \theta_{i2} \cdot \pi^2_{it} + \eta_{it}, \quad (3.4)$$

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 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 $\theta_{i1} > 0$.[11] 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 monetary search models, the inflation-RPV nexus depends on sellers' market power. U-shaped effects

[10] 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 that there exists a long-run relationship between inflation and RPV. Note that with the model given by Equation (3.3), the distinction between short- and long-run dynamics is purely data-driven.

[11] The minimum point of the quadratic function in Equation (3.4) 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 $\theta_{i2} > 0$.

should be found for product sectors characterized by high mark-ups, but the relationship should break down in a very competitive sector. In contrast, Calvo-pricing models with sectoral heterogeneity predict 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. To discover whether this is indeed the case, the empirical analysis presented below explicitly accounts for sectoral heterogeneity. Note that empirical researchers usually hypothesize that the effect of inflation on price dispersion is constant across different product groups and pool the coefficients on inflation, i.e. $\theta_{i1} = \theta_1$ and $\theta_{i2} = \theta_2$, see e.g. Parsley (1996), and Caglayan et al. (2008).

3.4.2 The Two-Digit Analysis

So as to include and cover as much as possible of the "consumption basket," empirical work on the inflation-price dispersion nexus often employs the broad two-digit aggregation scheme, see e.g. Grier and Perry (1996), Debelle and Lamont (1997), and Bick and Nautz (2008). In line with these studies, this Section presents evidence on the relationship between inflation and price dispersion in Europe using the two-digit data set. Given the marked degree of sectoral heterogeneity (see Section 3.3.2 and Table 3.5 in the Appendix), the system of equations is estimated without imposing any pooling restrictions across the two-digit product groups.

The estimation results are reported in Table 3.2.[12] The speed of adjustment coefficients, $\widehat{\alpha}_i$, indicating the degree of persistence in price dispersion, are highly significant for almost all product groups. In most cases, the estimated parameters are smaller than one-half, implying that price dispersion is quite persistent. Considering the long-run impact of inflation on price dispersion, the estimation results are mixed. In some product groups inflation has no impact on price dispersion; in

[12] To save space and to maintain focus on the long-run effects of inflation on price dispersion, I do not present estimates of all coefficients. The complete set of estimation results is available upon request.

Table 3.2: Relative Price Variability and Inflation in Europe (Two-Digit Data)

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

Product Group (i)	$\widehat{\alpha}_i$	$\widehat{\theta}_{i1}$	$\widehat{\theta}_{i2}$
CP 01	-0.134^{**} (0.054)	-0.672^{*} (0.386)	6.294^{**} (3.151)
CP 02	-0.406^{**} (0.165)	-0.366 (0.410)	9.456 (17.83)
CP 03	-0.359^{***} (0.112)	-0.661 (1.374)	-1.953 (8.501)
CP 04	-0.259^{***} (0.063)	-0.274^{**} (0.114)	3.249^{**} (1.431)
CP 05	-0.403^{***} (0.127)	2.971 (5.842)	17.05 (20.48)
CP 06	-0.230^{***} (0.084)	-1.356^{*} (0.779)	-2.761 (2.084)
CP 07	-0.331^{***} (0.126)	-0.466^{**} (0.229)	-2.704^{*} (1.552)
CP 08	-0.576^{***} (0.158)	0.215 (0.284)	25.60 (23.08)
CP 09	-0.398^{***} (0.145)	-0.197 (0.173)	-4.233 (6.435)
CP 10	-0.294 (0.254)	-0.532^{**} (0.255)	3.977^{***} (0.945)
CP 11	-0.361^{***} (0.110)	-0.482^{**} (0.209)	8.535^{**} (4.064)
CP 12	-0.370^{***} (0.122)	0.204 (0.681)	8.024 (0.084)

Tests of parameter equality

$H_0 : \theta_{11} = \theta_{21} = \ \ldots = \theta_{M1}$	24.57 [0.02]
$H_0 : \theta_{12} = \theta_{22} = \ \ldots = \theta_{M2}$	35.43 [0.00]

Notes: 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.

others, inflation significantly affects RPV. Given significant effects, the impact of inflation on price dispersion is U-shaped (CP01, CP04, CP10, and CP11), negative (CP06), or inverted U-shaped (CP07). The bottom part of Table 3.2 displays Likelihood Ratio test-statistics testing the null of cross-section parameter equality. For the coefficients on inflation-squared and the level of inflation, the pooling restrictions are clearly rejected. In line with theory, it is therefore inappropriate to assume a constant effect of inflation across different product groups.

However, the nature of the data set used in this section limits the scope of theoretical interpretations. Monetary search and Calvo-type models suggest that real effects of inflation are present for markets characterized by a high degree of sellers' market power or sticky prices, respectively. The broad two-digit categorization cannot differentiate between markets with varying mark-ups or price change frequencies. In contrast, almost every two-digit subcategory is comprised of a very heterogenous group of products with high/low mark-ups and sticky/flexible prices (see Table 3.5 in the Appendix). Thus, the next step, presented in Section 3.4.3, is to employ highly disaggregated four-digit price data, for which categorization is feasible.

3.4.3 The Four-Digit Analysis

Pooling of Product Groups

The results presented in the previous subsection are based on estimating cross-sectional specific coefficients for each two-digit product group. Since there is no pooling across cross-sectional units, the efficiency gains achieved by examining a panel data set might be modest. To improve upon this, the analysis in this subsection follows an alternative estimation strategy that is an intermediate approach between estimating each cross-sectional equation separately and classical panel estimators like dynamic Fixed Effects or Random Effects, see Pesaran et al. (1999). In a first step, four-digit products are grouped together according to similar market characteristics. For example, *Panel I* consists of five four-digit product groups for which mark-ups are high and prices are sticky, i.e. the frequency of price changes is low.[13] Given the theoretical predictions, it is now plausible to assume a homogenous long-run 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 (3.3) and maximizing the implied joint conditional log- likelihood function.[14]

The estimation results for the nine different product panels are shown in Table 3.3. Again, 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. A U-shaped relationship between inflation and price dispersion is predominantly found for panels with high/moderate mark-ups or low/moderate price change frequencies, whereas the non-linear profile disappears for markets exhibiting low mark-ups or highly flexible prices. In these markets, the effect of inflation either disappears completely (Panels VII and IX) or becomes linear (Panels III, VI, and VIII). 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).

However, the results of the Likelihood Ratio test-statistics indicate that the long-run homogeneity restriction of the pooled mean group 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

[13] 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%.

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

Table 3.3: Relative Price Variability and Inflation in Europe (Four-Digit Data)

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

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 ($\sum_{j=1}^{9} M_j = 38$). See Section 3.4.3 and Table 3.2 for further explanations.

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.

Parameter Conditioning

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:

$$\begin{aligned} \Delta RPV_{it} &= \omega_i + \alpha_i \cdot [RPV_{i,t-1} - \theta_1(\mu_i, \lambda_i) \cdot \pi_{i,t-1} - \theta_2(\mu_i, \lambda_i) \cdot \pi_{i,t-1}^2] \\ &\quad + \boldsymbol{\psi}_i' \cdot \boldsymbol{h}_{it} + \epsilon_{it}. \end{aligned} \tag{3.5}$$

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.[15] Under this set-up, an immediate approach to estimating Equation (3.5) would be to construct

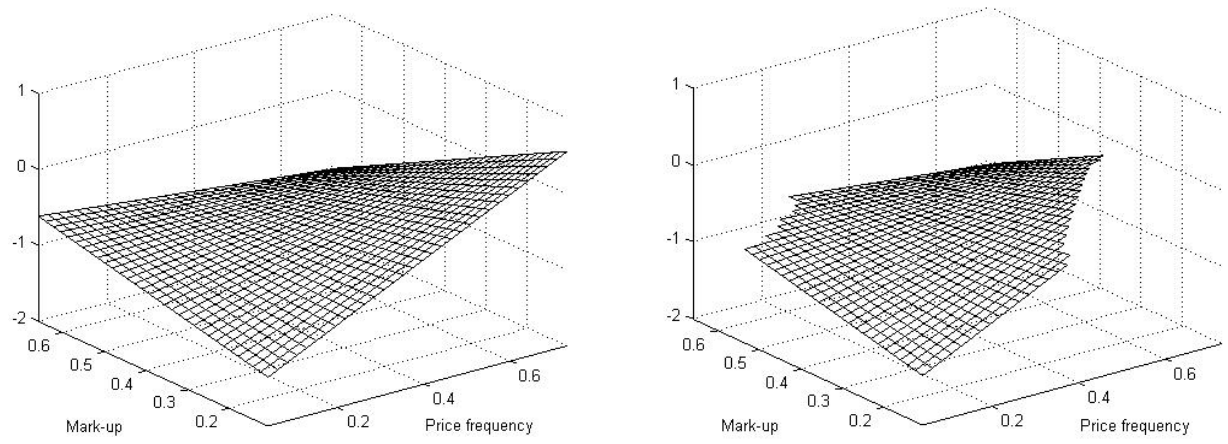
[15] For reasons of parsimony, only maximum Chebyshev polynomial orders of order two are considered. Indeed, information criteria detect the optimal polynomial order to be of order one.

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 procedure 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.

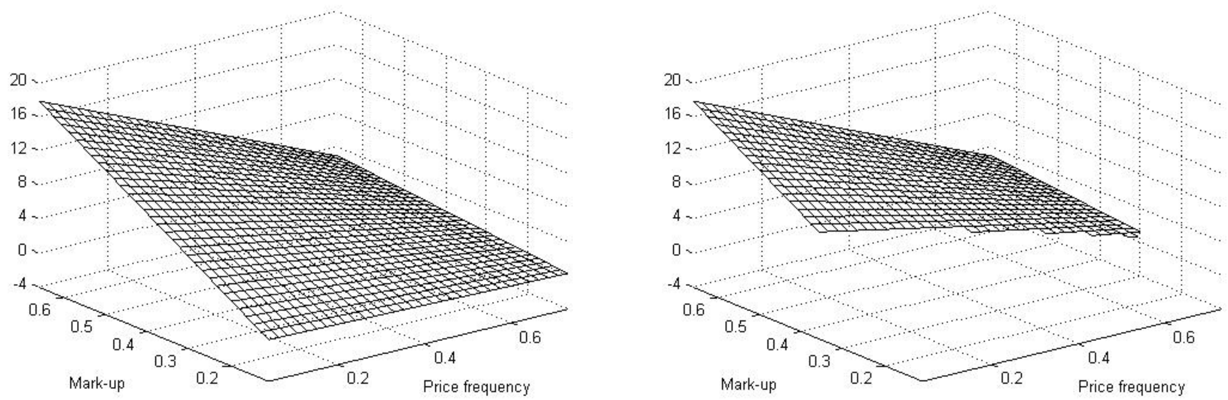
The two upper panels of Figure 3.1 show the estimated functional $\widehat{\theta}_1(\mu_i, \lambda_i)$, while $\widehat{\theta}_2(\mu_i, \lambda_i)$ is displayed in the two bottom panels. Compared to the left-hand panels in which the estimated functionals are plotted for the complete panel domain, all 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 3.1: 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 (3.5). 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 monetary search models 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 Calvo-type models with sectoral heterogeneity is limited: a U-shaped inflation-RPV profile is found for sectors with sticky prices and for sectors with highly flexible prices.

3.5 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 Head et al., 2010) 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 depends on market characteristics. In line with the predictions of monetary search models, 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

Calvo-type models 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 groups, 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.

3.6 Appendix

3.6.1 A1 Derivation of Monthly Price Level Index Data

The PLI data are based on PPP series that are constructed by comparing price level data of similar goods and services for country j (P_j^a) with its counterpart for the Euro-area economy (P_{EU}^a). Accordingly, a bilateral PPP exchange rate represents the hypothetical exchange rate that would be necessary to equalize price levels between two economies. 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 ($NX_{j/EU}^a$). Annual PLI for country j is defined as:

$$PLI_{j/EU}^a = \frac{PPP_{j/EU}^a}{NX_{j/EU}^a} * 100 = \frac{\frac{P_j^a}{P_{EU}^a}}{NX_{j/EU}^a} * 100 \tag{3.6}$$

The PLI series can be used to test whether PPP holds, in which case the PLI equals 100, i.e. the ratio of the price levels equals the nominal exchange rate. Thus, deviations of a country's PLI from the Euro-area average (which, by definition, equals 100) provide information about the price level of the country relative to the Euro-area. Note that the PLI for the Euro-area group is a weighted average of the Euro-area countries PLIs, $PLI_{EU}^a \equiv \sum_{j=1}^{N} w_j PLI_{j/EU}^a$.[16]

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 the Eurostat's extrapolation procedure.

[16] The weights are expenditures from national accounts. For example, at the level of GDP, total GDP is used as a weight, while at the level of the category "food," total food expenditure is used.

Annual PPP for country j can be written as:

$$PPP^a_{j/EU} = \frac{P^a_j}{P^a_{EU}} = \frac{\frac{1}{12}\left[P^{Jan}_j + P^{Feb}_j + P^{Mar}_j + ... + P^{Dec}_j\right]}{\frac{1}{12}\left[P^{Jan}_{EU} + P^{Feb}_{EU} + P^{Mar}_{EU} + ... + P^{Dec}_{EU}\right]} \tag{3.7}$$

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

$$\begin{aligned} PPP^a_{j/EU} &= \frac{P^{Jan}_j + P^{Jan}_j(1+\Pi^{Jan}_j) + ... + P^{Jan}_j(1+\Pi^{Jan}_j)(1+\Pi^{Feb}_j)...(1+\Pi^{Nov}_j)}{P^{Jan}_{EU} + P^{Jan}_{EU}(1+\Pi^{Jan}_{EU}) + ... + P^{Jan}_{EU}(1+\Pi^{Jan}_{EU})(1+\Pi^{Feb}_{EU})...(1+\Pi^{Nov}_{EU})} \\ &= \frac{P^{Jan}_j\left[1 + (1+\Pi^{Jan}_j) + ... + (1+\Pi^{Jan}_j)(1+\Pi^{Feb}_j)...(1+\Pi^{Nov}_j)\right]}{P^{Jan}_{EU}\left[1 + (1+\Pi^{Jan}_{EU}) + ... + (1+\Pi^{Jan}_{EU})(1+\Pi^{Feb}_{EU})...(1+\Pi^{Nov}_{EU})\right]} \\ &= PPP^{Jan}_{j/EU}\underbrace{\frac{1 + (1+\Pi^{Jan}_j + ... + (1+\Pi^{Jan}_j)(1+\Pi^{Feb}_j)...(1+\Pi^{Nov}_j)}{1 + (1+\Pi^{Jan}_{EU}) + ... + (1+\Pi^{Jan}_{EU})(1+\Pi^{Feb}_{EU})...(1+\Pi^{Nov}_{EU})}}_{\Pi} \\ &= PPP^{Jan}_{j/EU} * \Pi \end{aligned}$$

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

$$\begin{aligned} PPP^{Feb}_{j/EU} &= \frac{P^{Feb}_j}{P^{Feb}_{EU}} = \frac{P^{Jan}_j(1+\Pi^{Jan}_j)}{P^{Jan}_{EU}(1+\Pi^{Jan}_{EU})} = PPP^{Jan}_{j/EU}\frac{(1+\Pi^{Jan}_j)}{(1+\Pi^{Jan}_{EU})} \\ PPP^{Mar}_{j/EU} &= \frac{P^{Mar}_j}{P^{Mar}_{EU}} = \frac{P^{Jan}_j(1+\Pi^{Jan}_j)(1+\Pi^{Feb}_j)}{P^{Jan}_{EU}(1+\Pi^{Jan}_{EU})(1+\Pi^{Feb}_{EU})} \\ &= PPP^{Jan}_{j/EU}\frac{(1+\Pi^{Jan}_j)(1+\Pi^{Feb}_j)}{(1+\Pi^{Jan}_{EU})(1+\Pi^{Feb}_{EU})} \\ &. \\ &. \\ PPP^{Dec}_{j/EU} &= \frac{P^{Dec}_j}{P^{Dec}_{EU}} = \frac{P^{Jan}_j(1+\Pi^{Jan}_j)...(1+\Pi^{Nov}_j)}{P^{Jan}_{EU}(1+\Pi^{Jan}_{EU})...(1+\Pi^{Nov}_{EU})} \\ &= PPP^{Jan}_{j/EU}\frac{(1+\Pi^{Jan}_j)...(1+\Pi^{Nov}_j)}{(1+\Pi^{Jan}_{EU})...(1+\Pi^{Nov}_{EU})} \end{aligned}$$

Following Equation (3.6) monthly PLI for country j equals:

$$PLI^m_{j/EU} = \frac{PPP^m_{j/EU}}{NX^m_{j/EU}} * 100, \tag{3.8}$$

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

The last steps now include a rescaling of the monthly PLI data such that $PLI^m_{EU} \equiv \sum_{j=1}^{N} w_j PLI^m_{j/EU} = 100$:

1. calculate $X \quad \rightarrow \quad X = \sum_{j=1}^{N} w_j PLI^m_{j/EU}$
2. rescale $PLI^m_{j/EU} \quad \rightarrow \quad PLI^m_{j/EU-resc} = \frac{PLI^m_{j/EU}}{X}$

Given this enlarged data set, monthly European price dispersion for the 12 two-digit, as well as 38 four-digit subcategories, is computed according to Equation (3.1), see Section 3.3.1.

3.6.2 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:

$$y_t = \alpha_1 + \beta_1 t + \alpha_2 S(\gamma,\tau) + \beta_2 t S(\gamma,\tau) + \epsilon_t, \tag{3.9}$$

where $S(\gamma,\tau) = \{1 + exp\,[-\gamma(t - \tau T)]\}^{-1}$ is the logistic smooth transition function and T is the sample size. The parameter τ determines the timing of the transition midpoint since, for $\gamma > 0$, $S_{-\infty}(\gamma,\tau) = 0$, $S_{+\infty}(\gamma,\tau) = 1$, and $S_{\tau T}(\gamma,\tau) = 0.5$. The speed of adjustment is determined by the parameter γ. If γ is small then $S(\gamma,\tau)$ takes a long period of time to traverse the interval $(0,1)$. On the other hand, for large values of γ, $S(\gamma,\tau)$ traverse the interval very rapidly. Accordingly, under the assumption that ϵ_t is a zero-mean I(0) process, y_t in Equation (3.9) 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 (3.9) 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 (3.9) 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).

Table 3.4 presents the results of estimating a smooth transition model for the 12 two-digit RPV series. The estimated intercepts which are given by the parameters $\widehat{\alpha}_1$ and $\widehat{\alpha}_2$ are significant for almost all product groups. Moreover, $\widehat{\beta}_1$, the coefficient on the trend process is significant in all RPV series except CP10. When significant, the linear trend is positive in three product groups and negative in five. The parameter on the logistic trend component, $\widehat{\beta}_2$, is significantly different

Table 3.4: Smooth Transition in Price Dispersion

Product Group	$\widehat{\alpha}_1$	$\widehat{\beta}_1$	$\widehat{\alpha}_2$	$\widehat{\beta}_2$	$\widehat{\gamma}$	$\widehat{\tau}$	ADF-stat.	Lag
CP 01	0.083 (89.89)	–	0.014 (12.78)	–	4.279 (0.51)	0.301 (58.81)	−3.25	0
CP 02	0.210 (91.67)	0.0017 (23.08)	0.045 (3.40)	−0.002 (−13.24)	0.102 (6.06)	0.452 (29.41)	−6.12***	0
CP 03	0.124 (32.78)	–	−0.058 (−9.67)	–	0.466 (3.16)	0.057 (10.55)	−5.81***	0
CP 04	0.242 (83.57)	−0.0022 (−3.33)	−0.051 (−16.66)	0.002 (2.484)	0.673 (2.43)	0.076 (14.01)	−4.84*	0
CP 05	0.071 (24.82)	0.0003 (4.86)	−0.002 (−0.21)	−0.001 (−3.55)	0.437 (1.92)	0.543 (57.98)	−5.61***	0
CP 06	0.112 (28.23)	−0.0007 (5.91)	−0.078 (−15.30)	0.001 (13.86)	0.708 (2.33)	0.597 (121.1)	−5.35**	0
CP 07	0.085 (44.37)	0.0001 (16.52)	0.047 (7.98)	−0.001 (−16.31)	0.166 (6.57)	0.436 (35.41)	−6.31**	1
CP 08	0.168 (13.53)	0.0101 (5.77)	−0.276 (−9.66)	−0.008 (−3.77)	0.041 (6.48)	0.145 (3.83)	−4.66*	0
CP 09	0.094 (46.31)	−0.0009 (−9.17)	0.012 (3.81)	0.006 (5.80)	0.461 (3.41)	0.274 (54.37)	−6.82***	1
CP 10	0.211 (51.66)	0.0001 (0.33)	0.195 (21.39)	−0.002 (−13.05)	0.294 (3.06)	0.368 (41.85)	−6.38***	1
CP 11	0.147 (47.11)	−0.0013 (−9.98)	0.008 (1.93)	0.001 (3.94)	0.812 (1.82)	0.532 (40.38)	−5.45**	0
CP 12	0.156 (33.38)	−0.0023 (2.38)	−0.031 (−6.49)	0.002 (2.23)	0.200 (4.49)	0.265 (9.81)	−3.54	0

Notes: The coefficient estimates refer to the parameters of the smooth transition model given as $y_t = \alpha_1 + \beta_1 t + \alpha_2 S(\gamma, \tau) + \beta_2 t S(\gamma, \tau) + \epsilon_t$, where $S(\gamma, \tau) = \{1 + exp\,[-\gamma(t - \tau T)]\}^{-1}$. t-statistics in parentheses. The ADF test-statistic stands for the stationary test around a smooth logistic trend. *, **,*** indicate the significance of the ADF statistics at the 10%, 5%, and 1% significance level. Critical values are taken from Leybourne *et al.* (1998). Sample: 1996.02-2008.12.

from zero in all product groups. In addition, the sum $\widehat{\beta}_1 + \widehat{\beta}_2$, which describes the trend component after the transition process, is predominantly negative, indicating some degree of price convergence.[17] Furthermore, for eight RPV series the transition midpoint, given by the parameter $\widehat{\tau}$, is dated around the introduction of the Euro ($\widehat{\tau}_{0.265} \widehat{=}$ transition midpoint in 05/99 and $\widehat{\tau}_{0.543} \widehat{=}$ midpoint in 12/02). In line with Allington et al. (2005) and Foad (2005), these results suggest that the ongoing integration process in Europe and especially the introduction of the Euro cause downward movements in the level of European price dispersion.[18]

Examining the ADF statistics around a smooth transition process shows that only for two RPV series can the null of non-stationarity not be rejected.[19] All other product groups reject the null once the deterministic component describes a non-linear transition: two at the 10% level, three at the 5% level and five at the 1% level. As a consequence, for the majority of product groups the deterministic process of the price dispersion measures can be accurately described by a smooth transition process.[20]

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 3.4, the de-trended series are used to analyze the relationship between inflation and RPV.

[17] For the product groups CP01 and CP03, a smooth transition process on the intercept term only fits the data best. The estimates on the trend component are not significantly different from zero.

[18] The speed of adjustment is measured by the parameter $\widehat{\gamma}$. This estimate is significantly different from zero in nine product groups. In most cases where the parameter on the speed of adjustment is significant it is also small ($\widehat{\gamma} < 0.5$), implying a slow transition process.

[19] The RPV_{CP12} series for which a smooth transition process is not detected does reject the null of non-stationarity under a standard constant deterministic process. For this product group, a fixed mean is an adequate representation of the deterministic component.

[20] Similar results are obtained for the four-digit RPV series. For brevity, these estimation results are not presented but are available on request.

Table 3.5: 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 3.5 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 3.5 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 3.5 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 12 two-digit as well as 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).

Bibliography

Aarstol, Michael. 1999. Inflation, Inflation Uncertainty and Relative Price Variability. *Southern Economic Journal* 66: 414-23.

Allington, Nigel F.B., Paul A. Kattuman, and Florian A. Waldmannc. 2005. One Market, One Money, One Price? *International Journal of Central Banking* 1: 73-115.

Álvarez, Luis J., Emmanuel Dhyne, Marco M. Hoeberichts, Claudia Kwapil, Hervé L. Bihan, Patrick Lunnemann, Fernando Martins, Roberto Sabbatini, Harald Stahl, Philip Vermeulen and Jouko Vilmunen. 2006. Sticky Prices in the Euro Area: A Summary of New Micro Evidence. *Journal of the European Economic Association* 4: 575-84.

Andrews, Donald W.K. 1993. Test for a Parameter Instability and Structural Change with Unknown Change Point. *Econometrica* 61: 821-56.

Andrews, Donald W.K. and Werner Ploberger. 1994. Optimal Tests when a nuisance Parameter is Present Only Under the Alternative. *Econometrica* 62: 1383-1414.

Bacon, David W. and Donald G. Watts. 1971. Estimating the transition between two intersecting straight lines. *Biometrika* 58: 525-34.

Barro, Robert J. 1976. Rational Expectations and the Role of Monetary Policy. *Journal of Monetary Economics* 2: 1-32.

Beaulieu, Joe and Joe Mattey. 1999. The Effects of General Inflation and Idiosyncratic Cost Shocks on Within-Commodity Price Dispersion: Evidence from Microdata. *The Review of Economics and Statistics* 81: 205-16.

Becker, Sascha S. and Dieter Nautz. 2009. Inflation and Relative Price Variability: New Evidence for the United States. *Southern Economic Journal* 76: 146-64.

Becker, Sascha S. and Dieter Nautz. 2010. Inflation, Price Dispersion and Market Integration through the Lens of a Monetary Search Model. Freie Universität Berlin Discussion Paper Series 2010/2.

Benabou, Roland J. 1992. Inflation and Efficiency in Search Markets. *Review of Economic Studies* 59: 299-329.

Bick, Alexander and Dieter Nautz. 2008. Inflation Threshold and Relative Price Variability: Evidence from U.S. Cities. *International Journal of Central Banking* 4: 61-76.

Binder, Michael and Christian Offermanns. 2007. International Investment Positions and Exchange Rate Dynamics: A Dynamic Panel Analysis. Center for Financial Studies Working Paper No. 2007/23.

Binder, Michael, Georgios Georgiadis and Sunil Sharma. 2010. Growth Effects of Financial Globalization. Goethe-University Working Paper.

Burdett, Kenneth and Kenneth L. Judd. Equilibrium Price Dispersion. *Econometrica* 51: 955-969.

Caglayan, Mustafa and Alpay Filiztekin. 2003. Nonlinear Impact of Inflation on Relative Price Variability. *Economics Letters* 79: 213-18.

Caglayan, Mustafa, Alpay Filiztekin and Michael T. Rauh. 2008. Inflation, price dispersion, and market structure. *European Economic Review* 52: 1187-1208.

Caraballo, M. Ángeles, Carlos Dabús and Carlos Usabiaga. 2006. Relative prices and inflation: new evidence from different inflationary contexts. *Applied Economics* 38: 1931-44.

Choi, Chi-Young. 2010. Reconsidering the Relationship between Inflation and Relative Price Variability. *Journal of Money Credit and Banking* 42: 769-98.

Christopoulou, Rebekka and Philip Vermeulen. 2008. Markups in the Euro-area and the US over the period 1981-2004, a comparison of 50 sectors. ECB Working Paper No. 856.

Craig, Ben and Guillaume Rocheteau. 2008. Inflation and Welfare: A Search Approach. *Journal of Money, Credit and Banking* 40: 89-119.

Danziger, Leif. 1987. Inflation, Fixed Cost of Price Adjustment, and Measurement of Relative-Price Variability: Theory and Evidence. *American Economic Review* 77: 704-13.

Debelle, Guy and Owen Lamont. 1997. Relative Price Variability and Inflation: Evidence from US Cities. *Journal of Political Economy* 105: 132-52.

Dhyne, Emmanuel, Luis J. Álvarez, Hervé L. Bihan, Giovanni Veronese, Daniel Dias, Johannes Hoffmann, Nicole Jonker, Patrick Lunnemann, Fabio Rumler and Jouko Vilmunen. 2006. Price Setting in the Euro Area: Some Stylized Facts From Individual Consumer Price Data. *Journal of Economic Perspectives* 20: 171-92.

Dreger, Christian, Konstantin Kholodilin, Kirsten Lommatzsch, Jiri Slacalek, and Przemyslaw Wozniak. 2009. Price Convergence in an Enlarged Internal Market. *Eastern European Economics* 46: 57-68.

Égert, Balázs, Imed Drine, Kirsten Lommatzsch and Christophe Rault. 2003. The Balassa-Samuelson effect in Central and Eastern Europe: myth or reality? *Journal of Comparative Economics* 31: 552-72.

Elliott, Graham and Allan Timmermann. 2008. Economic Forecasting. *Journal of Economic Literature* 46: 3-56.

Engel, Charles and John H. Rogers. 2004. European market integration after the Euro. *Economic Policy* 19: 347-84.

European Central Bank. 2009. Price Stability: Why is it important for you?

European Commision. 1996. The 1996 single market review. Background information for the report to the Council and European Parliament. Commission Staff Working Paper, SEC (96) 2378, (December 16), Brussels, Belgium.

European Commision. 1999. Report on Economic and Structural Reform in the EU. European Economy. Suppl. A, Economic Trends, no. 1, January.

Eurostat-OECD. 2006. Methodological manual on purchasing power parities. Office for Official Publications of the European Communities. Luxembourg.

Fielding, David and Paul Mizen. 2000. Relative Price Variability and Inflation in Europe. *Economica* 67: 57-78.

Fielding, David and Paul Mizen. 2008. Evidence on the Functional Relationship Between Relative Price Variability and Inflation with Implications for Monetary Policy. *Economica* 75: 683-99.

Foad, Hisham. 2005. Europe without borders? The effects of EMU on relative prices. Working Paper Department of Economics, Emory University.

Gali, Jordi, Mark Gertler, and J. David Lopez-Salido. 2001. European Inflation Dynamics. *European Economic Review* 45: 1237-70.

Grier, Kevin B. and Mark J. Perry. 1996. Inflation, Inflation Uncertainty and Relative Price Dispersion: Evidence from bivariate GARCH-M Models. *Journal of Monetary Economics* 38: 391-405.

Hansen, Bruce E. 1997. Approximate Asymptotic P-Values for Structural-Change Tests. *Journal of Business and Economic Statistics* 15: 60-67.

Hansen, Bruce E. 1999. Threshold Effects in Non-Dynamic Panels: Estimation, Testing, and Inference. *Journal of Econometrics* 93: 345-68.

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

Head, Allen, Alok Kumar and Beverly Lapham. 2010. Market Power, Price Adjustment, and Inflation. *International Economic Review* 51: 73-98.

Hercowitz, Zvi. 1981. Money and the Dispersion of Relative Prices. *Journal of Political Economy* 89: 328-56.

Jaramillo, Carlos F. 1999. Inflation and Relative Price Variability: Reinstating Parks' Results. *Journal of Money, Credit, and Banking* 31: 375-85.

Judd, John F. and Bharat Trehan. 1995. Has the fed gotten tougher on inflation. *Federal Reserve Bank of San Francisco Weekly Letter* 95-13.

Kiley, Michael T. 2000. Price Stickiness and Business Cycle Persistence. *Journal of Money, Credit, and Banking* 32: 28-53.

Lach, Saul and Daniel Tsiddon. 1992 The Behavior of Prices and Inflation: An Empirical Analysis of Disaggregated Price Data. *Journal of Political Economy* 100: 349-89.

Lastrapes, William D. 2006. Inflation and the Distribution of Relative Prices: The Role of Productivity and Money Supply Shocks. *Journal of Money, Credit and Banking* 38: 2159-198.

Leybourne, Stephen, Paul Newbold, and Dimitrios Vougas. 1998. Unit Roots and Smooth Transitions. *Journal or Time Series Analysis* 19: 83-97.

Lucas, Robert E., Jr. 1973. Some international Evidence on Output-Inflation Tradeoffs. *American Economic Review* 63: 326-35.

Lucas, Robert. 2000. Inflation and Welfare. *Econometrica* 68:247-74.

Mankiw, Gregory N. 2001. U.S. Monetary Policy During the 1990s. *Harvard Institute of Economic Research Paper* 1927.

Nakamura, Emi and Jón Steinsson. 2008. Five Facts About Prices: A Reevaluation of Menu Cost Models. *The Quarterly Journal of Economics* 123: 1415-64.

Nautz, Dieter and Juliane Scharff. 2005. Inflation and Relative Price Variability in a low Inflation Country: Empirical Evidence from Germany. *German Economic Review* 6: 507-23.

Nautz, Dieter and Juliane Scharff. 2010. Inflation and Relative Price Variability in the Euro Area: Evidence from a Panel Threshold Model. *Applied Economics*, forthcoming.

Pagan, Adrian. 1984. Econometric Issues in the Analysis of Regressions with Generated Regressors. *International Economic Review* 25: 221-47.

Parks, Richard W. 1978. Inflation and Relative Price Variability. *Journal of Political Economy* 86: 79-95.

Parsley, David C. 1996. Inflation and Relative Price Variability in the Short and Long Run: New Evidence from the United States. *Journal of Money, Credit and Banking* 28: 323-41.

Parsley, David and Shang-Jin Wei. 2008. In search of a euro effect: Big lessons from a Big Mac Meal? *Journal of International Money and Finance* 27: 260-76.

Pesaran, Hashem M., Yonqcheol Shin and Ronald P. Smith. 1999. Pooled Estimation of Long-Run Relationships in Dynamic Heterogeneous Panels. *Journal of the American Statistical Association* 94: 621-34.

Pesaran, Hashem M. 2006. Estimation and Inference in Large Heterogeneous Panels With a Multifactor Error Structure. *Econometrica* 74: 967-1012.

Peterson, Brian and Shouyong Shi. 2004. Money, price dispersion and welfare. *Economic Theory* 24: 907-32.

Reinsdorf, Marshall. 1994. New Evidence on the Relation Between Inflation and Price Dispersion. *American Economic Review* 84: 720-31.

Roeger, Werner. 1995. Can Imperfect Competition Explain the Difference Between Primal and Dual Productivity Measures? Estimates for US Manufacturing. *Journal of Political Economy* 103: 316-30.

Rogers, John H. 2007. Monetary union, price level convergence, and inflation: How close is Europe to the USA? *Journal of Monetary Economics* 54: 785-96.

Rotemberg, Julio. 1983. Aggregate Consequences of Fixed Costs of Price Adjustment. *American Economic Review* 73: 433-63.

Sheshinski, Eytan and Yoram Weiss. 1977. Inflation and Costs of Price Adjustment. *Review of Economic Studies* 44: 287-303.

Silver, Mick and Christos Ioannidis. 2001. Intercountry Differences in the Relationship between Relative Price Variability and Average Prices. *Journal of Political Economy* 109: 355-74.

Wolszczak-Derlacz, Joanna. 2008. Price Convergence in the EU-an aggregate and disaggregate approach. *International Economics and Economic Policy* 5: 25-47.

Woodford, Michael. 2003. *Interest and Prices: Foundations of a Theory of Monetary Policy.* Princeton University Press, Princeton, New Jersey.

Curriculum Vitae

Der Lebenslauf ist in der Online-Version aus Gründen des Datenschutzes nicht enthalten.

Ehrenwörtliche Erklärung

Ich habe die vorgelegte Dissertation selbst verfasst und dabei nur die von mir angegebenen Quellen und Hilfsmittel benutzt. Alle Textstellen, die wörtlich oder sinngemäß aus veröffentlichten oder nicht veröffentlichten Schriften entnommen sind sowie alle Angaben, die auf mündlichen Auskünften beruhen, sind als solche kenntlich gemacht.

Berlin, den 30. August 2010