ESSAYS ON INFLATION DYNAMICS

Maarten Dossche

December 2008

Dissertation Submitted at Ghent University, to the Faculty of
Economics and Business Administration, in Fulfilment of
the Requirements for the Degree of Doctor in Economics

Advisor: prof. Dr. F. Heylen
Co-Advisor: prof. Dr. G. Everaert

Doctoral Jury

Prof. dr. Marc De Clercq
Prof. dr. Patrick Van Kenhove
Prof. dr. Freddy Heylen
Prof. dr. Gerdie Everaert
Prof. dr. Nils Gottfries
Prof. dr. Jurek Konieczny
Prof. dr. Frank Smets
Prof. dr. Raf Wouters

Acknowledgments

December 2, 2008

"What an exciting subject is economics and what an impossible combination of qualities does it not demand for its practice: Scientific observation of the facts of commercial life; commonsensical inference, from personal introspection, daily experience and psychological enquiry, about the way in which human beings are likely to react to different stimuli; a sense of the continuity and of the messages of history; logical and mathematical analysis of the implications of a complicated set of interactions; and an admixture of moral and political philosophy."

James Meade, Speech at the Nobel Banquet, December 10, 1977

To be able to study a subject as exciting as economics, one indeed needs an almost impossible combination of qualities. What James Meade forgot to tell is that you need the help of so many people at acquiring these qualities. Here is the right place to thank them.

First, I thank the members of the doctoral jury - professors De Clercq, Van Kenhove, Gottfries, Konieczny, Smets and Wouters - for the comments that substantially improved this thesis. In addition I thank my coauthors, Gerdie, Dirk and David, the colleagues at Ghent University, Universitat Pompeu Fabra, and the National Bank of Belgium (NBB) for their help.

Second, I thank my family and friends for their interest and support. My parents here deserve special mention. Even though they were (and are) sometimes sceptical of my sisters' and my endeavours, they have always given us the freedom to pursue our ambitions.

Third, there are three people that have contributed extraordinarily to the completion of this project. Without the help of each single one of them I would not have finished it. They supported me by challenging my ideas, but at the same time unconditionally trusting me. Freddy already started challenging me at the time I was an undergraduate at Ghent University. His unconditional support made it possible not only to start this project at Ghent University, but also to spend a year at Universitat Pompeu Fabra. Luc started challenging me when I began to work at the NBB, so much that I felt that without an extra effort I would all too often fall short in meeting his quality standards. I also thank him for his continuous search for synergy between the work in the NBB and the work for the thesis. Last but not least, I thank Vivien for her straight criticism of my work since we first met at the London School of Economics - she has no mercy -, as well as for sharing the difficult and euphoric moments. That you also wrote a PhD thesis made it so much easier for me.

Maarten Dossche, December 2, 2008

General Introduction

December 2, 2008

"Inflation is always and everywhere a monetary phenomenon." Milton Friedman

Why should we be interested in understanding inflation, or the change in the general level of prices of goods and services? There are basically two reasons. First, in the presence of price adjustment costs inflation entails wasteful expenses for firms and generates changes in the distribution of relative good prices that do not reflect changes in productivity. Second, inflation affects the real value of nominal assets, including money. In a market economy the distribution of relative prices and the real value of assets affect the allocation of the society's resources into consumption, leisure and investment. Through its effect on real good and asset prices inflation ultimately determines economic welfare. Public policy that aims at maximizing economic welfare thus needs to understand what drives inflation and how it affects the allocation of resources.

In this chapter I introduce the reader to the literature to which this thesis has contributed. As I go along I also refer to the subsequent chapters to give the reader an idea of how they are related to this broad literature. I first give an overview of the costs and benefits that are associated with inflation. Then I give a short overview of the features of the New Keynesian model that allows us to assess the size of the respective costs and benefits of inflation. Subsequently, I present the features of the inflation and price adjustment data that the model should try to match. Finally, I give a brief overview of the relevant literature on optimal policy.

Costs and Benefits of Inflation

Inflation and Costly Price Adjustment Unless price adjustment is costless, the average level of inflation will determine the frequency and thus the costs of resetting nominal prices.[1] The literature often refers to this type of cost as a menu costs referring to the printing costs restaurants incur when they change prices. Menu costs do not just comprise the costs of physically resetting prices, but also of reoptimizing the price. There are many decisions to be taken before a price can be reset.

Firms will not reset their price in response to every change in costs and demand. There will be a range in between which they will tolerate deviations of their actual price from its optimal level. This generates a change in the distribution of relative prices that does not reflect changes in productivity. These changes will thus entail efficiency and welfare losses. This cost is often referred to as a relative price distortion. See Lach and Tsiddon (1992), Hercowitz (1981) and Danziger (1987) for empirical evidence on the relation between inflation and the distribution of relative prices.

There can also be benefits of higher inflation. In a world where nominal wages cannot adjust downwardly, higher inflation will decrease the real value of nominal wages. If due to certain shocks optimal real wages need to decrease, then small or zero changes in nominal wages still entail real wage decreases that are optimal. This effect is due to Tobin (1972) who stressed that in this context inflation can "grease the wheels of the economy". The importance of this effect has recently been

---

[1] It seems hard to imagine that price adjustment is completely costless. Different goods will of course entail different costs of price adjustment. The costs will for instance depend on what type of market the good is sold. Is the good sold in an auction, then the costs of price adjustment might be lower than if the good is sold in a shop. However, the mere fact that the prices of some goods continuously adjust does not necessarily imply that the cost of price adjustment is zero. The shocks to the optimal price of this good can be so large that the benefits of adjusting the good's price outweigh the costs of price adjustment.

studied in Fahr and Smets (2008) and Fagan and Messina (2008).

Inflation and the Value of Nominal Assets Inflation affects the real value of nominal assets. This includes the real value of outstanding money balances. In this regard we need to realize that money is a special type of asset that on top of its function as a store of value, also has a transactions function. When inflation affects the real value of outstanding money balances, this affects the number of goods that can be purchased in an economy. Cooley and Hansen (1989) use a model with perfect competition and costless price adjustment. They do not find significant effects of inflation on output. Blanchard and Kiyotaki (1987), however, assume imperfect competition and find that in combination with sticky prices there are significant effects of changes in the money supply on output. This illustrates how the characteristics of inflation and price adjustment determine the welfare effects of monetary policy.

Another cost of inflation comes from the combined role of store of value and transaction technology of money. As holding money is not remunerated, the effective nominal interest rate is zero. As long as inflation is positive, this creates an opportunity cost of holding money balances. On the other hand, money makes transactions easier. Therefore, inflation determines the number of times someone goes to the bank in order to withdraw money and in such a way tries to save on money balances. With higher average inflation and nominal interest rates people will cut back money holdings as the opportunity cost increases, whereas the transaction benefits stay the same. This generates more trips to the bank, which explains the origin of the term shoe leather costs. In the literature this term covers all sorts of costs that are related to more cash management.

Another channel through which inflation can affect the aggregate economy is through its role in generating real wealth redistributions across different agents, and more in particular debtors and creditors. From an aggregate perspective it is not clear whether this is a cost or a benefit. It will depend on whether there is a wealth transfer from people that are unproductive to people that are productive and invest. Doepke and Schneider (2006) and Meh et al. (2008) are two recent contributions on the redistributional effects of inflation across different economic agents.

In a model with a role for the government and nominal government debt, surprises in inflation can also create a way to levy nondistortionary taxes. Because the government debt is nominal the rate of inflation will determine the real debt burden the government needs to finance. In the case of an inflation surprise the real government debt will decrease significantly without distorting economic activity as taxes on labor and capital do. In effect inflation can be a non-distortionary lump sum tax.

However, higher inflation variability will also increase risk premiums on nominal assets. See for instance De Graeve et al. (2008) for how higher inflation variability increases the inflation risk premium that investors demand from nominal assets. A related issue is that for long-term nominal debt contracts inflation will seriously affect the profile of real debt repayments. This can distort the allocation of investment in housing in a life-cycle model. Another issue is that to hedge themselves against the risk of inflation people will invest more in real assets contrary to nominal assets that entail more risk.

In the case of negative inflation, or deflation, the real value of money increases. So holding money then gives a positive real return. This can become problematic if the real interest rate should be lower than the rate of deflation. In that case the nominal interest rate hits the zero lower bound, so that the central bank loses control over the interest rate. For a recent example see the experience in Japan during the nineties as described by Krugman (1998).

Up to now we have only listed the different types of the costs and benefits of inflation. We have not been able to quantitatively assess the costs and benefits, so that we remain unsure about net welfare effects of inflation. This can be done in versions of the so-called New Keynesian model. The main virtue of this model is that it links the microeconomic price setting decisions of an infinite number of economic agents to the behavior of inflation and other macroeconomic variables. In this way it makes it possible to consider all the aspects of inflation and price adjustment in one coherent framework.

The New Keynesian Model

Today most of the questions raised in the previous section are studied in the so-called New Keynesian model. This model has been developed on the basis of a real business cycle model, adding monopolistic competition, infrequent price adjustment, and a role for monetary policy. The model is the result of a number of failures in the past that have continuously been fixed by using new frictions or techniques. An excellent overview of this model can be found in Woodford (2003) and Gali (2008).

This model is basically a real business cycle model with two additional frictions. This allows economists to profit from the virtues of the real business cycle model and the methodology to address economic questions. The most important virtues are the explicit use of optimization of agents and rational expectations. This is much more appealing than the ad hoc behavioral relations that were posited in the older Keynesian literature. The first additional ingredient that is present in the New Keynesian model is monopolistic price setting. Prices are not determined in perfectly competitive markets so that the price equals the marginal cost of producing an additional unit. Instead, there will be a distortion in output due to the monopoly power of an infinite number of differentiated goods producers. Often these are incorporated in the model using constant elasticity of substitution consumer preferences as in Dixit and Stiglitz (1977). A second ingredient are nominal price rigidities that are often modeled as costs to nominal price adjustment. This gives rise to nominal prices that are not adjusted continuously, which creates a constraint for the firm when it resets its price. The combination of imperfect competition and nominal rigidities generates the short run nonneutrality of monetary policy. Money has not necessarily an explicit role in versions of this model; it is just a unit of account. But still inflation is a purely monetary phenomenon, as suggested by Friedman and Schwartz (1963). It is ultimately the central bank that determines the price level and thus the inflation rate. Up to today people debate about the fact whether they should include an explicit role for money in the model or not, through e.g. introducing a cash in advance constraint.

The New Keynesian model can be used to evaluate different policies, but before we can do that we first need to remove a number of remaining uncertainties about the right extent to which different frictions are important or not. The success or failure of this framework needs to be evaluated against a number of properties of both the macroeconomic and microeconomic data. Often the model is only evaluated against macroeconomic data. This creates a number of observational equivalences between different microeconomic models of price adjustment. Because the welfare effects are crucially depending on the type of price adjustment the researcher assumes we also need to evaluate the microeconomic implications of the model. Therefore, since the last five years people have increasingly studied the characteristics of microeconomic price adjustment using large micro price datasets. The next two sections, respectively, give an overview of the macroeconomic and microeconomic statistical properties of the data and discuss what models might be consistent with these statistical properties.

Post-WWII Inflation Dynamics

Evidence on Inflation Persistence The persistence of inflation is not easy to model, and it intrigues policy makers because it is an important determinant of how strong their reaction should be to changes in the inflation rate. A common practice is to estimate a univariate autoregressive time series model and measure persistence as the sum of the autoregressive coefficients (e.g. Fuhrer and Moore, 1995; Pivetta and Reis, 2007). In most of these studies, inflation is found to exhibit high to very high persistence during the post-WW II period, i.e. persistence is found to be close to that of a random walk. We can design models that generate high inflation persistence using a variety of frictions: backward-looking agents (Galí and Gertler, 1999), price indexation (Christiano et al., 2005), consumption habit persistence (Christiano et al, 2005), learning (Milani, 2007), real wage rigidities (Blanchard and Galí, 2007). For a particular calibration these frictions will all be able to replicate the univariate reduced form inflation persistence. But it is important to note that this estimated high persistence is a measure of unconditional inflation persistence. The different frictions that can match the observed inflation persistence will affect the persistence of inflation differently. Some frictions will make inflation directly or intrinsically more persistent, whereas other frictions will make inflation persistent through making its drivers persistent. The drivers of inflation can be read off from the Phillips curve relation that generally emerges in New Keynesian models, and that links current inflation to expectations about future inflation and a measure of the output gap. Frictions that make inflation intrinsically more persistent typically augment the standard Phillips curve relation with lags of inflation.

In the first chapter (Dossche and Everaert, 2008), inflation persistence is conditional on the type of shock moving inflation. We distinguish three sources of cyclical inflation persistence. First, due to price indexation or backward-looking agents inflation can directly be related to its own lags. We call this kind of persistence *intrinsic* inflation persistence. Second, due to asymmetric information or imperfect credibility, private agents' perceptions about the central bank's inflation target can differ from the true inflation target. We call the persistence of such deviations *expectations-based* persistence. Third, inflation persistence is determined by the persistent movements in the output gap. We call this type of persistence *extrinsic* inflation persistence. Both expectations-based and extrinsic persistence can also be labeled inherited inflation persistence, because inflation inherits its persistence from the persistent movements in its driving variables. Each of these three types of inflation persistence represent persistence at the business cycle frequency. On top of this, changes in the long-run inflation rate will add a fourth source of inflation persistence that is not related to the business cycle. For designing business cycle models we are only interested in inflation persistence excluding the effect of changes in the long-run inflation rate. We use an unobserved component model to filter out these four different sorts of inflation persistence. The results show that intrinsic inflation persistence is fairly low, i.e. the half-life of a cost-push shock is less than one quarter. We conclude that a significant part of the observed univariate inflation persistence is inherited and that price-setting frictions such as indexation to past inflation or backward-looking expectations are not the best way to match the empirical evidence.

This is in line with evidence that the high persistence of inflation during the seventies was linked to the type of monetary policy regime in place (e.g. Benati, 2008). The dynamics of inflation went through substantial changes during the last five decades. In Table 1 and Figure 1 I distinguish three periods of different inflation dynamics: the Golden Sixties (1955-1964), the Great Inflation:

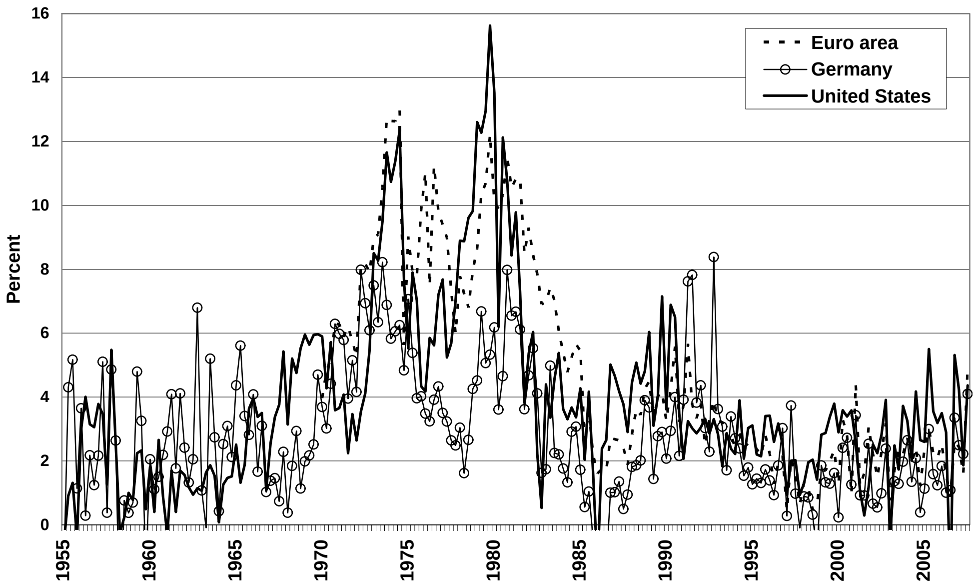
1965-1984, and the Great Moderation: 1985-2007. The first period was characterized by relatively low inflation with little persistence both in the United States and Germany. The second period is characterized by high, volatile and persistent inflation for both the euro area and the United States. Notice, however, that in Germany this rise in average inflation and persistence was much more muted than in the euro area and the United States. The volatility of inflation in Germany even decreased during that period. In the third period inflation is again low and exhibits low persistence. That is the reason why in the first chapter we account for changes in the inflation target of the central bank. These changes in the inflation target can come through genuine mistakes (Gali and Gertler, 1999), misperceptions of the natural rates (Orphanides, 2002), or just not knowing the natural rate principle that inflation cannot permanently increase economic activity (Sargent et al., 2006). To paraphrase Friedman, high inflation persistence seems to be always and everywhere a monetary phenomenon.

Table 1: Statistical Properties of Inflation

	United States	Euro area	Germany
		1955-1964	
Std.	1.32	-	2.09
Mean	1.56	-	2.15
Autocorr.	0.30	-	-0.12
		1965-1984*	
Std.	3.31	2.30	1.94
Mean	6.09	8.38	4.07
Autocorr.	0.82	0.74	0.71
		1985-2007	
Std.	1.51	1.16	1.66
Mean	3.00	2.59	1.94
Autocorr.	0.29	0.51	0.52

Note: the statistics are computed using the annualized quarterly log-differenced seasonally adjusted CPI. The source is OECD, except for the sample 1970-1998 for the euro area, which comes from the AWM dataset of the ECB. * The sample for the euro area only covers 1970-2007.

Figure 1: Inflation across Countries



Note: The graph shows annualized log-differences of quarterly seasonally adjusted CPI. See Table 1 for the data sources.

Evidence from VARs Christiano et al. (1999) survey the literature on evidence on the transmission of monetary policy through estimating the effect of a monetary policy shock on a large set of macroeconomic variables. They find that as the nominal interest rate increases, inflation, consumption, investment and output persistently fall. This literature delivers empirical evidence that structural models should try to match as well as possible. This is done by comparing the impulse response functions of the data with the impulse response functions implied by the model. Peersman and Smets (2003) use the same methodology for euro area data and find very similar results as for the United States. As this thesis does not do any work in this field I refer the reader for more background on this topic to Christiano et al. (1999).

The Role of Price Setting and Some Evidence

Two assumptions are key in the New Keynesian model. First, there is monopolistic competition in the goods market. This implies that firms are price setters, and not price takers as would be the case if markets were perfectly competitive. The second assumption is costly price adjustment. This assumption always goes together with monopolistic competition as then the price setter can make a trade-off between adjusting its price or not. Here we give an overview of the different ways costly price adjustment is introduced in the model, and what are the micro and macro implications. We also give an overview of the empirical evidence.

Theoretical Assumptions and Their Implications There are mainly two ways of introducing costly price adjustment in the New Keynesian model. First, there is so-called time dependent price setting. Under this assumption some prices in the economy can adjust in the current period, whereas other prices cannot adjust. Which prices can adjust and which cannot is exogenously determined; it is not chosen by the firms or price setters. One very popular model is the so-called Calvo (1983) model that assumes that a randomly chosen fraction of the prices, drawn from a uniform distribution, can adjust. The model is so popular because it gives rise to very simple optimality conditions. This implies that some prices will not adjust for ever. Even though there is some evidence of very long-lasting prices (Young and Levy, 2005), it seems very unlikely that prices do not adjust even though the firm makes losses and has to meet demand. This has very important implications for the relative price distortion that this model delivers (Ascari, 2004). Another very popular model is the so-called Taylor (1980) price adjustment model. This model assumes that every period there is a fixed fraction of firms that can adjust their prices. In this case the fraction of prices that can adjust is not random. It is always the same cohort of prices that can adjust after for instance four quarters. This model does not suffer from the problems of the Calvo model (Ascari, 2004).

A second way of introducing costly price adjustment is through explicitly assuming a cost of price adjustment that the firm needs to pay every time it changes its price. A very popular model is the so-called menu cost model where there is a fixed cost to be paid every time the firm wants to adjust its price. Because of the non-linearity this implies that it is more difficult to solve the model using perturbation methods. See Dotsey et al. (1999) for an example of a menu-cost model that can be solved with a perturbation method. In this model the frequency of price adjustment is endogenous and does not depend on an exogenous assumption. The firms that need the price adjustment most urgently adjust their prices. This feature is also called the selection effect (Golosov and Lucas, 2007). It implies that the response of inflation to a monetary shock is much faster than if the selection effect were not present.

Another often used model is the model of Rotemberg (1982). This model assumes that the price adjustment cost is quadratic in the size of the price adjustment. So the higher is the price adjustment the higher is the price adjustment cost. In this model the frequency of price adjustment is 100%; there is no staggering of price adjustment. This is at odds with the micro data as will become clear soon. However, in a first order approximation the model delivers the same Phillips curve as under the Calvo price adjustment. See Lombardo and Vestin (2008) for a comparison of the welfare implications of both models.

Another theory is the one recently proposed by Mankiw and Reis (2002). This theory does not assume that prices are reset irregularly because of nominal price rigidities. It assumes that prices can be reset every period, but that the firm can only infrequently choose the optimal rate of price adjustment. So information about the state of the economy is not immediately reflected in price adjustment decisions. This creates a short term impact of money on ouptut.

All the previous models assume that agents are perfectly rational and perfectly informed. This implies that the natural rate hypothesis is respected. Output cannot be increased forever by increasing the rate of inflation. One paper that proposes an alternative to the natural rate hypothesis is the paper of Akerlof et al (2000). They argue that under low inflation price and wage setters do not fully update their decisions to their expectations. Therefore, slightly higher inflation will push activity higher. As inflation gets higher they argue that then agents will start updating their decisions again with inflation expectations. So small deviations of the natural rate hypothesis are possible and efficient in that model.

Empirical Evidence The body of empirical research on costly price adjustment has been growing exponentially during the last years. Usually the fact that goods prices do not change is taken as indirect evidence for costs of price adjustment. Under the assumption that the optimal price changes continuously through continuously changing costs and demand. For a lot of goods this might be true, but it could as well be possible that some goods' prices do not change simply because the costs and demand do not change. On the other hand, there is also limited direct evidence on costly price adjustment. Levy et al. (1997) and Zbaracki et al. (2004) find direct evidence for the costs of price adjustment from a supermarket and an industrial firm, respectively. They find that price adjustment costs amount to 0.7% or 1.23% of revenues. Zbaracki et al. (2004) document that the direct cost of changing prices is very low. However, the managerial and customer costs are quite substantial. So to implement a price change a firm needs to spend a lot of resources on organizing the price change within the firm, and informing and explaining the price change to the customers of the firm.

Mills (1920) and Means (1927) are the earliest empirical studies of price adjustment. Between then and the early 2000s there exists a large number of empirical studies of price adjustment. The main characteristic of these studies is, however, that they only cover a subset of goods traded in the economy. Some examples are Kashyap (1995) for retail catalogues and Cecchetti (1986) for magazines. It took until Bils and Klenow (2004) and Nakamura and Steinsson (2008) before a large scale study on US consumer prices was done. At about the same time, the central banks of the euro area started a large research project within the Inflation Persistence Network (IPN). They study the stickiness of consumer (Dhyne et al., 2006) and producer prices (Vermeulen et al, 2007) using micro data underlying the CPI and PPI. In addition they study the adjustment of prices through a survey (Fabiani et al., 2007) sent to firms asking them directly about the way they adjust prices. This study was similar in approach to the study of Blinder et al. (1998). All these studies allow to calibrate macroeconomic models that cover almost the entire set of goods traded in the economy.

The main statistic that these studies compute is the frequency of price adjustment, which ranges between 10% and 30% depending on the time and country the data was sampled from. Next to that they also study the size of price adjustment and a number of other features of the price change distribution. The studies find infrequent price adjustment compared to perfectly competitive markets. Still, prices adjust too fast to be able to match evidence from VARs on the output and inflation effects of a monetary policy shock in a New Keynesian model. This gave rise to yet another puzzle.

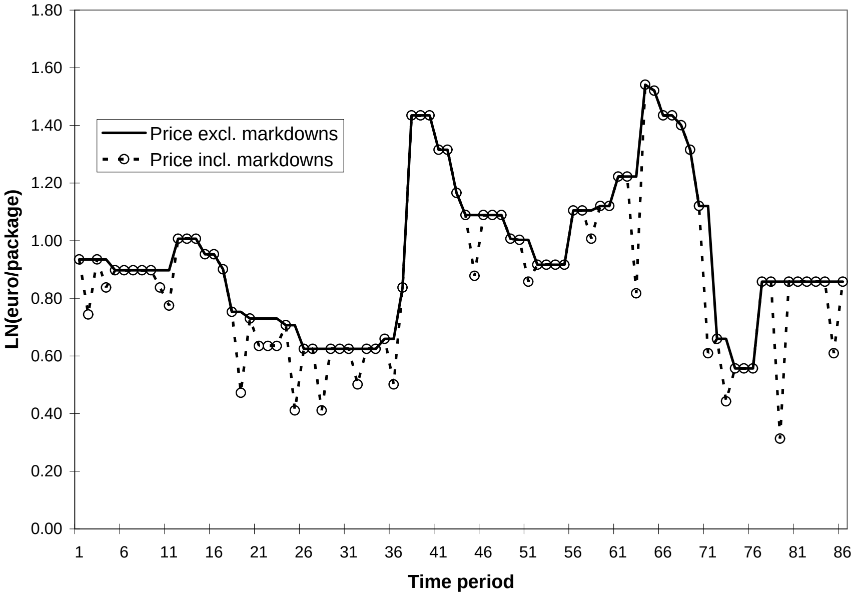
To solve this puzzle a series of papers have introduced real price rigidities (Ball and Romer, 1990). Real rigidities refer to strategic complementarity in the price setting decision of firms. A firm is more reluctant to adjust its price in response to changes in the state of the economy the less other firms adjust their prices. Different frictions can generate this strategic complementarity. One way to introduce strategic complementarity is through the preference specification of Kimball (1995). In contrast to the traditional Dixit and Stiglitz (1977) aggregator, Kimball (1995) no longer assumes a constant elasticity of demand. The price elasticity of demand becomes a function of the relative price. A key concept is the so-called curvature of the demand curve, which measures the price elasticity of the price elasticity. When the curvature is positive, Kimball's preferences generate a concave or smoothed "kinked" demand curve in a log price/log quantity framework. A price above the level of the firm's competitors increases the elasticity of demand for its product, so that the firm increasingly loses profits from relative price increases. Conversely, a price below the level of the firm's competitors reduces the elasticity of demand for its product, so that the firm again increasingly loses profits from relative price decreases. In this way the combination of small costs to nominal price adjustment and a concave demand curve generates slow adjustment to changes in the state of the economy. Despite its attractiveness, the literature suffers from a lack of empirical evidence on the curvature of a typical demand curve. Values for the curvature range from less than 2 to more than 400. The results in chapter 3 (Dossche et al., 2008) support the introduction of a kinked (concave) demand curve in a representative firm economy, but the median degree of curvature is much lower than currently calibrated.

Yet another way to introduce real rigidities is by assuming a production chain. In industrialized countries 40% of the value of a consumption good is typically generated in the distribution stage, whereas 60% of its value is generated in the production stage (Burstein et al., 2003). Chapter 2 (Cornille and Dossche, 2008) of this thesis contributes to understanding the way producer prices adjust. We document producer price adjustment using a Belgian micro price dataset. On average 24% of prices adjust each month, with an average increase/decrease of 6%. So producer prices adjust more frequently than consumer prices, but their size of adjustment is typically smaller.

A particular feature of the micro data is that the size of price adjustment is large compared to inflation. This implies that there must be large change in relative prices. To match this fact, one needs idiosyncratic shocks to be able to generate such big price changes (Golosov and Lucas, 2007). Another source of large price changes are price markdowns that are mainly present in micro consumer data and not in producer price data (Cornille and Dossche, 2008; Vermeulen et al., 2007). Nakamura and Steinsson (2008) argue that one should leave these price changes out to analyze macroeconomic questions. Kehoe and Midrigan (2007) argue that if one explicitly accounts for price markdowns in a macro model, the implications of the model are significantly different than from a model without these price markdowns. The difference between the price path that excludes the markdowns, and the one including the markdowns, is illustrated in Figure 2.

With respect to the Lucas (1976) critique models of price setting raise a lot of issues because they determine the welfare costs of costly price adjustment. So it is very important to be able to compare the microeconomic implications for price setting of these model with microeconomic data. The macroeconomic data cannot deliver a firm conclusion. Evidence from Klenow and Kryvtsov (2008) and Gagnon (2008) seems to suggest that a time-dependent model is consistent with an economy with low inflation such as the United States today. However, for an economy with high inflation such as Mexico during the Peso crisis of 1994 a state dependent model seems

Figure 2: Example of a Price Trajectory: Potatoes



Source: Dossche et al. (2008)

to be more useful. A time-dependent model would fatally fail in matching the increased frequency of price adjustment as inflation reaches higher levels. See also Mackowiak and Smets (2008) for an assessment of how microeconomic data can guide us in developing correctly microfounded models.

Optimal Inflation Dynamics

One very appealing feature of the New Keynesian model is that it is utility based. That means that households maximize utility when they choose their consumption, labor and savings decisions. This feature allows the model to conduct optimal public policy.

Another ingredient that is very important is that agents have rational expectations. The policy maker cannot repeatedly fool or surprise the agents. The policy outcomes will be very different under commitment and discretion as the current allocations will depend on the expectations of what the policy maker will do in the next period. This creates the problem of time inconsistency as described in Kydland and Prescott (1977). Under commitment the policy maker has access to a commitment technology where he can do promises that ex post he also will keep. As the welfare outcomes under commitment are superior to the outcomes under discretion most people assume commitment right away. This facilitates the problem. Also because most central banks in industrialized countries are now considered as independent from politicians that have difficulties in committing themselves to promises.[2] However, there still remains a large number of problems that are better described by discretion, in particular fiscal policy problems. This lies beyond the scope of this thesis.

Two distinct branches of the existing literature on optimal policy deliver diametrically opposed policy recommendations concerning the long-run and cyclical behavior of prices and interest rates. One branch follows the theoretical framework laid out in Lucas and Stokey (1983).[3] It studies the joint determination of optimal fiscal and monetary policy in flexible-price environments with perfect competition in product and factor markets. In this group of papers, the government problem consists in financing an exogenous stream of public spending by choosing the least disruptive combination of inflation and distortionary income taxes. A key result is that it is optimal for the government to make inflation highly volatile and serially uncorrelated. Under the Ramsey policy, the government uses unanticipated inflation as a lump-sum tax on financial wealth. This allows the fiscal authority to keep income tax rates remarkably stable over the business cycle.

On the other hand, a more recent literature focuses on characterizing optimal monetary policy in environments with nominal rigidities, and imperfect competition.[4] This literature differs from the

---

[2] See Cukierman et al. (1992) for evidence on how central bank independence has evolved during the last fifty years.

[3] See e.g. Chari et al. (1991).

[4] See e.g. Rotemberg and Woodford (1999). Clarida Gali Gertler (1999), Goodfriend and King (1997)

other branch in two important ways. First, it assumes explicitly or implicitly that the government has access to lump sum taxes to finance its budget. An important implication of this assumption is that there is no need to use unanticipated inflation as a lump-sum tax; regular lump sum taxes take up this role. Second, the government is assumed to be able to implement a production subsidy to eliminate the distortion from the presence of monopoly power in the goods and factor markets.

Schmitt-Grohé and Uribe (2004a,b) merge these two literatures. In Schmitt-Grohé and Uribe (2004b) they assume imperfect competition, sticky prices, nominal non-state-contingent debt and distortionary income taxes. The government faces a trade-off in choosing the path of inflation. On the one hand, the government would like to use unexpected inflation as a non-distorting tax on nominal wealth. In this way, the fiscal authority could minimize the need to vary distortionary income taxes over the business cycle. On the other hand, changes in the rate of inflation come at a cost, for firms face nominal rigidities. The main result of Schmitt-Grohé and Uribe (2004b) is that under plausible calibrations of the degree of price stickiness, this trade-off is overwhelmingly resolved in favor of price stability. The Ramsey allocation delivers a stable inflation process. The implication for fiscal policy is that in response to an unexpected increase in government spending the Ramsey planner does not generate a surprise increase in the price level. Instead, he chooses to finance the increase in government purchases partly through an increase in income tax rates and partly through an increase in public debt.

In the fourth chapter of the thesis (Dossche, 2008) I show that in a New Keynesian model economy with sticky prices and high labor taxes, optimal inflation volatility is significantly higher than for an economy with low labor taxes. Because the marginal tax revenue decreases in the level of taxes, the Ramsey planner needs to raise taxes more to finance the same adverse government spending shocks. This creates a larger tax distortion than under a low level of labor taxes. To minimize the tax distortion the planner changes taxes less than is needed to entirely finance the increase in spending and generates a surprise inflation to raise revenue from inflating the nominal public debt.

Conclusion

In the last two decades there has been a very high research interest in understanding inflation and price dynamics. First, this success is due to the emergence of a microfounded modeling framework where people can introduce explicit optimization of agents and rational expectations. This implies that questions on central bank commitment and discretion could be analyzed in these models. Second, there is now access to new databases that significantly increased the microeconomic evidence on price adjustment. In addition to that there is the macroeconomic evidence from VARs (e.g. Christiano et al., 1999) combined with evidence on inflation persistence.

This thesis has contributed to this research in the way that we provide evidence on the sources of inflation persistence. We find that a large part of the empirically high inflation persistence can be attributed to changes in the monetary policy inflation target. Second, we provide direct evidence on microeconomic producer price adjustment. This shows that producer prices are more flexible than consumer prices. Third, we find some, but only limited evidence on real rigidities coming from changes in the demand elasticity. This implies that some of the challenges the model faces in terms of matching impulse responses from a monetary policy shock should be resolved using other sources of strategic complementarity such as multiple sectors, a production chain, or learning. In the last chapter I find that changing the fiscal parameters in realistic dimensions so as to match fiscal characteristics in Europe, increases optimal inflation and makes it more volatile than for instance in the United States.

Whereas during the eighties and nineties central banks had turned away from formal analysis[5], they are now investing more and more resources in improving the New Keynesian model as well as using it for policy analysis and forecasting (see e.g. Smets and Wouters, 2004, 2007). Already today the Swedish central bank publishes optimal macroeconomic forecasts. That is finding an instrument-rate path that minimizes a quadratic loss function under commitment (Adolfson et al., 2008). This type of analysis is currently becoming an often used tool in many other central banks. However, recent criticism of the New Keynesian model has also pointed to a number of weak spots (e.g. Chari et al., 2008; Gottfries and Söderberg, 2008). So when we use these new tools, we should be aware of their weaknesses and remain careful while formulating policy advice.

References

[1] Adolfson M., Laséen S., Lindé J. and L. Svensson, 2008, Optimal Monetary Policy in an Operational Medium-Sized DSGE Model, Sveriges Riksbank, *mimeo*

[2] Akerlof G., Dickens W. and G. Perry, 2000, Near Rational Wage and Price Setting and the Long-Run Phillips Curve, *Brookings Papers on Economic Activity*

[3] Ascari G., 2004, Staggered Prices and Trend Inflation: Some Nuisances, *Review of Economic Dynamics*, 7, 642-667

[4] Benati L., 2008, Investigating Inflation Persistence across Monetary Regimes, *Quarterly Journal of Economics*, 123, 1005-1060

---

[5] In the 1980s and 1990s, many central banks continued to use reduced-form statistical models to produce forecasts of the economy that presumed no structural change, but they did so knowing that these models could not be used with any degree of confidence to predict the outcome of policy changes.

[5] Bils M. and P. Klenow, 2004, Some Evidence on the Importance of Sticky Prices, *Journal of Political Economy*, 112, 947-985

[6] Blanchard O.J. and J. Galí, 2007, Real Wage Rigidities and the New Keynesian Model, *Journal of Money Credit and Banking*, 39, 35-65

[7] Blanchard O. and N. Kiyotaki, 1987, Monopolistic Competition and the Effects of Aggregate Demand, *American Economic Review*, 77, 647-666

[8] Blinder A., Canetti E., Lebow D. and J. Rudd, 1998, *Asking About Prices: A New Approach to Understanding Price Stickiness*, Russell Sage Foundation, New York

[9] Burstein A., Neves J. and S. Rebelo, 2003, Distribution Costs and Real Exchange Rate Dynamics During Exchange-Rate-Based Stabilizations, *Journal of Monetary Economics*, 1189-1214

[10] Cecchetti S., 1986, The Frequency of Price Adjustment: A Study of the Newsstand Prices of Magazines, *Journal of Econometrics*, 31, 255-274

[11] Chari V. and P. Kehoe, 1999, Optimal Fiscal and Monetary Policy, in J. Taylor & M. Woodford (eds) *Handbook of Macroeconomics*, 1671-1745

[12] Chari V., Kehoe P. and E. McGrattan, 2008, New Keynesian Models: Not Yet Useful for Policy Analysis, *Federal Reserve Bank of Minneapolis Staff Report*, n° 409

[13] Christiano L., Eichenbaum M. and C. Evans, 1999, Monetary Policy Shocks: What Have We Learned and to What End?, in J. Taylor & M. Woodford (eds) *Handbook of Macroeconomics*, 65-148

[14] Christiano L., Eichenbaum M. and Evans C., 2005, Nominal Rigidities and the Dynamic Effects of Shock to Monetary Policy, *Journal of Political Economy*, 113, 1-45

[15] Clarida R., Gali J. and M. Gertler, The Science of Monetary Policy: A New Keynesian Perspective, *Journal of Economic Literature*, 37, 1661–1707

[16] Cooley T. and G. Hansen, 1989, In‡ation Tax in a Real Business Cycle Model, *American Economic Review*, 79, 733-748

[17] Cornille, D. and M. Dossche, 2008, Some Evidence on the Adjustment of Producer Prices, *Scandinavian Journal of Economics*, 110, 489-518

[18] Cukierman A., Webb S. and B. Neyapti, 1992, Measuring the Independence of Central Banks and Its Effect on Policy Outcomes, *The World Bank Economic Review*, 6, 353-98

[19] Danziger L., 1987, Inflation, Fixed Cost of Price Adjustment, and Measurement of Relative-Price Variability: Theory and Evidence, *American Economic Review*, 77, 704-713

[20] De Graeve F., Dossche M., Emiris M. Sneessens H. and R. Wouters, 2008, Risk Premiums and Macroeconomic Dynamics in a Heterogeneous Agents Model, *National Bank of Belgium Working Paper Series*, n° 150

[21] Dhyne E., Álvarez L., Le Bihan H., Veronese G., Dias D., Hoffmann J., Jonker N., Lunnemann P., Rumler F., and J. Vilmunen, 2006, Price Changes in the Euro Area and the United States: Some Facts from Individual Consumer Price Data, *Journal of Economic Perspectives*, 20, 171-192

[22] Dixit A. and J. Stiglitz, 1977, Monopolistic Competition and Optimum Product Diversity, *American Economic Review*, 67, 297-308

[23] Doepke M. and M. Schneider, 2006, Inflation and the Redistribution of Nominal Wealth, *Journal of Political Economy*, 114, 1069-1097

[24] Dossche M., 2008, Optimal Inflation, Imperfect Competition and Labor Taxes, Ghent University, *mimeo*

[25] Dossche M. and G. Everaert, 2008, Disentangling the Sources of Inflation Persistence, Ghent University, *mimeo*

[26] Dossche M., Heylen F. and D. Van den Poel, 2008, The Kinked Demand Curve and Price Rigidity: Evidence from Scanner Data, Ghent University, *mimeo*

[27] Dotsey M., King R. and A. Wolman, 1999, State Dependent Pricing and the General Equilibrium Dynamics of Money and Output, *Quarterly Journal of Economics*, 114, 655–690

[28] Fabiani S., Druant M., Hernando I., Kwapil C., Landau B., Loupias C., Martins F., Mathä t. and R. Sabbatini, 2006, What Firms Surveys Tell Us About Price-setting Behaviour in the Euro Area, *International Journal of Central Banking*, 3-47

[29] Fagan G. and J Messina, 2008, Downward Wage Rigidity and Optimal Steady State Inflation, European Central Bank, *mimeo*

[30] Fahr S. and F. Smets, 2008, Downward Wage Rigidities and Optimal Monetary Policy in a Monetary Union, European Central Bank, *mimeo*

[31] Friedman M. and A. Schwartz , 1963, *A Monetary History of the United States, 1867-1960*, Princeton University Press

[32] Fuhrer, J. and G. Moore, 1995, Inflation Persistence, *Quarterly Journal of Economics*, 110, 127-159.

[33] Gagnon E., 2008, Price Setting during Low and High Inflation: Evidence from Mexico, *Quarterly Journal of Economics*, forthcoming

[34] Gali, J., 2008, *Monetary Policy, Inflation and the Business Cycle*, Princeton University Press

[35] Galí J. and M. Gertler, 1999, Inflation Dynamics: A Structural Econometric Analysis, *Journal of Monetary Economics*, 44, 195-222

[36] Golosov M. and R. Lucas, 2007, Menu Costs and Phillips Curves, *Journal of Political Economy*, 115, 171-199

[37] Goodfriend M. and R. King, 1997, The New Neoclassical Synthesis and the role of Monetary Policy, *NBER Macroeconomics Annual*, 12, 231-283

[38] Gottfries N. and J. Söderberg, 2008, Do Sticky Prices Make Sense?, Uppsala University, *mimeo*

[39] Hercowitz Z., 1981, Money and the Dispersion of Relative Prices, *Journal of Political Economy*, 89, 328-356

[40] Kashyap A., 1995, Sticky Prices: New Evidence from Retail Catalogs, *Quarterly Journal of Economics*, 245-74

[41] Kehoe P. and V. Midrigan, 2007, Sales and the Real Effects of Monetary Policy, *Federal Reserve Bank of Minneapolis Working Papers*, N° 652

[42] Kimball M., 1995, The Quantitative Analytics of the Basic Neomonetarist Model, *Journal of Money, Credit and Banking*, 27, 1241-1277

[43] Klenow P. and O. Kryvtsov, 2008, State-Dependent or Time-Dependent Pricing: Does It Matter for Recent U.S. Inflation?, *Quarterly Journal of Economics*, 123, 863-904

[44] Krugman P., 1998, It's Baaack: Japan's Slump and the Return of the Liquidity Trap, *Brookings Papers on Economic Activity*, 49, 137-205

[45] Kydland F. and E. Prescott, 1977, Rules Rather than Discretion: The Inconsistency of Optimal Plans, *Journal of Political Economy*, 85, 473-492

[46] Lach S. and D. Tsiddon, 1992, The Behavior of Prices and Inflation: An Empirical Analysis of Disaggregate Price Data, *Journal of Political Economy*, 100, 349-389

[47] Levy D., Bergen M., Dutta S. and R. Venable, 1997, The Magnitude of Menu Costs: Direct Evidence from Large US Supermarket Chains, *Quarterly Journal of Economics*, 112, 791–825

[48] Lombardo G. and D. Vestin, 2008, Welfare Implications of Calvo vs. Rotemberg-Pricing Assumptions, *Economics Letters*, 100, 275-279

[49] Lucas R., 1976, Econometric Policy Evaluation: A Critique, *Carnegie-Rochester Conference Series on Public Policy*, 1, 19-46

[50] Lucas R. and N. Stokey, 1983, Optimal Fiscal and Monetary Policy in an Economy without Capital, *Journal of Monetary Economics*, 12, 55-93

[51] Mackowiak B. and F. Smets, 2008, On Implications of Micro Data for Macro Models, *European Central Bank Working Papers Series*, n° 960

[52] Mankiw G. and R. Reis, 2002, Sticky Information versus Sticky Prices: A Proposal to Replace the New Keynesian Phillips Curve, *Quarterly Journal of Economics*, 117, 1295-1328

[53] Means G., 1936, Notes on Inflexible Prices, *American Economic Review*, 23-35

[54] Meh A., Rios-Rull V. and Y. Terajima, 2008, Aggregate and Welfare Effects of Redistribution of Wealth Under Inflation and Price-Level Targeting, Bank of Canada, *mimeo*

[55] Milani F., 2007, Expectations, Learning and Macroeconomic Persistence, *Journal of Monetary Economics*, 54, 2065-2082

[56] Mills F., 1927, *The Behaviour of Prices*, New York, NBER

[57] Nakamura E. and J. Steinsson, 2008, Five Facts about Prices: A Reevaluation of Menu Cost Models, *Quarterly Journal of Economics*, 123, 1415-1464

[58] Orphanides A., 2002, Monetary-Policy Rules and the Great Inflation, *American Economic Review*, 92, 115-120

[59] Peersman G. and F. Smets, 2003, The Monetary Transmission Mechanism in the Euro Area: More Evidence From VAR Analysis, in *Monetary Policy Transmission in the Euro Area*, Angeloni, Kashyap and Mojon (eds), Cambridge University Press

[60] Pivetta, F. and R. Reis, 2007, The persistence of inflation in the United States, *Journal of Economic Dynamics and Control*, 31, 1326-1358

[61] Rotemberg J., 1982, Sticky Prices in the United States, *Journal of Political Economy*, 90, 1187-1211

[62] Sargent T., Williams N. and T. Zha, 2006, Shocks and Government Beliefs: The Rise and Fall of American Inflation, *American Economic Review*, 96, 1193-1224

[63] Schmitt-Grohé S. and M. Uribe, 2004a, Optimal Fiscal and Monetary Policy under Imperfect Competition, *Journal of Macroeconomics*, 26, 183-209

[64] Schmitt-Grohé S. and M. Uribe, 2004b, Optimal Fiscal and Monetary Policy under Sticky Prices, *Journal of Economic Theory*, 114, 198-230

[65] Smets F. and R. Wouters, 2003, An Estimated Dynamic Stochastic General Equilibrium Model for the Euro Area, *Journal of the European Economic Association*, 1, 1123-1175

[66] Smets F. and R. Wouters, 2007, Shocks and Frictions in US Business Cycles: A Bayesian DGSE Approach, *American Economic Review,* 97, 586-606

[67] Taylor J., 1980, Aggregate Dynamics and Staggered Contracts, *Journal of Political Economy*, 88, 1-23

[68] Tobin J., 1972, Inflation and Unemployment, *American Economic Review*, 62, 1-18

[69] Vermeulen P., Dias D., Dossche M., Gautier E., Hernando I., Sabbatini R. and H Stahl, 2007, Price Setting in the Euro Area: Some Stylised Facts from Individual Producer Price Data, *ECB Working Papers*, N° 727

[70] Woodford M., 2003, *Interest and Prices*, Princetion University Press.

[71] Young A. and D. Levy, 2005, Explicit Evidence on an Implicit Contract,*Emory Economics Working Paper*, 0519, Emory University

[72] Zbaracki M., Ritson M., Levy D., Dutta S. and M. Bergen, 2004, The Managerial and Customer Costs of Price Adjustment: Direct Evidence from Industrial Markets, *Review of Economics and Statistics*, 514–533

Disentangling the Sources of Inflation Persistence[*]

Maarten Dossche[†] Gerdie Everaert[‡]

November 28, 2008

Abstract

We define the sources of inflation persistence at the business cycle frequency as either intrinsic, extrinsic, or expectations-based. To disentangle these different sources of persistence we formulate an unobserved component model and estimate it using the Kalman filter and Bayesian estimation techniques. We find that inflation persistence, expressed as the half-life of a shock, can range from less than one quarter for intrinsic persistence, to several years for extrinsic or expectations-based persistence. This indicates that a significant part of the observed univariate inflation persistence is inherited and that price-setting frictions such as indexation to past inflation or backward-looking expectations are not the best way to match the empirical evidence.

JEL classification: C11, C22, C32, E31
Keywords: inflation persistence, unobserved component model

---

[*] The paper reflects research conducted within the Inflation Persistence Network (IPN), a team of Eurosystem economists undertaking joint research on inflation persistence in the euro area. We thank Luc Aucremanne, Freddy Heylen, Andrew Levin, Benoît Mojon, Gert Peersman, Peter Tinsley, Raf Wouters, and participants of various conferences and workshops for useful comments and suggestions. The views expressed in this paper are those of the authors and do not necessarily reflect the views of the National Bank of Belgium. We acknowledge support from the Interuniversity Attraction Poles Program - Belgian Science Policy, contract no. P5/21. All remaining errors are the authors'.

[†] National Bank of Belgium, Boulevard de Berlaimont 14, 1000 Brussels, Belgium and SHERPPA, Ghent University, E-mail: maarten.dossche@nbb.be.

[‡] SHERPPA, Ghent University, Tweekerkenstraat 2, 9000 Ghent, Belgium, E-mail: gerdie.everaert@ugent.be.

1 Introduction

To design business cycle models that can explain cyclical inflation dynamics we need to know how persistent inflation is. A common practice is to estimate a univariate autoregressive time series model and measure persistence as the sum of the autoregressive coefficients (e.g. Nelson and Plosser, 1982; Fuhrer and Moore, 1995; Pivetta and Reis, 2007). In most of these studies, inflation is found to exhibit high to very high persistence during the post-WW II period, i.e. persistence is found to be close to that of a random walk.

We can design models that generate high inflation persistence using a variety of frictions: backward-looking agents (Galí and Gertler, 1999), price indexation (Christiano et al., 2005), consumption habit persistence (Christiano et al, 2005), learning (Milani, 2007), real wage rigidities (Blanchard and Galí, 2007). For a particular calibration these frictions will all be able to replicate the univariate reduced form inflation persistence. But it is important to note that this estimated high persistence is a measure of unconditional inflation persistence. The different frictions that can match the observed inflation persistence will affect the persistence of inflation differently. Some frictions will make inflation directly or intrinsically more persistent, whereas other frictions will make inflation persistent through making its drivers persistent. The drivers of inflation can be read off from the Phillips curve relation that generally emerges in New Keynesian models, and that links current inflation to expectations about future inflation and a measure of the output gap. Frictions that make inflation intrinsically more persistent typically augment the standard Phillips curve relation with lags of inflation.

We provide evidence that can help identify which frictions are important to match the observed inflation persistence. We disentangle inflation persistence in a number of economically meaningful sources. We loosely follow Angeloni et al. (2006) in distinguishing three sources of cyclical inflation persistence. First, due to price indexation or backward-looking agents inflation can directly be related to its own lags. We call this kind of persistence *intrinsic* inflation persistence. Second, due to asymmetric information (Andolfatto et al., 2007) or imperfect credibility (Erceg and Levin, 2003), private agents' perceptions about the central bank's inflation target can differ from the true inflation target. We call the persistence of such deviations *expectations-based* persistence. Third, inflation persistence is determined by the persistent movements in the output gap. We call this type of persistence *extrinsic* inflation persistence. Both expectations-based and extrinsic persistence can also be labeled inherited inflation persistence, because inflation inherits its persistence from the persistent movements in its driving variables. Each of these three types of inflation persistence represent persistence at the business cycle frequency. On top of this, changes in the long-run inflation rate will add a fourth source of inflation persistence that is not related to the business cycle. For designing business cycle models we are only interested in inflation persistence excluding the effect of changes in the long-run inflation rate.[1] It is widely accepted that this long-run inflation rate is determined by the central bank's inflation target.[2]

We use an unobserved component model to filter out these four different sorts of inflation persistence. This type of model can decompose a time series in a number of distinct components. This is particularly useful given the different sources of inflation persistence we want to measure. See Canova (2007) for how this filtering method compares to other methods for extracting cyclical information from the data. We estimate the parameters of the filter using Bayesian estimation techniques. As the number of parameters is quite large we get the same problem of overfitting as in the case of VARs (Canova, 2007). To overcome this problem we use prior information from a number of older studies using similar models as ours. We estimate inflation persistence for the euro area and the U.S. The results show that intrinsic inflation persistence is fairly low, i.e. the half-life of a cost-push shock is less than one quarter. We conclude that a significant part of the observed inflation persistence is inherited and that price-setting frictions such as indexation to past inflation or backward-looking expectations are not the best way to match the empirical evidence.

---

[1] Recently, a number of authors has estimated measures of inflation persistence corrected for changes in the long-run inflation rate. See e.g. Altissimo et al. (2006), O'Reilly and Whelan (2005), Pivetta and Reis (2007), Levin and Piger (2004), Ireland (2007), Gadzinski and Orlandi (2004), Cogley and Sargent (2001, 2005), and Benati (2004).

[2] Although inflation targeting is a monetary policy strategy that only emerged in the 1990s, we will still use this framework for the 1970s and 1980s. It enables us to identify the implicit inflation target of central banks from their policy choices.

2 An Unobserved Component Model

In this section, we present an unobserved component model for inflation which takes into account (i) possible shifts in the central bank's inflation target, (ii) expectations-based persistence, (iii) intrinsic persistence and (iv) extrinsic persistence. We use a variant of the Rudebusch and Svensson (1999) model to impose some economic structure. The state space representation of the model is given in Appendix A.

$$\begin{aligned}
\varphi(L)\pi_t &= (1-\varphi)\pi_t^P + \beta_1 z_{t-1} + \varepsilon_{1t} && (1)\\
\pi_{t+1}^T &= \pi_t^T + \eta_{1t} && (2)\\
\delta(L)\pi_{t+1}^P &= \delta\pi_{t+1}^T + \eta_{2t} && (3)\\
i_t &= \rho_2 i_{t-1} + (1-\rho_2)\left(r_t^* + \pi_t^P\right) + \rho_1(\pi_{t-1} - \pi_t^T) + \varepsilon_{2t} && (4)\\
y_t^r &= y_t^P + z_t && (5)\\
z_t &= \beta_2 z_{t-1} + \beta_3 z_{t-2} - \beta_4\left(i_{t-1} - \pi_{t-1}^P - r_{t-1}^*\right) + \varepsilon_{3t} && (6)\\
y_{t+1}^P &= \lambda_{t+1} + y_t^P + \eta_{3t} && (7)\\
\lambda_{t+1} &= \lambda_t + \eta_{4t} && (8)\\
r_{t+1}^* &= \gamma\lambda_{t+1} + \tau_{t+1} && (9)\\
\tau_{t+1} &= \theta\tau_t + \eta_{5t} && (10)
\end{aligned}$$

where

$$\begin{aligned}
\varphi(L) &= \left(1 - \varphi_1 L - \varphi_2 L^2 - \varphi_3 L^3 - \varphi_4 L^4\right) && (11)\\
\beta(L) &= 1 - \beta_2 L - \beta_3 L^2, && (12)\\
\varphi &= \sum\nolimits_{i=1}^{q} \varphi_i < 1 && (13)\\
\delta(L) &= (1 - (1-\delta)L), \quad 0 < \delta \leq 1 && (14)
\end{aligned}$$

Where π_t is the observed inflation rate, π_t^P is the perceived inflation target, π_t^T is the central bank's inflation target and z_t is the output gap, i.e. the percentage deviation of real output from potential output. L is the lag operator so that $L^i \pi_t = \pi_{t-i}$.

Equation (2) specifies π_t^T as a random walk process, i.e. shifts in the central bank's inflation target are assumed to be permanent. This assumption is consistent with general equilibrium models where long-run inflation is usually pinned down by the inflation target of the central bank. Shifts in π_t^T are unlikely to be passed on to inflation expectations immediately. Castelnuovo et al. (2003) present data on long-run inflation expectations. These suggest that in the aftermath of shifts in monetary policy, convergence towards the new equilibrium evolves smoothly over time. Even if the central bank clearly announces a new inflation target, it can take quite some time before the new policy target is incorporated into long-run inflation expectations of private agents (Castelnuovo et al., 2003). This is often attributed to asymmetric information and signal extraction or imperfect credibility (see e.g. Erceg and Levin, 2003 and Andolfatto et al., 2007). Agents must then form expectations about the inflation target π_t^T. Equation (3) introduces the perceived inflation target π_t^P, which captures the private agents' beliefs about the central bank's inflation target π_t^T.

The perceived inflation target π_{t+1}^P is defined as a weighted average of $\pi_t^P$and π_{t+1}^T, where η_{2t} is a zero mean white noise process. Note that shocks to the perceived inflation target, η_2, only have a short-run impact on π^P. These shocks should be interpreted as misperceptions of private agents about the central bank's inflation target. Shocks to the central bank's inflation target, η_1, have a unit long-run impact on π^P, i.e. π^T is the long-run inflation rate. This is consistent with the widely accepted view that long-run inflation is a purely monetary phenomenon.

Equation (1) is a Phillips curve relation, linking the observed inflation rate π_t to the perceived inflation target π_t^P, q lags of inflation and the lagged output gap z_{t-1}. The perceived inflation target π_t^P is the inflation rate consistent with the private agents' inflation expectations. Therefore, it serves as the medium-run inflation anchor. Both shocks to the output gap z_{t-1} and cost-push shocks ε_{1t} induce temporary deviations of π_t from π_t^P. The sluggish adjustment of π_t in response to cost-push shocks ε_{1t} is measured by the sum of the AR coefficients, φ. The sluggish adjustment of π_t in response to output gap shocks is determined, besides the intrinsic inflation persistence, by the persistence of the output gap z_t. We call this source of inflation persistence extrinsic inflation persistence.

We assume that all shocks are mutually independent zero mean white noise processes. The interest rate rule in equation (4) infers on the stance of monetary policy through comparing the central bank's key nominal interest rate, i_t, with a measure for the neutral stance of monetary policy. Following Laubach and Williams (2003), this measure is assumed to be the natural short-run nominal interest rate $\left(r_t^* + \pi_t^P\right)$, where r_t^* is the time-varying real short-term interest rate consistent with output equal to potential. As the perceived inflation target π_t^P is the medium-run inflation anchor consistent with long-run inflation expectations, $r_t^* + \pi_t^P$ is the medium-run nominal interest rate anchor for monetary policy. The term $(\pi_{t-1} - \pi_t^T)$ captures the reaction of the central bank to deviations of inflation from its target, i.e. monetary authorities will increase the nominal interest rate i_t when observed inflation π_{t-1} lies above the inflation target π_t^T. The lagged interest rate i_{t-1} introduces a degree of nominal interest rate smoothing or policy inertia (see e.g. Amato and Laubach, 1999; English et al., 2003; Erceg and Levin, 2003). We assume that the policy parameters ρ_1 and ρ_2 are time-invariant. Although Clarida et al. (1998) find that the policy parameters are unstable in a number of countries, this assumption is not in contradiction with their results. They estimate the parameters conditional on a constant inflation target, whereas we estimate the inflation target conditional on constant policy parameters. Both strategies are observationally equivalent. The reason why we do so is that we are interested in the implied time-varying inflation target and not in the policy parameters. For examples of the same approach see e.g. Kozicki and Tinsley (2005) or Smets and Wouters (2005).

Equation (5) decomposes the log of real output y_t^r into potential output y_t^P and the output gap z_t. Equation (6) relates the output gap z_t to its own lags and a term $\left(i_{t-1} - \pi_{t-1}^P - r_{t-1}^*\right)$ which captures monetary policy transmission. Following Harvey (1985), Stock and Watson (1998) and Laubach and Williams (2003), equations (7)-(8) model potential output as a random walk with drift, where the drift term λ_t varies over time according to a random walk process. The time-variation in λ_t allows for the possibility of permanent changes in the trend growth of real output, e.g. the productivity slowdown of the early 1970s.

Laubach and Williams (2003) argue that the natural real rate of interest varies over time due to shifts in the trend growth of output and other factors such as households' rate of time preference. Therefore, equation (9) relates the real short-term interest rate r_t^* to the trend growth in potential output λ_t and a component τ_t that captures other determinants like time preferences. τ_t is assumed to be an AR process that, depending on the value for θ, can be either stationary or non-stationary.

3 Data, Estimation and Results

3.1 Data

We use quarterly data for the euro area and the United States from 1970:1 to 2005:4.[3] The inflation series π_t is the annualized first difference of the log of the seasonally adjusted GDP deflator. For the interest rate, i_t, we use the annualized central bank key interest rate. This interest rate should be most appropriate to infer changes in the central bank's behavior. Real output, y_t^r, is measured as the log of seasonally adjusted GDP at constant prices. See Appendix B for a more detailed data description.

3.2 Bayesian Estimation

To calculate the likelihood function of our model we write it in state space form (see the Appendix) and use the Kalman filter. The Kalman filter algorithm requires that parameter vector ψ of the model is known. One approach is to derive, from the exact Kalman filter, the diffuse loglikelihood function for our model (de Jong, 1991; Koopman and Durbin, 2000; Durbin and Koopman, 2001) and replace the unknown parameter vector ψ by its maximum likelihood estimate. This is not the approach we pursue here. First, given the fairly large number of unknown parameters, the numerical optimization of the sample loglikelihood function is difficult. As a lot of the unknown parameters in ψ were estimated previously for different countries and samples we analyze the state space models from a Bayesian point

---

[3] Although the euro area did not exist for the larger part of our data sample (1970:2-1998:4), we use synthetic data aggregating the national data (Fagan et al., 2005). We implicitly assume that the euro area was an economy with a homogeneous monetary policy over the entire sample.

of view, i.e. we treat ψ as a random parameter vector with a known prior density $p(\psi)$. We estimate the posterior densities $p(\psi \mid y, x)$ for the parameter vector ψ, by combining prior information contained in $p(\psi)$ and sample data in y and x denoting vectors of data for the endogenous and exogenous variables. This boils down to calculating the posterior mean $\overline{g}$:

$$\overline{g} = E\left[g(\psi) \mid y, x\right] = \int g(\psi)\, p(\psi \mid y, x)\, d\psi \tag{15}$$

where g is a function which expresses the moments of the posterior densities $p(\psi \mid y, x)$ in terms of the parameter vector ψ. See the Appendix for more details on the estimation method.

Prior Information

We include prior information about the unknown parameter vector ψ in Table 1 through the prior density $p(\psi)$. Where possible prior information is taken from previous studies. We use the same priors for the euro area and the United States. If no adequate information is available, we leave considerable uncertainty around the chosen priors. The prior distribution is assumed to be Gaussian for all elements in ψ, except for the variance parameters, which are assumed to be gamma distributed.

The priors for the AR coefficients φ_i are chosen from studies allowing for a break in the mean of the inflation rate. Levin and Piger (2004) for instance find a value of 0.36 for the sum of the AR coefficients of the United States GDP deflator. Gadzinski and Orlandi (2004) find a somewhat higher figure of 0.6 for the euro area. We choose a prior for the sum of the AR coefficients of 0.4 for both the United States and the euro area. As these parameter values are important for our question, we leave a large degree of uncertainty around the priors values. Our prior for δ is 0.15, which is close to the parameter values determining signal extraction in Erceg and Levin (2003) and Kozicki and Tinsley (2005). The prior for the variance of the inflation target shocks $\sigma^2_{\eta_1}$ is close to the evidence Kozicki and Tinsley (2005) and Smets and Wouters (2005) find. For the impact of the lagged output gap on inflation we choose a value of 0.2. As we use annualized quarterly inflation this value is consistent with a lot of studies reporting a value of 0.05 for the output gap impact on the inflation rate. The AR coefficients of the output gap equation are chosen in order to generate a hump-shaped response of output in reaction to a shock. This feature is often found in previous empirical studies (Gerlach and Smets, 1999; Rudebusch and Svensson, 1999; Laubach and Williams, 2003; Rudebusch, 2005). The parameter value for ρ_2 assumes considerable interest rate smoothing (Smets and Wouters, 2005). The parameter values for ρ_1 and ρ_2 are chosen so that the Taylor (1993) principle $\left(1 + \frac{\rho_1}{1-\rho_2} = 1.5 > 1\right)$ holds for deviations of π_t^P from π_t^T. The central bank reacts less vigorously $\left(\frac{\rho_1}{1-\rho_2} = 0.5\right)$ in response to deviations of π_t from π_t^T. This is consistent with the view that an inflation-targeting central bank should stabilize inflation in the medium run and pay less attention to short-term deviations.

Table 1: Prior information

	Reference(s)	5%	Mean	95%
φ_1	-	0.04	0.20	0.36
φ_2	-	-0.06	0.10	0.26
φ_3	-	-0.11	0.05	0.21
φ_4	-	-0.11	0.05	0.21
$\sum_{i=1}^{4} \varphi_1$	Gadzinski et al. (2004), Levin et al. (2004)	0.16	0.40	0.64
δ	Erceg et al. (2003), Kozicki et al. (2003)	-0.01	0.15	0.31
β_1	Gerlach et al. (1999), Rudebusch (2005), Rudebusch et al. (1999)	0.18	0.20	0.22
β_2	Gerlach et al. (1999), Rudebusch (2005), Rudebusch et al. (1999)	1.32	1.35	1.38
β_3	Gerlach et al. (1999), Rudebusch (2005), Rudebusch et al. (1999)	-0.50	-0.47	-0.44
β_4	Gerlach et al. (1999), Rudebusch (2005), Rudebusch et al. (1999)	-0.01	0.15	0.31
ρ_1	Taylor (1993)	0.02	0.05	0.08
ρ_2	Taylor (1993), Smets et al. (2005)	0.87	0.90	0.93
γ	Laubach et al. (2003)	3.67	4.00	4.33
θ	Laubach et al. (2003)	0.95	0.97	0.99
$\sigma_{\varepsilon_1}^2$	-	0.35	1.30	2.77
$\sigma_{\varepsilon_2}^2$	-	0.21	0.30	0.40
$\sigma_{\varepsilon_3}^2$	Laubach et al. (2003)	0.11	0.16	0.21
$\sigma_{\eta_1}^2$	Kozicki et al. (2003), Smets et al. (2005)	0.03	0.12	0.25
$\sigma_{\eta_2}^2$	-	2.8e-5	1.0e-4	2.1e-4
$\sigma_{\eta_3}^2$	-	0.4e-3	1.5e-3	3.4e-3
$\sigma_{\eta_3}^{2\prime}$	Laubach et al. (2003)	0.26	0.37	0.49
$\sigma_{\eta_4}^2$	Laubach et al. (2003)	4.5e-4	6.5e-4	8.8e-4
$\sigma_{\eta_5}^2$	Laubach et al. (2003)	0.07	0.10	0.14

Note: All variances are expressed at annual rates except for $\sigma_{\varepsilon_3}^2$, $\sigma_{\eta_3}^2$ and $\sigma_{\eta_4}^2$ which are expressed as quarterly rates. The prior distribution is assumed to be Gaussian for all elements in ψ, except for the variance parameters which are assumed to be gamma distributed.

3.3 Results

3.3.1 Posterior Distribution of the Parameters

Table 2 presents the posterior mean and the 5th and 95th percentile of the posterior distribution of ψ for the euro area and the United States. Two important conclusions stand out. First, the intrinsic inflation persistence estimates are 0.45 and 0.73 for the euro area and the United States. In the case of the United States, intrinsic inflation persistence is somewhat higher than in the euro area. Note that this result is consistent with Galí et al. (2001), who for the United States also find a relatively higher degree of backward-lookingness compared to the euro area. Second, expectations-based persistence, measured by $(1 - \delta)$, is at least as high or higher than intrinsic inflation persistence, i.e. higher than 0.73 for both economies across the different models. The persistence in the output gap, measured by the sum of β_2 and β_3, is close to 0.9. This implies considerable extrinsic inflation persistence.

3.3.2 Posterior Distribution of the States

Figures 1 to 6 show the dynamics of the inflation rate together with the central bank's inflation target and the perceived inflation target, and four shocks. These figures reveal considerable variation in the central bank's inflation target in both the euro area and the United States. The dynamics of the perceived inflation target show that inflation expectations adjust smoothly in response to shifts in the central bank's inflation target.

Figure 1: **Inflation in the United States**

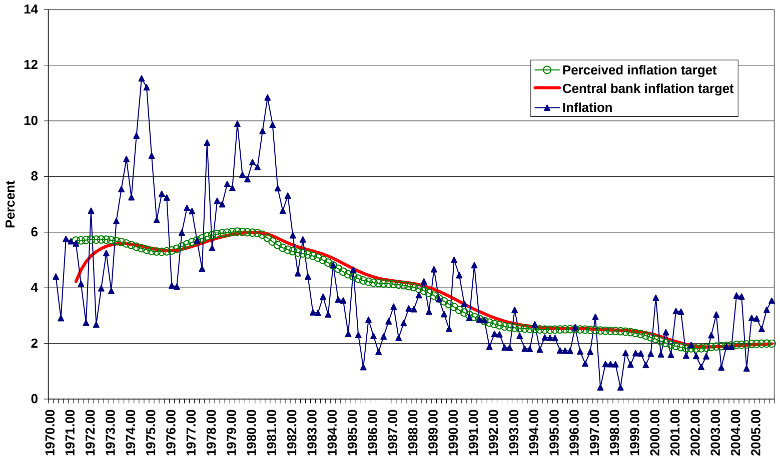


Table 2: Posterior Distribution

	Euro area			United States		
	5%	Mean	95%	5%	Mean	95%
φ_1	0.15	0.25	0.35	0.19	0.30	0.40
φ_2	0.01	0.11	0.21	0.04	0.14	0.24
φ_3	-0.17	-0.07	0.03	0.04	0.14	0.25
φ_4	0.06	0.16	0.26	0.05	0.15	0.25
$\sum_{i=1}^{4} \varphi_i$	**0.25**	**0.45**	**0.64**	**0.59**	**0.73**	**0.88**
δ	0.16	0.27	0.40	0.11	0.27	0.43
β_1	0.16	0.22	0.29	0.15	0.21	0.28
β_2	1.23	1.34	1.44	1.26	1.36	1.47
β_3	-0.48	-0.37	-0.27	-0.53	-0.43	-0.32
β_4	0.01	0.02	0.02	0.01	0.01	0.02
ρ_1	0.01	0.04	0.07	0.01	0.05	0.09
ρ_2	0.85	0.89	0.92	0.85	0.88	0.92
γ	3.38	3.94	4.49	3.42	3.99	4.55
θ	0.95	0.97	0.99	0.95	0.97	0.99
$\sigma_{\varepsilon_1}^2$	1.23	1.51	1.87	0.99	1.20	1.48
$\sigma_{\varepsilon_2}^2$	0.23	0.28	0.34	0.70	0.81	0.94
$\sigma_{\varepsilon_3}^2$	0.08	0.11	0.14	0.10	0.14	0.19
$\sigma_{\eta_1}^2$	0.03	0.08	0.18	0.03	0.08	0.21
$\sigma_{\eta_2}^2$	1.3e-5	5.2e-5	1.6e-4	1.3e-5	5.2e-5	1.6e-4
$\sigma_{\eta_3}^{2\prime}$	0.14	0.18	0.24	0.25	0.32	0.41
$\sigma_{\eta_4}^2$	4.4e-4	6.2e-4	8.5e-4	4.3e-4	6.2e-4	8.6e-4
$\sigma_{\eta_5}^2$	0.07	0.10	0.14	0.08	0.11	0.15

Note: The approximate covariance matrix $\widehat{\Omega}$ is inflated with a factor 1.5. The coefficient of variation of the weights stabilized after 1 update of the importance function for both the euro area and the United States. With $n = 10000$, the probabilistic error bound for the importance sampling estimator $\overline{g}_n$is well below 10% for all coefficients.

Figure 2: **Shocks in the United States (1)**

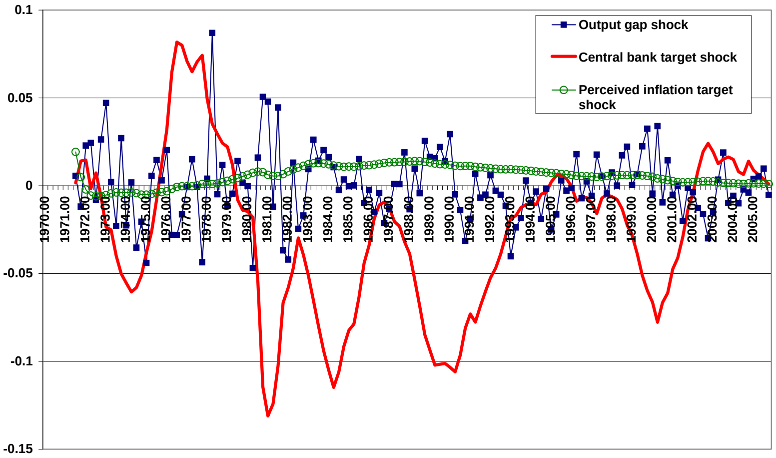
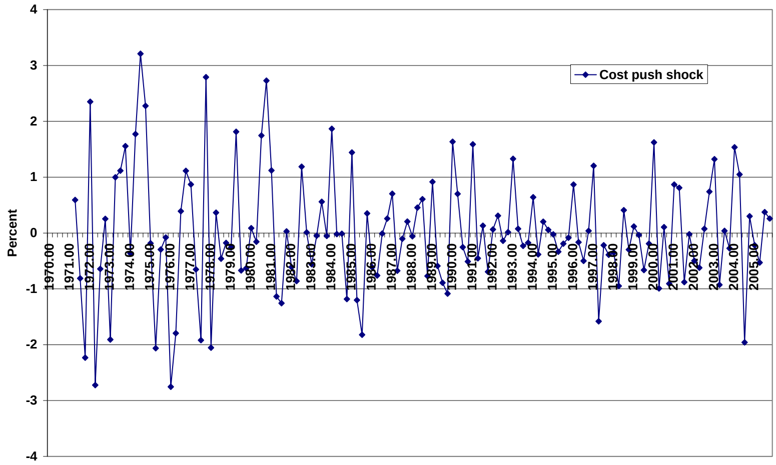


Figure 3: **Shocks in the United States (2)**



The timing of the shifts in the central bank's inflation target seems to be in line with common knowledge about the historical conduct of monetary policy. A first disinflationary period happens in the early 1980s. In the United States, the inflation target decreased from about 6 p.c. in the late 1970s to about 4 p.c. in the mid 1980s. This is consistent with the disinflationary policy of Paul Volcker, who was appointed president of the Federal Reserve in 1979. During the Greenspan chairmanship of the Fed the target came down with an additional 2 percentage points. A similar decrease during the 1980s, from about 7 p.c. to about 5 p.c., is observed for the euro area. This decrease is more difficult to match with narrative evidence, though, as no unified monetary policy existed before 1999. Still, several

Figure 4: **Inflation in the euro area**

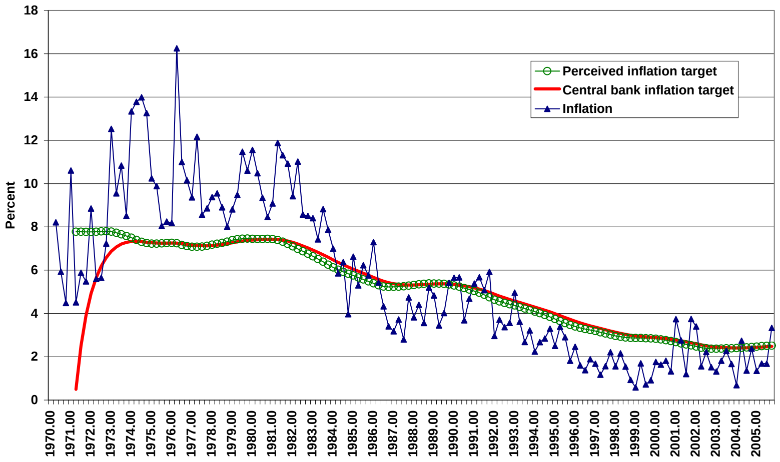
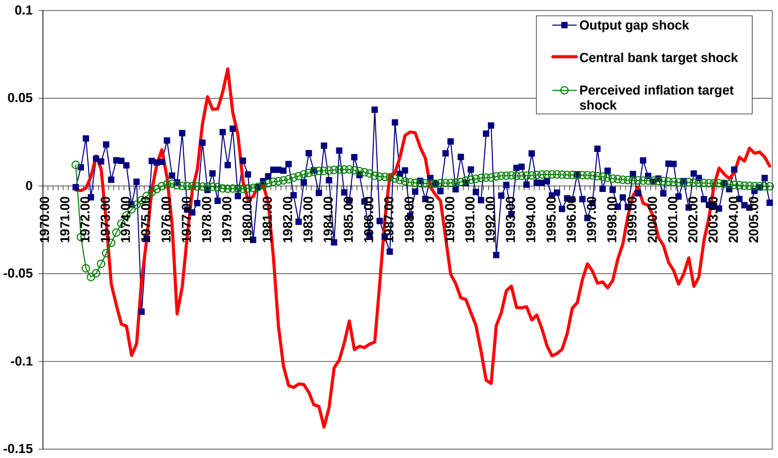


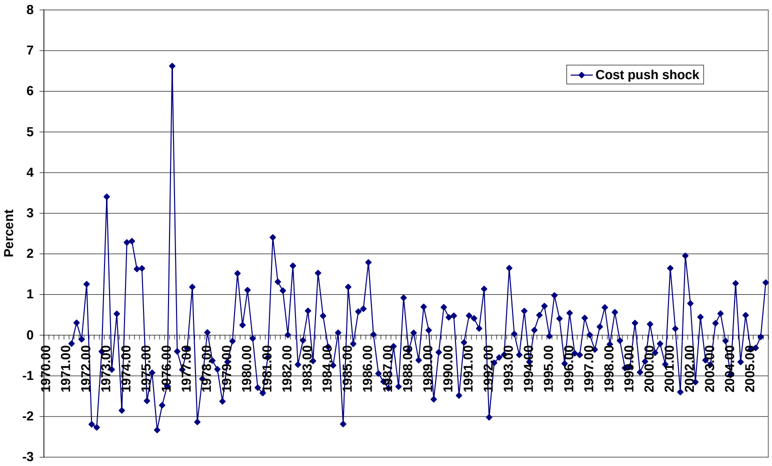
Figure 5: **Shocks in the euro area (1)**



future euro area member countries (e.g. Austria, Belgium, France, The Netherlands) were disinflating in the beginning of the eighties. For the euro area, a second disinflationary period is also present in the beginning of the nineties. Other future euro area member countries (e.g. Greece, Italy, Portugal, Spain) were then disinflating in order to comply with the Maastricht criteria.

Comparing the shocks, it turns out that the shock to the perceived inflation target is not very important to explain the inflation rate. What seems most important is the shock to the inflation target to explain the long run shifts in the inflation rate, and the shock to the output gap and the cost push shock to explain the short run fluctuations.

Figure 6: **Shocks in the euro area (2)**



3.3.3 Half-Life and Impulse Response Analysis

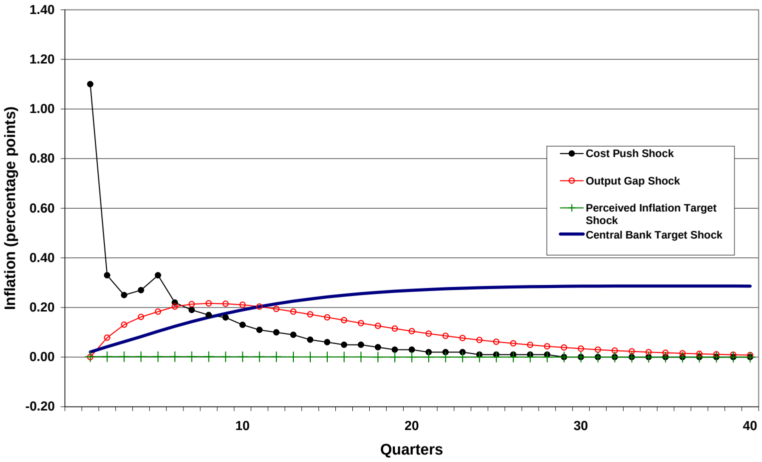
An alternative way of analyzing inflation persistence is to look at the half life and impulse response functions of different shocks to inflation. The half-life counts the number of periods for which the effect of a shock to inflation remains above half its initial impact. An important difference with the sum of estimated AR coefficients as a measure of persistence is that both the half life and impulse response analysis take all the roots of the AR equation into account while the sum of AR coefficients only measures the average speed of convergence. A second important difference with the point estimates of the AR coefficients is that different sources of persistence in response to a shock can reinforce each other. The inflation dynamics in response to a shock will thus not only depend on the persistence in the variable that was shocked, but will also depend on the interaction with other variables. Therefore, also the persistence in the latter will play a role.

Table 4 reports half lives for four shocks to inflation. The half life of a cost push shock (ε_{1t}) is less than one quarter. For a shock to the perceived inflation target (η_{2t}), the half life is 5 and 11 quarters in the euro area and the United States respectively. For a shock to the output gap (ε_{3t}), the half life even amounts to 35 quarters in the euro area and to 27 quarters the United States. Finally, a shock to the inflation target (η_{1t}) is permanent and therefore its half life is equal to infinity. The latter result is obtained by construction because we assume a random walk process for the shifts in the central bank's inflation target. It shows that ignoring a component with an infinite half life must create a considerable bias in the estimates of the other kinds of persistence.

Table 3: Half Lives of Inflation (Quarters)

	Euro area	United States
Cost Push Shock	0	0
Perceived Inflation Target Shock	5	11
Output Gap Shock	35	27
Central Bank Target Shock	∞	∞

Figure 7: **Impulse Responses United States**



Note: The responses to a unit shock for the euro area are similar to those for the United States. To save space we do not report them here.

The responses to a one standard deviation shock convey the same message in Figure 7. A shift in the central bank's inflation target (η_{1t}) has a permanent impact on inflation. Still, it takes various periods before the inflation rate stabilizes at the new target, both in the euro area and in the United States. This is to a big extent due to considerable expectations-based persistence that creates persistent deviations of the perceived inflation target from the central bank's inflation target. In case of a temporary shock to inflation (ε_{1t}), the convergence to the target goes much faster. According to the sum of the AR coefficients, intrinsic and expectations-based persistence are not statistically significantly different. Still, due to the persistence in the reaction of the central bank and the output gap, the number of quarters that inflation is affected by a difference between the perceived and the central bank's inflation target can be considerably higher. The shock to the perceived inflation target does not move inflation very much. It thus confirm that this shock is not very important to explain the historical inflation dynamics.

4 Conclusion

To design realistic business cycle models that can explain cyclical inflation dynamics we need to know how persistent inflation is. A common practice is to estimate a univariate autoregressive time series model and measure persistence as the sum of the autoregressive coefficients (e.g. Nelson and Plosser, 1982; Fuhrer and Moore, 1995; Pivetta and Reis, 2007). In most of these studies, inflation is found to exhibit high to very high persistence over the post-WW II period, i.e. persistence is found to be close to that of a random walk.

But it is important to note that this estimated high persistence is a measure of unconditional inflation persistence. Our paper extends the set of statistical inflation properties by disentangling inflation persistence in a number of economically meaningful sources. We use an unobserved component model to filter out four different sorts of inflation persistence. We estimate inflation persistence for the euro area and the U.S. The results show that intrinsic inflation persistence is fairly low, i.e. the half-life of a cost-push shock is less than one quarter. We conclude that a significant part of the observed univariate inflation persistence is inherited and that price-setting frictions such as indexation to past inflation or backward-looking expectations are not the best way to match the empirical evidence.

References

[1] Altissimo F., Bilke L., Levin A., Mathä T. and B. Mojon, 2006, Sectoral and Aggregate Inflation Dynamics in the Euro Area, *Journal of the European Economic Association,* 4, 585-593

[2] Amato, J.D. and T. Laubach, 1999, The value of interest rate smoothing: how the private sector helps the federal reserve, *Federal Reserve Bank of Kansas City Economic Reviews*, Third Quarter, 47-64.

[3] Andolfatto, D., Hendry, S. and K. Moran, 2007, Are Inflation Expectations Rational?, *Journal of Monetary Economics*, forthcoming

[4] Angeloni, I., Aucremanne, L., Ehrmann, M., Gali, J., Levin, A. and F. Smets, 2006, New Findings on Inflation Persistence and Price Stickiness in the Euro Area: Implications for Macro Modeling, *Journal of the European Economic Association*, 4, 562-574

[5] Ansley, C. and R. Kohn, 1985, Estimation, filtering and smoothing in state space models with incompletely specified initial conditions, *Annals of Statistics*, 13, 1286-1316.

[6] Bauwens, L., Lubrano, M. and J.F. Richard, 1999, *Bayesian Inference in Dynamic Econometric Models*, Oxford University Press, Oxford.

[7] Benati, L., 2004, International Evidence on the Persistence in Inflation, paper presented at the NBER Summer Institute 2004, 13-16 July 2004.

[8] Blanchard O.J. and J. Galí, 2007, Real Wage Rigidities and the New Keynesian Model, *Journal of Money Credit and Banking*, 39, 35-65

[9] Canova F., 2007, *Methods for Applied Macroeconomic Research*, Princeton University Press

[10] Castelnuovo E., Nicoletti-Altimari S. and D. Rodriguez-Palenzuela, 2003, Definition of Price Stability, Range and Point Inflation Targets: The Anchoring of Long-Term Inflation Expectations, in *Background Studies for the ECB's Evaluation of Its Monetary Policy Strategy*, O. Issing ed.

[11] Christiano L., Eichenbaum M. and Evans C., 2005, Nominal Rigidities and the Dynamic Effects of Shock to Monetary Policy, *Journal of Political Economy*, 113, 1-45

[12] Clarida R., Galí J. and M. Gertler, 1998, Monetary policy rules in practice. Some international evidence, *European Economic Review*, 42, 1033-1067.

[13] Cogley, T. and T. Sargent, 2001, Evolving Post World War II US Inflation Dynamics, *NBER Macroeconomics Annual 2001*, 331-372.

[14] Cogley, T. and T. Sargent, 2005, Drifts and Volatilities: Monetary Policies and Outcomes in the Post World War US, *Review of Economic Dynamics*, 8, 262-302

[15] de Jong, P., 1991, The diffuse Kalman filter, *Annals of Statistics*, 19, 1073-1083

[16] Durbin, J. and S. Koopman, 2001, *Time Series Analysis by State Space Methods*, Oxford Statistical Science Series, Oxford University Press, Oxford.

[17] English, W.B., Nelson, W.R. and B.P. Sack, 2003, "Interpreting the significance of the lagged interest rate in estimated monetary policy rules", *The B.E. Journal of Macroeconomics - Contributions*, 3, article 5.

[18] Erceg, C. and A. Levin, 2003, Imperfect credibility and inflation persistence, *Journal of Monetary Economics*, 50, 914-944.

[19] Fagan, G., Henry J. and R. Mestre, 2005, An area-wide model (AWM) for the euro area, *Economic Modelling*, 22, 39-59.

[20] Fuhrer, J. and G. Moore, 1995, Inflation Persistence, *Quarterly Journal of Economics*, 110, 127-159.

[21] Gadzinski, G. and F. Orlandi, 2004, Inflation Persistence for the EU Countries, the Euro Area and the US, ECB Working Paper 414.

[22] Galí J. and M. Gertler, 1999, Inflation Dynamics: A Structural Econometric Analysis, *Journal of Monetary Economics*, 44, 195-222

[23] Galí J., Gertler M. and D. Lopez-Salido, 2001, European inflation dynamics, *European Economic Review*, 45, 1237-1270.

[24] Gerlach, S. and F. Smets, 1999, Output Gaps and Monetary Policy in the Euro Area, *European Economic Review*, 43, 801-812.

[25] Geweke, J., 1989, Bayesian inference in econometric models using Monte Carlo integration, *Econometrica*, 57, 1317-1339.

[26] Hamilton, J., 1994, *Time Series Analysis*, Princeton University Press, Princeton.

[27] Harvey, A.C., 1985, Trends and Cycles in Macroeconomic Time Series, *Journal of Business and Economic Statistics*, 3, 216-227.

[28] Ireland P., 2007, Changes in the Federal Reserve's Inflation Target: Causes and Consequences, *Journal of Money Credit and Banking*, 39, 1851-1882

[29] Koopman, S., 1997, Exact initial Kalman filtering and smoothing for non-stationary time series models, *Journal of the American Statistical Association*, 92, 1630-1638.

[30] Koopman, S. and J. Durbin, 2000, Fast Filtering and Smoothing for Multivariate State Space Models, *Journal of Time Series Analysis*, 21, 281-296.

[31] Koopman, S. and J. Durbin, 2003, Filtering and Smoothing of State Vector for Diffuse State-Space Models, *Journal of Time Series Analysis*, 24, 85-98.

[32] Kozicki, S. and P.A. Tinsley, 2005, Permanent and Transitory Policy Shocks in an Empirical Macro Model with Asymmetric Information, *Journal of Economic Dynamics and Control*, 29, 1985-2015

[33] Laubach, T. and J. Williams, 2003, Measuring the Natural Rate of Interest, *Review of Economics and Statistics*, 85, 1063-1070.

[34] Levin, A.T. and J.M. Piger, 2004, Is Inflation Persistence Intrinsic in Industrial Economies?, ECB Working Paper 334.

[35] Milani F., 2007, Expectations, Learning and Macroeconomic Persistence, *Journal of Monetary Economics*, 54, 2065-2082

[36] Nelson, C.R. and C.I. Plosser, 1982, Trends and Random Walks in Macroeconomic Time Series: Some Evidence and Implications, *Journal of Monetary Economics*, 10, 139-162.

[37] O'Reilly, G. and K Whelan, 2005, Has euro area inflation persistence changed over time?, *Review of Economics and Statistics*, 87, 709-720

[38] Pivetta, F. and R. Reis, 2007, The persistence of inflation in the United States, *Journal of Economic Dynamics and Control*, 31, 1326-1358

[39] Rudebusch, G., 2005, Assessing the Lucas Critique in Monetary Policy Models, *Journal of Money, Credit and Banking*, 37, 245-272.

[40] Rudebusch, G. and L. Svensson, 1999, Policy Rules for Inflation Targeting, in J. Taylor, ed., *Monetary Policy Rules*, Chicago University Press, Chicago.

[41] Smets, F. and R. Wouters, 2005, Comparing shocks and frictions in US and euro area business cycles: a Bayesian DSGE approach, *Journal of Applied Econometrics*, 20, 161-183.

[42] Stock, J. and M. Watson, 1998, Median Unbiased Estimation of Coefficient Variance in a Time-Varying Parameter Model, *Journal of the American Statistical Association*, 93, 349-358.

[43] Taylor, J., 1993, Discretion versus policy rules in practice, *Carnegie-Rochester Conference Series on Public Policy*, 39, 195-214

Appendix A: Details on Estimation Method[4]

A.1 State Space Representation

The unobserved component models outlined in section 2 both include a number of unobserved components $(\pi_t^P, \pi_t^T, ...)$. In order to estimate these models, it is necessary to write them into state space form[5]. In a state space model, the development over time of the system under study is determined by an unobserved series of vectors $\alpha_1, \ldots, \alpha_n$, which are associated with a series of observed vectors $y_1, \ldots, y_n$. A general linear Gaussian state space model can be written in the following form:

$$y_t = Z\alpha_t + Ax_t + \varepsilon_t, \qquad \varepsilon_t \sim N(0, H), \tag{A.1}$$

$$\alpha_{t+1} = T\alpha_t + R\eta_t, \qquad \eta_t \sim N(0, Q), \qquad t = 1, \ldots, n, \tag{A.2}$$

where y_t is a $p \times 1$ vector of observed endogenous variables, modelled in the observation equation $(A.1)$, x_t is a $k \times 1$ vector of observed exogenous variables and α_t is a $m \times 1$ vector of unobserved states, modelled in the state equation $(A.2)$. The disturbances ε_t and η_t are assumed to be independent sequences of independent normal vectors. The matrices Z, A, T, R, H, and Q are parameter matrices.

$$y_t = \left[\begin{array}{ccc} \pi_t & i_t & y_t^r \end{array}\right]'; \; x_t = \left[\begin{array}{ccccccc} \pi_{t-1} & \pi_{t-2} & \cdots & \pi_{t-q} & y_{t-1} & y_{t-2} & i_{t-1} \end{array}\right]';$$

$$\alpha_t = \left[\begin{array}{cccccccccc} \pi_t^T & \pi_t^P & \pi_{t-1}^P & y_t^P & y_{t-1}^P & y_{t-2}^P & \lambda_t & \lambda_{t-1} & \tau_t & \tau_{t-1} \end{array}\right]';$$

$$A = \begin{bmatrix} \varphi_1 & \varphi_2 & \cdots & \varphi_q & \beta_1 & 0 & 0 \\ \rho_1 & 0 & \cdots & 0 & 0 & 0 & \rho_2 \\ 0 & 0 & \cdots & 0 & \beta_2 & \beta_3 & -\beta_4 \end{bmatrix};$$

$$Z = \begin{bmatrix} 0 & (1 - \sum_{i=1}^{q} \varphi_i) & 0 & 0 & -\beta_1 & 0 & 0 & 0 & 0 & 0 \\ -\rho_1 & (1-\rho_2) & 0 & 0 & 0 & 0 & (1-\rho_2)\gamma & 0 & (1-\rho_2) & 0 \\ 0 & 0 & \beta_4 & 1 & -\beta_2 & -\beta_3 & 0 & \beta_4\gamma & 0 & \beta_4 \end{bmatrix};$$

---

[4] The method outlined in this section was implemented using a set of GAUSS procedures. The code of these procedures is available from the authors on request.

[5] See e.g. Durbin and Koopman (2001) for an extensive overview of state space methods.

$$T = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \delta & (1-\delta) & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \theta & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}; \quad R = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ \delta & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\varepsilon_t = \begin{bmatrix} \varepsilon_{1t} & \varepsilon_{2t} & \varepsilon_{3t} \end{bmatrix}'; \quad \eta_t = \begin{bmatrix} \eta_{1t} & \eta_{2t} & \eta'_{3t} & \eta_{4t} & \eta_{5t} \end{bmatrix}';$$

$$H_t = \begin{bmatrix} \sigma^2_{\varepsilon_1} & 0 & 0 \\ 0 & \sigma^2_{\varepsilon_2} & 0 \\ 0 & 0 & \sigma^2_{\varepsilon_3} \end{bmatrix}; \quad Q_t = \begin{bmatrix} \sigma^2_{\eta_1} & 0 & 0 & 0 & 0 \\ 0 & \sigma^2_{\eta_2} & 0 & 0 & 0 \\ 0 & 0 & \sigma^2_{\eta_3} & 0 & 0 \\ 0 & 0 & 0 & \sigma^2_{\eta_4} & 0 \\ 0 & 0 & 0 & 0 & \sigma^2_{\eta_5} \end{bmatrix}$$

A.2 Kalman Filter and Smoother

Assuming that Z, A, T, R, H, and Q are known, the purpose of state space analysis is to infer the relevant properties of the α_t's from the observations $y_1, \ldots, y_n$ and $x_1, \ldots, x_n$. This can be done through the subsequent use of two recursions, i.e. the Kalman filter and the Kalman smoother. The objective of filtering is to obtain the distribution of α_t, for $t = 1, \ldots, n$, conditional on Y_t and X_t, where $Y_t = \{y_1, \ldots, y_t\}$ and $X_t = \{x_1, \ldots, x_t\}$. In a linear Gaussian state space model, the distribution of α_t is entirely determined by the filtered state vector $a_t = E(\alpha_t \mid Y_t, X_t)$ and the filtered state variance matrix $P_t = Var(\alpha_t \mid Y_t, X_t)$. The (contemporaneous) Kalman filter algorithm (see e.g. Hamilton, 1994, or Durbin and Koopman, 2001) estimates a_t and P_t by updating, at time t, a_{t-1} and P_{t-1} using the new information contained in y_t and x_t. The Kalman filter recursion can be initialized by the assumption that $\alpha_1 \sim N(a_1, P_1)$. In practice, a_1 and P_1 are generally not known though. Therefore, we assume that the distribution of the initial state vector α_1 is

$$\alpha_1 = V\Gamma + R_0\eta_0, \qquad \eta_0 \sim N(0, Q_0), \qquad \Gamma \sim N(0, \kappa I_r), \tag{A.3}$$

where the $m \times r$ matrix V and the $m \times (m-r)$ matrix R_0 select the r elements of the state vector that are non-stationary and the $m-r$ elements that are stationary respectively. They are composed of columns of the identity matrix I_m and are defined so that, when taken together, their columns constitute all the columns of I_m and $V'R_0 = 0$. The unconditional variance matrix Q_0 of the stationary elements of the state vector is positive definite and can be computed from the model parameters. The $r \times 1$ vector Γ is a vector of unknown random quantities which, as we let $\kappa \to \infty$, is referred to as the diffuse vector. This leads to

$$\alpha_1 \sim N(0, P_1), \qquad P_1 = \kappa P_\infty + P_*, \tag{A.4}$$

where $P_\infty = VV'$ and $P_* = R_0 Q_0 R_0'$. The Kalman filter is modified to account for this diffuse initialization implied by letting $\kappa \to \infty$ by using the exact initial Kalman filter introduced by Ansley and Kohn (1985) and further developed by Koopman (1997) and Koopman and Durbin (2003).

Subsequently, the Kalman smoother algorithm is used to estimate the distribution of α_t, for $t = 1, \ldots, n$, conditional on Y_n and X_n, where $Y_n = \{y_1, \ldots, y_n\}$ and $X_n = \{x_1, \ldots, x_n\}$. Thus, the smoothed state vector $\widehat{a}_t = E(\alpha_t \mid Y_n, X_n)$ and the smoothed state variance matrix $\widehat{P}_t = Var(\alpha_t \mid Y_n, X_n)$ are estimated using all the observations for $t = 1, \ldots, n$. In order to account for the diffuse initialization of α_1, we use the exact initial state smoothing algorithm suggested by Koopman and Durbin (2003).

A.3 Bayesian Analysis

In principle, the integral in equation (15) can be evaluated numerically by drawing a sample of n random draws of ψ, denoted $\psi^{(i)}$ with $i = 1, \ldots, n$, from $p(\psi \mid y, x)$ and then estimating $\overline{g}$ by the sample mean of $g(\psi)$. As $p(\psi \mid y, x)$ is not a density with known analytical properties, such a direct sampling method is not feasible, though. Therefore, we switch to importance sampling. The idea is to use an importance density $g(\psi \mid y, x)$ as a proxy for $p(\psi \mid y, x)$, where $g(\psi \mid y, x)$ should be chosen as a distribution that can be simulated directly and is as close to $p(\psi \mid y, x)$ as possible. By Bayes' theorem and after some manipulations, equation (15) can be rewritten as

$$\overline{g} = \frac{\int g(\psi)\, z^g(\psi, y, x)\, g(\psi \mid y, x)\, d\psi}{\int z^g(\psi, y, x)\, g(\psi \mid y, x)\, d\psi} \tag{A.5}$$

with

$$z^g(\psi, y, x) = \frac{p(\psi)\, p(y \mid \psi)}{g(\psi \mid y, x)} \tag{A.6}$$

Using a sample of n random draws $\psi^{(i)}$ from $g(\psi \mid y, x)$, an estimate $\overline{g}_n$ of $\overline{g}$ can then be obtained as

$$\overline{g}_n = \frac{\sum_{i=1}^{n} g\left(\psi^{(i)}\right) z^g\left(\psi^{(i)}, y, x\right)}{\sum_{i=1}^{n} z^g\left(\psi^{(i)}, y, x\right)} = \sum_{i=1}^{n} w_i g\left(\psi^{(i)}\right) \tag{A.7}$$

with w_i

$$w_i = z^g\left(\psi^{(i)}, y, x\right) / \sum_{i=1}^{n} z^g\left(\psi^{(i)}, y, x\right) \tag{A.8}$$

the weighting function reflecting the importance of the sampled value $\psi^{(i)}$ relative to other sampled values.

Geweke (1989) shows that if $g(\psi \mid y, x)$ is proportional to $p(\psi \mid y, x)$, and under a number of weak regularity conditions, $\overline{g}_n$ will be a consistent estimate of $\overline{g}$ for $n \to \infty$.

A.4 Computational Aspects of Importance Sampling

As a first step importance density $g(\psi \mid y, x)$, we take a large sample normal approximation to $p(\psi \mid y, x)$, i.e.

$$g(\psi \mid y, x) = N\left(\widehat{\psi}, \widehat{\Omega}\right) \tag{A.9}$$

where $\widehat{\psi}$ is the mode of $p(\psi \mid y, x)$ obtained from maximizing

$$\log p(\psi \mid y, x) = \log p(y \mid \psi) + \log p(\psi) - \log p(y) \tag{A.10}$$

with respect to $\widehat{\psi}$ and where $\widehat{\Omega}$ denotes the covariance matrix of $\widehat{\psi}$. Note that $p(y \mid \psi)$ is given by the likelihood function derived from the exact Kalman filter and we do not need to calculate $p(y)$ as it does not depend on ψ.

In drawing from $g(\psi \mid y, x)$, efficiency was improved by the use of antithetic variables, i.e. for each $\psi^{(i)}$ we take another value $\widetilde{\psi}^{(i)} = 2\widehat{\psi} - \psi^{(i)}$, which is equiprobable with $\psi^{(i)}$. This results in a simulation sample that is balanced for location (Durbin and Koopman 2001).

As any numerical integration method delivers only an approximation to the integrals in equation $(A.5)$, we monitor the quality of the approximation by estimating the probabilistic error bound for the importance sampling estimator $\overline{g}_n$ (Bauwens, Lubrano and Richard 1999, chap. 3, eq. 3.34). This error bound represents a 95% confidence interval for the percentage deviation of $\overline{g}_n$ from $\overline{g}$. It should not exceed 10%. In practice this can be achieved by increasing n, except when the coefficient of variation of the weights w_i is unstable as n increases. An unstable coefficient of variation of w_i signals poor quality of the importance density. This was exactly the problem encountered in the empirical analysis.

Note that the normal approximation in equation $(A.9)$ selects $g(\psi \mid y, x)$ in order to match the location and covariance structure of $p(\psi \mid y, x)$ as good as possible. One problem is that the normality assumption might imply that $g(\psi \mid y, x)$ does not match the tail behavior of $p(\psi \mid y, x)$. If $p(\psi \mid y, x)$ has thicker tails than $g(\psi \mid y, x)$, a draw $\psi^{(i)}$ from the tails of $g(\psi \mid y, x)$ can imply an explosion of $z^g\left(\psi^{(i)}, y, x\right)$. This is due to a very small value for $g(\psi \mid y, x)$ being associated with a relatively large value for $p(\psi)\,p(y \mid \psi)$, as the latter is proportional to $p(\psi \mid y, x)$. Importance sampling is inaccurate in this case as this would lead to a weight w_i close to one, i.e. $\overline{g}_n$ is determined by a single draw $\psi^{(i)}$. This is signaled by instability of the weights and a probabilistic error bound that does not decrease in n.

In order to help prevent explosion of the weights, we change the construction of the importance density in two respects (Bauwens *et al.* 1999, chap. 3). First, we inflate the approximate covariance matrix $\widehat{\Omega}$ a little. This reduces the probability that $p(\psi \mid y, x)$ has thicker tails than $g(\psi \mid y, x)$. Second, we use a sequential updating algorithm for the importance density. This algorithm starts from the importance density defined by $(A.9)$, with inflation of $\widehat{\Omega}$, estimates posterior moments for $p(\psi \mid y, x)$ and then defines a new importance density from these estimated moments. This improves the estimates for $\widehat{\psi}$ and $\widehat{\Omega}$. We continue updating the importance density until the weights stabilize. The number of importance samples n was chosen to make sure that the probabilistic error bound for the importance sampling estimator $\overline{g}_n$ does not exceed 10%.

Appendix B: Data

The sample of all data we use runs from 1970:2 to 2005:4.

- **Inflation**: quarterly inflation rate, defined as $400(lnP_t - lnP_{t-1})$, with P_t the seasonally adjusted quarterly GDP deflator. Sources: Area Wide Model (Fagan et al, 2005) and Bank for International Settlements;

- **Real output**: quarterly output, defined as $100ln(GDP_t)$, with GDP_t the seasonally adjusted quarterly GDP in constant prices. Sources: Area Wide Model (Fagan et al, 2005) and Bank for International Settlements;

- **Key interest rate**: quarterly central bank key interest rate. Sources: European Central Bank and Bank for International Settlements.

Some Evidence on the Adjustment of Producer Prices[*]

David Cornille[†] Maarten Dossche[‡]

April 26, 2008

Abstract

We document producer price adjustment using a low-inflation micro price dataset. On average 24% of prices adjust each month, with an average increase/decrease of 6%. Producer prices adjust more frequently than consumer prices, but their size of adjustment is typically smaller. Sectoral heterogeneity in the frequency of price adjustment is strongly related to heterogeneity in the cost structure. Fluctuations in aggregate producer price inflation occur to a large extent through variation in the relative share of upward and downward price adjustment.

JEL classification: D40, E31
Keywords: price adjustment, producer prices

---

[*] *Forthcoming in The Scandinavian Journal of Economics.* We thank two anonymous referees and the editor for their insightful comments. This study was developed within the Eurosystem Inflation Persistence Network. We are grateful to participants in this network and in particular Luc Aucremanne, Emmanuel Dhyne, Vivien Lewis, Philip Vermeulen for helpful comments. We also thank the Federal Public Service Economy, SMEs, Self-Employed and Energy and Koen Hooyberghs for providing us with the data. Special thanks also to Emmanuel Dhyne and Mauro Pisu for providing us with statistics on consumer price adjustment and sectoral four-firm concentration ratios. The views expressed in this paper are those of the authors and do not necessarily reflect the views of the National Bank of Belgium. All remaining errors are the authors'. Maarten Dossche acknowledges financial support from the Interuniversity Attraction Poles Program (Belgian Science Policy), contract n° P5/21.

[†] National Bank of Belgium

[‡] Corresponding author. National Bank of Belgium and Ghent University - SHERPPA, Maarten.Dossche@nbb.be

1 Introduction

The way producer prices adjust is important in macroeconomics for at least three reasons. First, producer prices play an important role in models with intermediate goods.[1] The adjustment of producer prices determines how shocks to production costs and demand for intermediate goods are passed through to consumer prices. In a model with intermediate goods and an inflation targeting central bank the extent of producer price stickiness determines the optimal weight the central bank attaches to producer versus consumer price inflation.[2] Second, producer prices play an important role in recent models of open economies and exchange rate pass-through. In these models only intermediate goods are tradable, whereas consumer goods are a combination of intermediate goods and non-tradable retail services.[3] Third, even to calibrate macroeconomic models that abstract from the distinction between consumer and producer prices, one would ideally combine empirical evidence from consumer and producer prices. In industrialized countries 40% of the value of a consumption good is typically generated in the distribution stage, whereas 60% of its value is generated in the production stage (Burstein et al., 2003). Combining evidence from both prices is at least important if there are significant differences in the way both sorts of prices adjust. For the United States, for instance, Bils and Klenow (2004) find more frequent price changes than the survey evidence of Blinder et al. (1998). They suggest that this difference might be due to Blinder et al. (1998) mainly surveying intermediate products.

The purpose of this paper is to gather a set of empirical facts about producer price adjustment that can be used when calibrating the supply side of macroeconomic models. We compare some of these facts to facts about consumer price adjustment, and document the determinants of producer price adjustment in response to sectoral and aggregate shocks. We find that producer price adjustment does not differ much qualitatively from consumer price adjustment. However, there are some quantitative differences that should be important enough not to be neglected when calibrating models with intermediate goods.

---

[1] E.g. Blanchard (1983), Basu (1995) and Nakamura and Steinsson (2007b).

[2] Huang and Liu (2005) show that the relative weight of producer price inflation is a function of its stickiness. If producer prices approach full flexibility, the weight in the objective function goes to zero.

[3] E.g. Burstein et al. (2003) and Corsetti and Dedola (2005).

Contrary to Bils and Klenow's (2004) conjecture, we find that producer price adjustment happens more frequently, but is smaller-sized than consumer price adjustment. Differences in the degree of competition or price adjustment costs seem necessary to explain the difference between consumer and producer price adjustment. We also find that differences in frequencies of price adjustment *within* the producer sector are strongly related to differences in the cost structure, in particular the share of energy and labor costs. Finally, aggregate price adjustment is to a large extent driven by variation in the relative share of upward and downward price adjustment.

We contribute to a limited number of studies analyzing producer price adjustment as opposed to a rapidly growing number of studies of consumer price adjustment.[4] The paper uses prices covering nearly the entire Belgian industrial sector and is written within the Eurosystem Inflation Persistence Network (IPN), a network of euro area central bank researchers.[5] Vermeulen et al. (2007) summarize a number of euro area findings on producer price adjustment, confirming their robustness across individual countries. For the United States there exists evidence on producer price adjustment too, albeit limited. Nakamura and Steinsson (2007a) focus only on producer prices for finished goods. Carlton (1986) analyzes a relatively old sample recorded from 1957 to 1966.

In Section 2 we describe the dataset. In Section 3 we gather a number of facts characterizing producer price adjustment, and compare some of them with facts about consumer price adjustment. In Section 4 we investigate the determinants of producer price adjustment in response to sectoral and aggregate shocks. Section 5 concludes.

2 Data

Our dataset consists of price records collected by the Belgian National Statistics Institute (NSI) to compute the Belgian producer price index (PPI). The PPI is a short-term indicator measuring monthly

---

[4] A non-exhaustive list of studies covering almost all consumer products is Bils and Klenow (2004) and Nakamura and Steinsson (2007a) for the United States, Dhyne et al. (2006) for the euro area, Higo and Saita (2007) for Japan and Gagnon (2007) for Mexico.

[5] Other studies of producer price adjustment within the IPN are Dias et al. (2004) for Portugal, Álvarez et al. (2005) for Spain, Gautier (2006) for France, Sabbatini et al. (2006) for Italy, and Stahl (2006) for Germany.

price developments of industrial products. The common European rules concerning the collection of prices have been established in a number of European Council and Commission Regulations (Eurostat, 2002). Prices are recorded ex-factory, including all duties and taxes except VAT. They refer to actual transaction prices, not list prices. Each price record refers to the time the order is placed, and not the time the commodities leave the factory. The prices are collected through a monthly survey, in which each firm takes part voluntarily.

The NSI allowed access to its micro data for research under strict confidentiality. The micro data we have access to cover 83% of the PPI. The price records corresponding to the 17% of the PPI we did not get access to mainly refer to the export market. The prices are quoted in euro, and for each price quote we observe a branch of economic activity code[6], a firm code, a code identifying whether the price is valid in Belgium or abroad, a code describing the product version, and the month and year the price was recorded. The sample contains over 100,000 price level observations from January 2001 to January 2005 of around 1,500 firms. This implies a seasonally balanced sample of monthly price changes from February 2001 to January 2005. The average number of price quotes per month is 2,100.[7] Firms may not report a price during a certain month, or even stop participating in the survey so that the coverage of the dataset slightly varies across months. When the price of a product is no longer observed, the product is replaced by a close substitute from the same firm. This replacement implies the end of the price trajectory for the old product, and implies the start of the price trajectory for the new product. The dataset contains only 214 product replacements, implying an average replacement rate of 0.2%. This is low compared to the 3% that Klenow and Kryvtsov (2007) report for U.S. consumer prices. We do not observe any product introductions or retirements in our sample. The low degree of substitution and product introduction/retirement could be explained by the fact that firms in our survey are asked for their most important product, which is probably more established and has a lower chance of leaving

---

[6] We observe the 8-digit PRODCOM code. PRODCOM stands for PRODucts of the European COMmunity.

[7] During the first months of 2001 the dataset covers only about 1,800 price quotes per month. If we discard the first months of 2001, the condition to have a seasonally balanced sample would imply that all observations of 2001 should be discarded, which is about 25% of the dataset. We choose not to do this.

the catalogue. We decide to report statistics on price adjustment excluding product replacement.

The main NACE[8] branches covered are Mining, Quarrying, Manufacturing Industry, Electricity, Gas and Water Supply. Together these branches constitute the national accounts category Total Industry Excluding Construction. Our data set can be disaggregated into 207 NACE 4-digit level branches, 97 NACE 3-digit level branches, and 27 NACE 2-digit level branches. The NACE classification also allows a breakdown in six Main Industrial Groupings (MIG), classifying the goods at the NACE 3-digit level according to their purpose of use. The classification distinguishes between consumer food, consumer non-durables, consumer durables, intermediate goods, energy and capital goods. The classification is somewhat different from the one used in the United States by the Bureau of Labor Statistics (2007) (BLS). Intermediate goods and crude materials in the Stage of Processing (SoP) classification of the BLS correspond roughly to intermediate goods and a part of energy in Eurostat's classification. Finished goods in the SoP classification correspond roughly to consumer food, consumer non-durables, consumer durables, capital goods and a part of energy. To distinguish the term "intermediate goods" in economic models from the term "intermediate goods" in the statistical classifications of Eurostat (2002) and the BLS (2007), we henceforth label intermediate goods in the Eurostat classification as "MIG-intermediate goods" and in the BLS classification as "SoP-intermediate goods."

Between February 2002 and January 2005, the official twelve-month PPI inflation rate varied between -1.5% and 6%, while the average twelve-month inflation rate was 1.5%. Note that throughout the text we will refer to PPI inflation as (aggregate) inflation or aggregate price adjustment. The twelve-month inflation rate in our data set varied between -3.3% and 4.9%, while the average twelve-month inflation rate was 0.7%. The difference between official inflation and the inflation implied in our data mainly comes from the export market. We conjecture that in the period our sample covers buoyant export markets pushed up prices more than in the domestic market. The missing goods are spread over different product categories, so we do not think that this difference in average inflation seriously affects our results. We also compare our main statistics with other countries that have somewhat higher infla-

---

[8] NACE stands for Statistical Classification of Economic Activities in the European Community.

tion rates and do not find significant differences. The correlation between the official inflation rate and the inflation rate in the data is 0.72. What is most important is that in our sample inflation fluctuates considerably and average inflation is low.

3 Facts about Producer Price Adjustment

3.1 Frequency and Size of Price Adjustment

Adjustment to shocks can occur through variation in the frequency as well as the size of price adjustment. That is the reason why these two statistics are so often used in studies of price adjustment. In Appendix A we show how we compute the frequency and size of price adjustment for the overall dataset, across time, and across sectors. We obtain these statistics at the NACE 4-digit level, and then aggregate to higher levels of aggregation using the PPI weights.[9] As long as enough observations are available, we analyze the data at the most disaggregate level. Exploiting the panel structure of our dataset we here document the overall frequency and size of price adjustment, as well as variations across time and sectors.

Overall Frequency and Size

Contrary to consumer prices we do not find evidence for temporary price markdowns in producer prices. Only 0.1% of the prices show the typical V-shaped pattern, where after a temporary price markdown the price returns back to its previous level. This is one important qualitative difference between consumer and producer price adjustment. Therefore, we do not account for temporary price markdowns as Nakamura and Steinsson (2007a) and Midrigan (2006) do for consumer prices. Kehoe and Midrigan (2007) show that the presence of markdowns in consumer price data complicates modeling the price setting decision. The absence of markdowns in producer prices attenuates this problem somewhat.

Each month on average 24% of prices adjust. This measure is a weighted average of the frequencies originally computed for each of the branches of economic activity at the NACE 4-digit level. Our

---

[9] The NSI uses firm- and product-specific turnover to weight each price observation. As we have no access to these weights, we assume that every observation has an equal weight at the NACE 4-digit level. We then use the official PPI weights to aggregate to higher levels of aggregation.

average frequency of price adjustment fr is similar to the average frequency in other studies of micro producer prices. Except for Italy all IPN studies find an average frequency of price adjustment that is higher than 20%. Nakamura and Steinsson (2007a) find that 25% of finished goods prices adjust each month. They exclude crude materials and SoP-intermediate goods, that have a share of 53% in our dataset. We believe that including this part of the production chain contributes to the value added of our paper, precisely to document price adjustment at the earlier stages of production.

Inverting the average frequency yields an average implied price duration of 4.2 months. The implied duration is 10 months if we compute the weighted average of the implied durations at the NACE 4-digit level. The difference also applies for other countries and follows from Jensen's inequality.[10] Bils and Klenow (2004) choose to calculate the weighted median of the inverse frequencies, which is 7 months for our data. The inverse of the weighted median frequency gives the same result. Using survey evidence, Aucremanne and Druant (2005) find that the average price duration in the Belgian industry is 11.9 months, which is comparable to our average of the implied durations at the disaggregate level. In the remainder of the paper we will continue to work with the average frequency of price adjustment fr.[11]

The average absolute size of price adjustment is 6%. This is 100 times the average monthly inflation rate of 0.06%. We see this as evidence for large idiosyncratic shocks as in Golosov and Lucas (2007). The coexistence of upward and downward price adjustment corroborates this interpretation. The other IPN studies find an average size of adjustment ranging between 3.3% in Germany and 4.8% in Portugal. Nakamura and Steinsson (2007a) find a median size of 7.7% for finished goods.

<insert Figure 1 about here>

The average frequency of a price decrease is 11%, whereas a price increase is slightly more frequent with 13%. So 54% of price changes are price increases. The average downward price adjustment is

---

[10] For more details concerning this issue we refer to Baharad and Eden (2004).

[11] If we assume that prices can change at any moment, not just at monthly intervals, then the instantaneous probability of a price change is $-\ln(1-fr)$. Bils and Klenow (2004) use the latter formula instead of a simple inversion of the frequency to compute implied durations. If we use this formula instead of our simple inversion, we get an implied average duration of 3.7 months, a weighted average implied duration of 9.4 months, and an implied median duration of 6.5 months. The difference between this approach and the one in the main text is always approximately 0.5 months.

as large as the average upward price adjustment, so that we infer that there is limited evidence for downward nominal rigidity. Downward nominal rigidity would imply that the distribution of price changes is positively skewed. The skewness of the overall distribution of price changes in Figure 1 is however negative with -0.36.[12] Another way to compare asymmetry in upward and downward price adjustment is to compare the distribution mass left from zero with the mass right from zero. Eyeballing Figure 1 shows that if there is somewhat less frequent downward price adjustment, then this must come from fewer small price decreases.

Frequency and Size Across Time

Figure 2 documents the frequency of price adjustment across time. The seasonality is very outspoken. In January more than 40% of prices adjust compared to about 20% for the other months of the year. We regress the monthly frequencies on a constant and 11 monthly dummies and indeed find that only the frequency in January significantly differs from the other months. For the sizes of price adjustment in Figure 3 it is harder to tell whether there is a clear seasonal pattern. We regress the absolute value of price changes on a constant and 11 monthly dummies, and again find a significant effect in January. On the one hand, a time-dependent model with more nominal price contracts adjusting in January could reproduce this result. On the other hand, if changes in costs or demand are seasonal, then a state-dependent model will also be able to reproduce this result. In Section 4.2 we analyze more in depth how variation in the frequencies and sizes generates variation in aggregate inflation.

<insert Figure 2 about here>

<insert Figure 3 about here>

Frequency and Size Across Sectors

Comparing the price adjustment frequencies in Table 1 across the six MIGs, we find that the frequency of price adjustment ranges from 50% for energy to 11% for consumer non-durables. Especially prices for

---

[12] We compute the weighted skewness of the distribution of price changes conditional on adjustment using the PPI weights for each price change. See also Figure 1.

food, intermediate goods and energy change often, whereas consumer non-durables, consumer durables and capital goods change less often. Prices of less processed goods typically change more often. At the more disaggregate level of the 97 NACE 3-digit branches of economic activity the standard deviation of the frequencies is 20%. Table 1 shows that the average price adjustment ranges between 3% for consumer durables and 7% for intermediate goods. At the NACE 3-digit branches of economic activity the standard deviation is 4% for the absolute value of the sizes.

<insert Table 1 about here>

We find that the correlation between the sectoral frequencies and sizes of price adjustment is not significantly different from zero. So for a given aggregate inflation rate it is not so that some sectors adjust relatively more through the frequency of price adjustment, and less through the size of price adjustment. If there are sectoral differences in competition or price adjustment costs, in a basic (s,S)-type model of price adjustment à la Barro (1972) there would be a negative correlation between sizes and frequencies. If there are sectoral differences in the volatility of shocks we expect a positive or no correlation.[13] If there are at the same time differences in competition, price adjustment costs and the volatility of shocks it is hard to interpret the zero correlation. In Section 4.1 we assess more in depth the importance of differences in competition and cost structure for sectoral frequencies and sizes. In Appendix B we report sectoral price adjustment statistics at the NACE 3-digit level.

A Comparison with Consumer Prices

Before comparing the adjustment of consumer and producer prices, it is worth noting that there are two important dimensions along which the coverage of the CPI and PPI differs. First, the CPI covers goods and services, whereas the PPI only covers goods. Second, the stage of processing of the goods

---

[13] There are mainly three factors that can affect the frequency/size of price adjustment in a menu cost model à la Barro (1972). First, a larger adjustment cost implies that the frequency of price adjustment decreases, and the size of price adjustment increases. Second, more competition increases the opportunity cost of non-adjustment, so that the frequency of price adjustment increases, and the size of price adjustment decreases. Third, more volatile shocks to costs and demand increase the frequency of price adjustment, and the size of price adjustment increases or can remain constant. The effect of more volatile shocks on the size of price adjustment will depend on the distribution of the shocks and their persistence. It is unlikely that higher volatility will decrease the size of price adjustment in this model.

differs.[14] Before a finished good can appear in the CPI it needs to be distributed. Distribution includes wholesale, retail, marketing, advertisement, and transportation services. As in most industrialized countries (Burstein et al., 2004) the distribution margin in Belgium accounts for about 40% of the retail price of goods.

The choice of the level of aggregation to compare consumer and producer price adjustment depends on the purpose of the comparison. For example, if we simply want to calibrate an economy with consumer and producer prices and price setting à la Calvo, we should compare the entire baskets. For Belgium Aucremanne and Dhyne (2004) find that on average consumer goods adjust with a frequency of 14% and a size of 8%.[15] We find that producer goods adjust with a frequency of 24% and a size of 6%.[16] [17] This goes against the conjecture of Bils and Klenow (2004), that the difference between their results and Blinder et al. (1998) may be due to producer prices adjusting less frequently. Nakamura and Steinsson (2007a) compare consumer and producer price adjustment and conclude that there is no significant difference. However, they only use finished producer goods and discard the more frequently changing SoP-intermediate goods and crude materials.

If we want to understand what model can explain differences in price adjustment arising from progressing along the production chain, we should use comparable goods. We are able to match 82 pairs of goods covered both in the CPI and the PPI.[18] Figures 4 and 5 illustrate that for consumer goods the frequencies of price adjustment are on average lower, whereas the sizes of price adjustment are larger. We also perform a t-test, Wilcoxon rank test, Kruskal-Wallis test comparing the mean and median of the consumer and producer frequencies and sizes. All tests show that at the 1% significance

---

[14] Another difference is that the CPI also covers imported goods, whereas the PPI only covers goods produced at home.

[15] These numbers refer to the sample 1996-2003. In fact, Aucremanne and Dhyne (2004) report an average frequency of price adjustment of 17% for the sample 1989-2001. They do not report an aggregate average size of price adjustment. As our sample period is more recent, we prefer to use the more recent statistics provided by the authors.

[16] This result cannot be driven by an incomplete accounting for temporary markdowns in the CPI, because these markdowns imply more frequent and larger price adjustment. Neither can the result for the frequencies be driven by the fact that in the CPI data there is no indicator for the version of the product, whereas for producer price statistics we decide to exclude product replacement. The different treatment of replacements in the CPI can only increase the estimate of the frequency of consumer price adjustment, and thus narrow the gap between the two frequencies.

[17] Aucremanne and Druant (2005) find that the frequency of price adjustment in the industrial sector is in between other intermediate goods sectors such as construction and business services. Producer prices thus seem to represent well price adjustment at the earlier stages of production.

[18] The list of goods can be obtained on request from the corresponding author.

level the statistics are different, except for the median tests on the frequencies where the significance level is only 10%. So even if we use comparable goods we find that for producer prices the frequencies of price adjustment are higher, whereas the sizes are smaller. Except for Portugal all other IPN producer price studies find the same result.

<insert Figure 4 about here>

<insert Figure 5 about here>

Because of the larger share of labor-intensive services in the CPI we expect that consumer prices change less frequently. Gordon (1990) also suggests that the stage of processing could have an effect on the frequency of price adjustment through the law of large numbers. At the end of the production chain goods get more complicated so that input costs are more diversified and output prices need to change less often. However, the arguments of more labor-intensive and better cost-diversified consumer goods have difficulty in explaining a jointly larger size and lower frequency of consumer price adjustment. Theories based on differences in competition or price adjustment costs could account for this observation. The fact that goods become more differentiated at the end of the production chain, which generally lowers competition, is supportive of this idea.

3.2 Some Additional Summary Statistics

The recent literature that documents price setting using micro data mostly focuses on the frequency and size of price adjustment. However, we cannot calibrate some aspects of price setting unless we use other moments of the data containing additional information. Some authors therefore use an extended set of moments. We here report these statistics for our data and briefly compare them.

Golosov and Lucas (2007) focus on the role of idiosyncratic shocks for price adjustment. They use five statistics computed by Klenow and Kryvtsov (2007) using US micro consumer prices. For a detailed description of how to compute these statistics we refer to Klenow and Kryvtsov (2007). The first two statistics are the across time average and standard deviation of aggregate *quarterly* inflation, which are 0.1% and 0.87%, as compared to 0.64% and 0.62% in the US. Their third statistic is the average fraction of items adjusting, and is 24% compared to 21.9% in the US. The fourth statistic is the weighted average price increase, and is 6% compared to 9.5% in the US. The fifth statistic is the average standard deviation of newly set prices and is a measure of how disperse newly set relative prices are *within* a product category. The measure is based on the log deviation of a price from the product category price index. For each item we compute the standard deviation of the log deviation across months with price increases. Then we compute a weighted average of these standard deviations. We calculate this statistic at the NACE 4-digit level, and is 0.071 compared to 0.087 in the US.

Midrigan (2006) reports the mean, standard deviation and kurtosis of the price change distribution conditional on adjustment. We respectively find 0.00%, 9.58%, and 16.41, compared to 1.5%, 10.4% and 5.4 in the Dominick's Finer Foods scanner dataset.[19] The high kurtosis reflects the overrepresentation of small price changes compared to a normal distribution. This is also very clear in Figure 1, comparing the histogram of price changes with the corresponding histogram of the normal distribution. Midrigan (2006) also measures the share of small price changes by the share of absolute price changes that are smaller than half the average price change. This is 54% of the price changes in our data, compared to 35% in the Dominick's Finer Foods scanner dataset. Although Midrigan looks at a narrow set of consumer prices, this indicates that small price changes are more important for producer prices. The assumption of a multi-product retailer can account for this large share of small price changes. To assess the plausibility of the multi-product retailer assumption we unfortunately do not have information on how many products each firm in our dataset sells.

We compute the Fisher and Konieczny (2000) index that measures the degree of synchronization in price adjustment across items. The index ranges from 0 to 1, corresponding respectively to perfect staggering and perfect synchronization.[20] We do this at the 4-, 3-, and 2-digit level, and compute a

---

[19] Midrigan (2006) also computes the same statistics for ACNielsen data.

[20] The synchronization ratio in product category j is defined as: $FK_j = \sqrt{\frac{1}{\tau-1}\frac{\sum_{t=2}^{\tau}\left(fr_{jt}-fr_j\right)^2}{fr_j\left(1-fr_j\right)}}$. τ is the number of time periods.

weighted average. We get a value of respectively 0.46, 0.44, and 0.37, indicating that price adjustment is more synchronized at a more disaggregate level. This is consistent with Dhyne and Konieczny (2007) for consumer prices.

These additional moments indicate that producer price adjustment does not differ much qualitatively from consumer price adjustment, except that quantitatively there might be some difference in the kurtosis of the price change distribution.

4 What Determines Price Adjustment?

First, we ask what explains the sectoral heterogeneity in frequencies and sizes of price adjustment. Second, we ask to what extent time variation in the frequency vs. time variation in the size of price adjustment explain (in an accounting sense) aggregate inflation fluctuations.

4.1 Sectoral Fluctuations

In Section 3.1 we documented that the frequencies and sizes of price adjustment are heterogeneous across sectors. We here run a number of reduced form regressions linking the sectoral frequencies/sizes of price adjustment at the NACE 3-digit level to proxies for the degree of competition and the cost structure suggested by economic theory. We distinguish between the overall, downward and upward frequency/size of price adjustment. The proxies for the determinants are either calculated on the basis of the Belgian input-output tables, an ad hoc survey on price setting for Belgium by Aucremanne and Druant (2005), or the firms' annual balance sheets. We provide the sources and a detailed description in Appendix A. First, we test the importance of the degree of competition. Sectors with less competition have a less curved profit function, so that the extent to which they deviate from their optimal price has less impact on their profits. In a basic (s,S)-type model à la Barro (1972) we expect them to adjust their price less frequently and with a larger size. Second, we test the importance of the cost structure. In a basic (s, S)-type model higher volatility of the optimal price raises the frequency of price adjustment, whereas the size increases or remains stable.

<insert Table 2 about here>

Competition

We measure the degree of competition in two ways. First, we use a standard sectoral four-firm concentration ratio (C4) calculated using the annual balance sheets of firms. This measure is widely used, but it is also known to be problematic in measuring competition. Concentration ratios have been criticized as there are examples of highly concentrated industries in which competition is intense (e.g. telecommunications), and industries with a large number of competitors in which competition is low (e.g. bars and restaurants). Our second and potentially better proxy (MARKUP) comes from Aucremanne and Druant (2005). It is the share of firms in a sector that states that setting the price according to their costs and to a self-determined profit margin is an "important" or "very important" practice. We find no relation between the concentration ratio and the frequency and size of price adjustment. Regressing the frequencies and sizes on the second proxy we find that higher market power decreases the frequency of price adjustment. However, the result is not robust to including measures for the cost structure. Contrary to what theory would predict the size of price adjustment is also not related to this second proxy. We conclude that if there is a link between the degree of competition and sectoral price adjustment it appears to be rather weak.

Cost Structure

To proxy the cost structure of the different sectors, we use the share of labor costs (LABOR) and energy inputs (ENERGY) in total costs.[21] We regress the frequency/size of price adjustment on these proxies, accounting for differences in the degree of competition. The share of labor costs decreases the frequency of price adjustment, whereas the share of energy inputs increases the frequency of price adjustment. This is intuitive as the price of energy (labor) inputs changes both frequently (infrequently) and with a large (small) amount. Only in one case is the size of price adjustment positively related to energy. In

---

[21] Other important inputs in the production are business services, capital costs and non-energy intermediate inputs.

the other cases the size of price adjustment is not related to any of the cost structure proxies. This is in line with theory. All findings hold for upward as well as downward price adjustment. We interpret the strong relation between the cost structure and the frequencies of price adjustment as reflecting the importance of idiosyncratic shocks in explaining sectoral frequencies.

4.2 Aggregate Fluctuations

Different models have different implications about whether aggregate inflation occurs through variation in size (dp) or frequency (fr) of price adjustment. A purely time-dependent model implies adjustment only through variation in the size of price adjustment. A large class of state-dependent pricing models mainly relies on variation in the frequency of price adjustment to adjust aggregate prices. Other state-dependent models such as the one in Golosov and Lucas (2007) rely on variation in both the size and frequency. In this Section we document through which margin aggregate price adjustment comes about. Klenow and Kryvtsov (2007) show that inflation π_t can be written as the weighted sum of the percentage log difference of current prices P_{it} and previous prices P_{it-1}, using PPI weights w_{it}. The indicator function I is equal to 1 if the current price is different from the previous price, and 0 otherwise. This weighted sum is also equal to the share of prices that are changing fr_t times the average price change dp_t. Equation (1) is the result of a first-order Taylor-series expansion of $fr_t dp_t$ around $\overline{fr_t}$ and $\overline{dp_t}$.

$$\begin{aligned}
\pi_t &= \sum_{i=1}^{n} w_{it}\left(\ln P_{it} - \ln P_{it-1}\right) = \underbrace{\sum_{i=1}^{n} w_{it} I_{it}}_{fr_t} \underbrace{\frac{\sum_i w_{it}\left(\ln P_{it} - \ln P_{it-1}\right)}{\sum_{i=1}^{n} w_{it} I_{it}}}_{dp_t} = fr_t dp_t \\
\pi_t - \overline{fr_t dp_t} &= \underbrace{\overline{fr_t}\left(dp_t - \overline{dp_t}\right)}_{\text{Si}\,ze} + \underbrace{\overline{dp_t}\left(fr_t - \overline{fr_t}\right)}_{Frequency} \qquad (1) \\
&\quad + \underbrace{\left(fr_t - \overline{fr_t}\right)\left(dp_t - \overline{dp_t}\right)}_{Mixed}
\end{aligned}$$

<insert Figure 6 about here>

In Figure 6 we show the contribution to demeaned inflation $\pi_t - \overline{fr_t dp_t}$ of the three terms in equation (1). Mainly variation in the size of price adjustment contributes to inflation. To determine the contribution to the variation in inflation, in Table 3 we regress inflation on dp_t and fr_t. We find that 80% of the variance is explained by this regression and that only dp_t has a significant coefficient. Klenow and Kryvtsov (2007) compute the contribution of the variance of an intensive and an extensive margin to the variance of inflation. Their extensive margin is a composite of the variance of the frequencies, the covariance of frequencies and sizes, and higher order terms.[22] In this way in our data 36% of the variance is accounted for by the intensive margin, whereas 64% is accounted for by the extensive margin. The variance and covariance term in their extensive margin is always close to zero, whereas the higher order terms contribute largely due to the seasonality in January. When we exclude January we get that 85% is accounted for by the intensive margin. The higher order terms represent 15%.

<insert Table 3 about here>

In a similar way we can decompose inflation distinguishing between upward and downward price adjustment.

$$
\begin{aligned}
\pi_t &= fr_t^+ dp_t^+ + fr_t^- dp_t^- \\
\pi_t - \overline{fr_t^+ dp_t^+} - \overline{fr_t^- dp_t^-} &= \underbrace{\overline{fr_t^+}\left(dp_t^+ - \overline{dp_t^+}\right)}_{\mathrm{Si}\,ze^+} + \underbrace{\overline{fr_t^-}\left(dp_t^- - \overline{dp_t^-}\right)}_{\mathrm{Si}\,ze^-} \qquad (2) \\
&\quad + \underbrace{\overline{dp_t^+}\left(fr_t^+ - \overline{fr_t^+}\right)}_{Frequency^+} + \underbrace{\overline{dp_t^-}\left(fr_t^- - \overline{fr_t^-}\right)}_{Frequency^-} \\
&\quad + \underbrace{\left(fr_t^+ - \overline{fr_t^+}\right)\left(dp_t^+ - \overline{dp_t^+}\right)}_{Mixed^+} + \underbrace{\left(fr_t^- - \overline{fr_t^-}\right)\left(dp_t^- - \overline{dp_t^-}\right)}_{Mixed^-}
\end{aligned}
$$

If we compute the contribution of the six terms in equation (2), we get in Figure 7 that variation in the size and frequency of price adjustment account for a more or less equal share in inflation variation. To determine the contribution to variation in inflation, we regress inflation on the upward and downward sizes/frequencies and get that each of them is important in explaining the variation in inflation. So explicitly accounting for upward and downward price adjustment, we find that there is a role for both

---

[22] From equation (1) they get:

$$var\left(\pi_t\right) = \underbrace{var\left(dp_t\right)\overline{fr}^2}_{Intensive\ margin} + \underbrace{var\left(fr_t\right)\overline{dp}^2 + 2\overline{frdp}cov\left(fr_t, dp_t\right) + higher\ order\ terms}_{Extensive\ m\arg in}$$

variation in the size and frequency of price adjustment.

<insert Figure 7 about here>

The difference with the previous result comes from the offsetting movements in the frequency of price increases and decreases. Whereas apart from large seasonal fluctuations fr_t remains fairly constant, dp_t varies a lot. Note that dp_t is equal to $\frac{fr_t^+ dp_t^+ + fr_t^- dp_t^-}{fr_t}$. The variation in dp_t does not just come from variation in dp_t^- and dp_t^+, but also from offsetting variation in fr_t^+ and fr_t^-. This is consistent with the findings of Klenow and Kryvtsov (2007), Nakamura and Steinsson (2007a), and Gagnon (2007) for US and Mexican consumer prices.

5 Conclusion

We find that on average 24% of producer prices adjust each month with an average increase/decrease of 6%. Consumer prices only adjust with an average frequency of 14%, but a size of 8%. Even for a selection of 82 comparable goods, we still find more frequent but smaller-sized producer price adjustment. Differences in the degree of competition or price adjustment costs seem necessary to explain the difference in consumer and producer price adjustment. Across (sub)-sectors *within* the producer sector the frequencies and sizes of price adjustment are heterogeneous. The heterogeneity in the frequencies is to a large extent driven by heterogeneity in the cost structure, reflecting a different exposure to idiosyncratic shocks. In the presence of large upward and downward idiosyncratic shocks, aggregate inflation in our low-inflation environment comes to a large extent from variation in the share of upward and downward price adjustment.

In sum, we find that a lot of qualitative facts on producer price adjustment coincide with earlier evidence on consumer prices. However, the quantitative differences should be important enough not to be neglected when calibrating models with intermediate goods.

References

[1] Álvarez L., Burriel P. and I. Hernando, 2005, Price setting behavior in Spain: Evidence from micro PPI data, *ECB Working Paper*, n° 522

[2] Aucremanne L. and Dhyne E., 2004, How Frequently Do Prices Change? Evidence Based on the Micro Data Underlying the Belgian CPI, *ECB Working Paper*, n° 331

[3] Aucremanne L. and Druant M., 2005, Price-setting behavior in Belgium: what can be learned from an ad hoc survey?, *ECB Working Paper*, n° 448

[4] Baharad E. and B. Eden, 2004, Price Rigidity and Price Dispersion: Evidence from Micro Data, *Review of Economic Dynamics*, 7, 613-641

[5] Barro R., 1972, A Theory of Monopolistic Price Adjustment, *Review of Economic Studies*, 39, 17-26

[6] Basu S., 1995, Intermediate Goods and Business Cycles: Implications for Productivity and Welfare, *American Economic Review*, 85, 512-31

[7] Bils M. and P. Klenow, 2004, Some Evidence on the Importance of Sticky Prices, *Journal of Political Economy*, 112, 947-985

[8] Blanchard O., 1983, Price Asynchronization and Price Level Inertia, in *Inflation, Debt and Indexation*, edited by R. Dornbusch and M. H. Simonsen, MIT Press

[9] Blinder A., Canetti E., Lebow D. and J. Rudd, 1998, *Asking About Prices: A New Approach to Understanding Price Stickiness*, Russell Sage Foundation, New York

[10] Bureau of Labor Statistics, 2007, *BLS Handbook of Methods*, http://www.bls.gov

[11] Burstein A., Neves J. and S. Rebelo, 2003, Distribution Costs and Real Exchange Rate Dynamics During Exchange-Rate-Based Stabilizations, *Journal of Monetary Economics*, 1189-1214

[12] Carlton D., 1986, The Rigidity of Prices, *American Economic Review*, 76, 637-658

[13] Corsetti G. and L. Dedola, 2005, Macroeconomics of International Price Discrimination, *Journal of International Economics*, 67, 129-55

[14] Dhyne E., Álvarez L., Le Bihan H., Veronese G., Dias D., Hoffmann J., Jonker N., Lunnemann P., Rumler F., and J. Vilmunen, 2006, Price Changes in the Euro Area and the United States: Some Facts from Individual Consumer Price Data, *Journal of Economic Perspectives*, 20, 171-192

[15] Dhyne E. and J. Konieczny, 2007, Temporal Distribution of Price Changes: Staggering in the Large and Synchronization in the Small, *NBB Working Paper Series*, n° 116

[16] Dias M., Dias D. and P. Neves, 2004, Stylised Features of Price Setting Behaviour in Portugal: 1992-2001, *ECB Working Paper*, n° 332

[17] Eurostat, 2002, Methodology of Short-Term Business Statistics: Interpretation and Guidelines, *http://epp.eurostat.cec.eu.int*

[18] Fisher T. and J. Konieczny, 2000, Synchronization of Price Changes by Multiproduct Firms: Evidence from Canadian Newspaper Prices, *Economics Letters*, 68, 271-277

[19] Gagnon E., 2007, Price-Setting during Low and High Inflation: Evidence from Mexico, Fed International Finance Discussion Papers, n° 896

[20] Gautier E., 2006, The Behaviour of Producer Prices: Some Evidence from the French PPI Micro Data, *ECB Working Paper*, n° 699

[21] Golosov M. and R. Lucas, 2007, Menu Costs and Phillips Curves, *Journal of Political Economy*, 115, 171-199

[22] Gordon R., 1990, What is New-Keynesian Economics?, *Journal of Economic Literature*, 28, 1115-1171

[23] Higo M. and Y. Saita, 2007, Price-Setting in Japan: Evidence from CPI Micro Data, Bank of Japan, *mimeo*

[24] Huang K. and Z. Liu, 2005, Inflation Targeting: What Inflation to Target?, *Journal of Monetary Economics*, 52, 1435-1462

[25] Kehoe P. and V. Midrigan, 2007, Sales and the Real Effects of Monetary Policy, *Federal Reserve Bank of Minneapolis Working Papers*, N° 652

[26] Klenow P. and O. Kryvtsov, 2007, State-Dependent or Time-Dependent Pricing: Does it Matter for Recent U.S. Inflation?, Stanford University, *mimeo*

[27] Midrigan V., 2006, Menu Costs, Multi-Product Firms, and Aggregate Fluctuations, New York University, *mimeo*

[28] Nakamura E. and J. Steinsson, 2007a, Five Facts about Prices: A Reevaluation of Menu Cost Models, Harvard University, *mimeo*

[29] Nakamura E. and J. Steinsson, 2007b, Monetary Non-Neutrality in a Multi-Sector Menu Cost Model, Harvard University, *mimeo*

[30] Sabbatini R., Fabiani S., Gatulli A. and G. Veronese, 2006, Producer Price Behaviour in Italy: Evidence from Micro PPI Data, Banca d'Italia, *mimeo*

[31] Stahl H., 2006, Producer Price Adjustment at the Micro Level: Evidence from Individual Price Records Underlying the German PPI, Deutsche Bundesbank, *mimeo*

[32] Vermeulen P., Dias D., Dossche M., Gautier E., Hernando I., Sabbatini R. and H Stahl, 2007, Price Setting in the Euro Area: Some Stylised Facts from Individual Producer Price Data, *ECB Working Papers*, N° 727

Appendix A: Data Issues

Construction Basic Statistics

We define the following binary variables for a price P_{ijt} of a product in branch of economic activity j sold by firm i at time t at the NACE 4-digit level:

$$DEN_{ijt} = \begin{matrix} 1 \text{ if } P_{ijt} \text{ and } P_{ijt-1} \text{ are observed} \\ 0 \text{ if } P_{ijt} \text{ exists but not } P_{ijt-1} \end{matrix} ; \qquad NUM_{ijt} = \begin{matrix} 1 \text{ if } P_{ijt} \neq P_{ijt-1} \\ 0 \text{ otherwise} \end{matrix} ;$$

$$NUMUP_{ijt} = \begin{matrix} 1 \text{ if } P_{ijt} > P_{ijt-1} \\ 0 \text{ otherwise} \end{matrix} ; \qquad NUMDOWN_{ijt} = \begin{matrix} 1 \text{ if } P_{ijt} < P_{ijt-1} \\ 0 \text{ otherwise} \end{matrix} .$$

One can calculate the frequency and size of price adjustment at time t for branch of economic activity j as:

Average Frequency of price adjustment:

$$fr_{jt} = \frac{\sum_{i=1}^{n_j} NUM_{ijt}}{\sum_{i=1}^{n_j} DEN_{ijt}}; \qquad fr^{+}_{jt} = \frac{\sum_{i=1}^{n_j} NUMUP_{ijt}}{\sum_{i=1}^{n_j} DEN_{ijt}}; \qquad fr^{-}_{jt} = \frac{\sum_{i=1}^{n_j} NUMDOWN_{ijt}}{\sum_{i=1}^{n_j} DEN_{ijt}}.$$

Average size of price adjustment:

$$dp_{jt} = \frac{\sum_{i=1}^{n_j} (\ln P_{ijt} - \ln P_{ijt-1})}{\sum_{i=1}^{n_j} NUM_{ijt}}; \qquad dp^{+}_{jt} = \frac{\sum_{i=1}^{n_j} (\ln P_{ijt} - \ln P_{ijt-1})}{\sum_{i=1}^{n_j} NUMUP_{ijt}}; \qquad dp^{-}_{jt} = \frac{\sum_{i=1}^{n_j} ((\ln P_{ijt} - \ln P_{ijt-1}))}{\sum_{i=1}^{n_j} NUMDOWN_{ijt}}.$$

n_j is the number of firms selling a product belonging to branch of economic activity j. The branch of economic activity statistics can subsequently be aggregated to statistics at the NACE 3-digit, NACE 2-digit or the entire Industry level using the PPI weights. All these statistics can also be aggregated/averaged across time t and/or branches of economic activity j. When we drop a time t or branch of economic activity j subscript this means that the statistic is the result of an aggregation over time or branches of economic activity. For the total Industry, the notation for the frequency of price adjustment, the frequency of upward price adjustment, the frequency of downward price adjustment, the size of price adjustment, the absolute size of price adjustment, the downward size of price adjustment and the upward size of price adjustment is respectively as follows: fr, fr^{+}, fr^{-}, dp, $|dp|$, dp^{-}, dp^{+}.

Additional Data

	Description	Source
MARKUP	Share of firms stating that setting price fully according to costs and self-determined margin is 'important' or 'very important' to set price of their main product.	Aucremanne and Druant (2004)
C4	Average '02-'05 four-firm-concentration ratio.	NBB Balance Sheet Office
LABOR	Share of labor costs in total costs.	Input/output tables; NSI & NBB
ENERGY	Share of energy intermediate inputs in total costs.	Input/output tables; NSI & NBB

Tables and Figures

Table 1: Monthly Size and Frequency of Price Adjustment

	Overall adjustment		Up. adjustment		Down. adjustment	
	fr	$\|dp\|$	fr^+	dp^+	fr^-	$\|dp^-\|$
Consumer food	20%	5%	11%	5%	9%	5%
Consumer non-durables	11%	4%	6%	4%	5%	5%
Consumer durables	14%	3%	8%	3%	6%	3%
MIG-Intermediate goods	28%	7%	15%	7%	14%	6%
Energy	50%	3%	33%	3%	17%	4%
Capital goods	13%	6%	7%	5%	6%	7%
Total	**24%**	**6%**	**13%**	**6%**	**11%**	**6%**

Table 2: Determinants of Sectoral Price Adjustment

	fr_j	fr_j^+	fr_j^-	fr_j	fr_j^+	fr_j^-	fr_j	fr_j^+	fr_j^-	fr_j	fr_j^+	fr_j^-
c	0.13^{**} (0.06)	0.06^{*} (0.03)	0.07^{**} (0.03)	0.25^{***} (0.03)	0.13^{***} (0.02)	0.12^{***} (0.02)	0.35^{***} 0.08	0.18^{***} 0.04	0.18^{***} 0.04	0.46^{***} 0.08	0.24^{***} 0.04	0.23^{***} 0.04
C4	0.07 (0.09)	0.06 (0.05)	0.01 (0.04)	-	-	-	0.00 0.08	0.02 0.04	-0.02 0.04	-	-	-
MARKUP	-	-	-	-0.20^{**} (0.08)	-0.10^{**} (0.05)	-0.10^{**} (0.04)	-	-	-	-0.11 0.07	-0.05 0.04	-0.06^{*} 0.03
LABOR	-	-	-	-	-	-	-1.32^{***} 0.31	-0.70^{***} 0.17	-0.62^{***} 0.15	-1.64^{***} 0.37	-0.85^{***} 0.21	-0.79^{***} 0.17
ENERGY	-	-	-	-	-	-	1.53^{***} 0.44	0.95^{***} 0.25	0.58^{***} 0.21	1.99^{***} 0.63	1.16^{***} 0.35	0.84^{***} 0.30
R^2	0.01	0.02	0.00	0.08	0.07	0.08	0.24	0.26	0.21	0.39	0.37	0.38

	$\|dp_j\|$	dp_j^+	dp_j^-	$\|dp_j\|$	dp_j^+	dp_j^-	$\|dp_j\|$	dp_j^+	dp_j^-	$\|dp_j\|$	dp_j^+	dp_j^-
c	0.04^{***} (0.01)	0.04^{***} (0.01)	-0.03^{**} (0.02)	0.05^{***} (0.01)	0.05^{***} (0.00)	-0.05^{***} (0.01)	0.02 0.02	0.04^{**} 0.02	-0.03 0.03	0.03^{**} 0.01	0.04^{***} 0.01	-0.03 0.02
C4	0.03^{*} (0.02)	0.01 (0.02)	-0.04 (0.02)	-	-	-	0.02 0.02	0.00 0.02	-0.04 0.02	-	-	-
MARKUP	-	-	-	0.01 (0.01)	0.00 (0.01)	0.02 (0.02)	-	-	-	0.01 0.01	0.01 0.01	-0.02 0.02
LABOR	-	-	-	-	-	-	0.05 0.07	0.02 0.06	0.00 0.10	0.05 0.06	0.02 0.06	-0.09 0.09
ENERGY	-	-	-	-	-	-	0.17^{*} 0.10	0.27^{***} 0.09	-0.01 0.14	0.11 0.10	0.10 0.10	-0.12 0.15
R^2	0.03	0.01	0.03	0.01	0.00	0.02	0.07	0.09	0.03	0.03	0.02	0.04

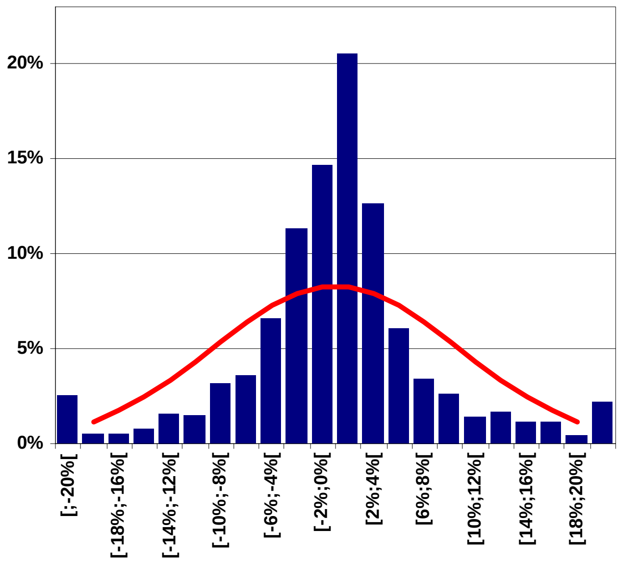
Note: We regress the sectoral frequency/size of price adjustment on different sets of determinants. ***/**/* indicate that the coefficient estimate is significant at the 1%/5%/10% level. Standard errors are reported in brackets. The sample contains 74 of the 97 NACE 3-digit sectors.

Table 3: Determinants of Aggregate Inflation

	π_t							
c	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	-0.01^{***} (0.00)	0.01^{***} (0.00)	0.00 (0.00)	0.01^{***} (0.00)	0.00 (0.00)
fr_t	0.00 (0.01)	-	0.01 (0.01)	-	-	-	-	-
dp_t	-	0.36^{***} (0.03)	0.37^{***} (0.03)	-	-	-	-	-
fr_t^+	-	-	-	0.06^{***} (0.02)	-	-	-	0.08^{***} (0.01)
fr_t^-	-	-	-	-	-0.06^{***} (0.02)	-	-	-0.08^{***} (0.01)
dp_t^+	-	-	-	-	-	0.09 (0.06)	-	0.20^{***} (0.03)
dp_t^-	-	-	-	-	-	-	0.16^{***} (0.06)	0.21^{***} (0.03)
R^2	0.00	0.80	0.81	0.26	0.18	0.04	0.16	0.86

Note: We regress inflation on different sets of determinants. ***/**/* indicate that the coefficient estimate is significant at the 1%/5%/10% level. Standard errors are reported in brackets. The sample covers 2001:2-2005:1.

Figure 1: **Distribution Non-Zero Price Changes**



Note: The line is the histogram for the normal distribution with the same mean and variance as the empirical histogram.

Figure 2: **Frequency of Price Adjustment Across Time**

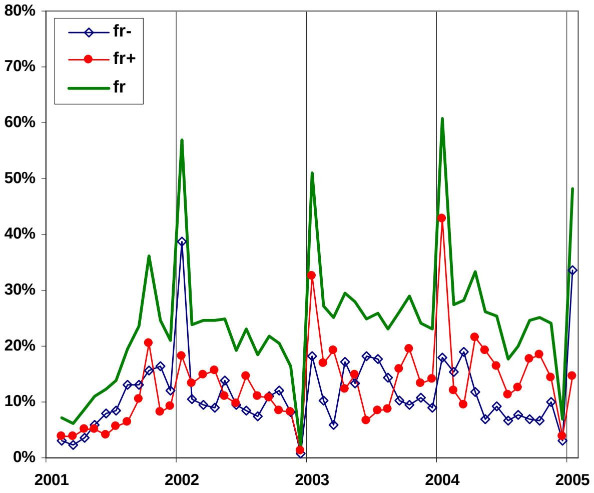
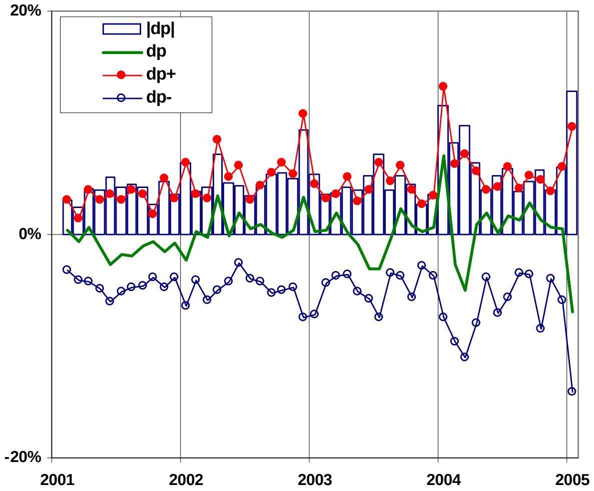
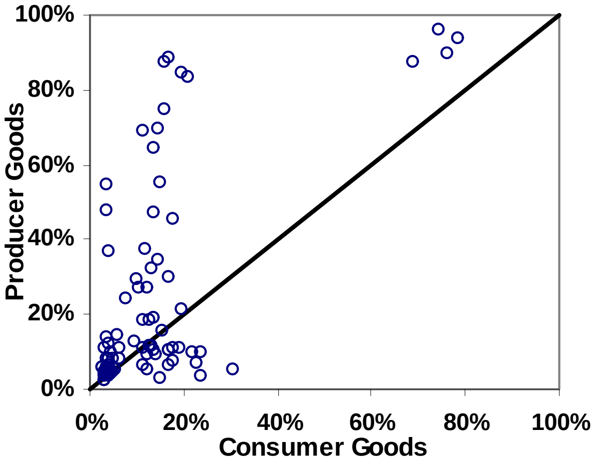


Figure 3: **Size of Price Adjustment Across Time**



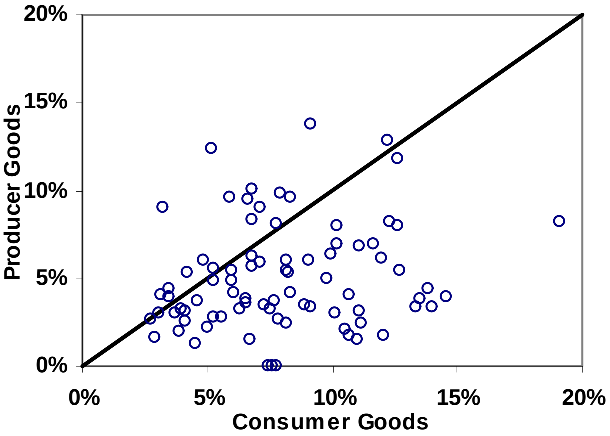
Note: The average price adjustment is computed as $dp_t = \frac{fr_t^+ dp_t^+ + fr_t^- dp_t^-}{fr_t}$.

Figure 4: **Frequency of Price Adjustment Across Goods**



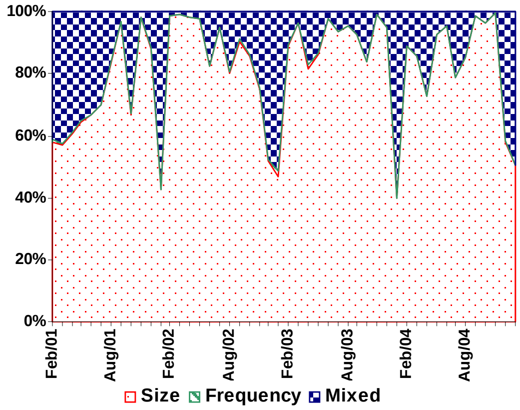
Note: We link the frequencies of price adjustment of 82 producer and consumer items.

Figure 5: **Size of Price Adjustment Across Goods**



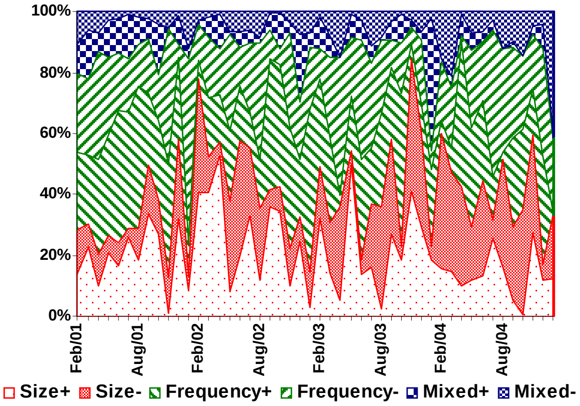
Note: We link the absolute sizes of price adjustment of 82 producer and consumer items.

Figure 6: **Inflation Decomposition I**



Note: Decomposition of inflation in variation in the size and frequency of price adjustment as in equation (1). The contribution is computed as the ratio of the absolute value of a term over the sum of the absolute values of the three terms.

Figure 7: **Inflation Decomposition II**



Note: Decomposition of inflation in variation in the size and frequency of price adjustment as in equation (2). The contribution is computed as the ratio of the absolute value of a term over the sum of the absolute values of the six terms.

The Kinked Demand Curve and Price Rigidity: Evidence from Scanner Data*

Maarten Dossche† Freddy Heylen‡ Dirk Van den Poel§

November 28, 2008

Abstract

We estimate the curvature of the demand curve for a wide range of products. We use an extension of Deaton and Muellbauer's Almost Ideal Demand System and scanner data from a large euro area retailer. We find evidence that the price elasticity of demand is higher for price increases than for price decreases. However, the empirical degree of curvature is one to two orders of magnitude smaller than the value economists usually impose. Contrary to what theory suggests, we do not find that items with a different curvature have a different frequency or size of nominal price adjustment in our data.

JEL classification: C33, D12, E3
Keywords: price setting, real price rigidity, kinked demand, Almost Ideal Demand System

---

[*] This paper is written with the financial support of the National Bank of Belgium in preparation of its biennial conference "Price and Wage Rigidities in an Open Economy", October 2006. The authors also acknowledge support from the Belgian Program on Interuniversity Poles of Attraction, initiated by the Belgian State, Federal Office for scientific, technical and cultural affairs, contract UAP No. P 6/07. We thank Filip Abraham, Kenn Ariga, Luc Aucremanne, Gerdie Everaert, Etienne Gagnon, Alan Kackmeister, Jurek Konieczny, Joep Konings, Oleksiy Kryvtsov, Daniel Levy, Morten Ravn, Adam Reiff, Dirk Van de gaer, Frank Verboven, Jon Willis and Raf Wouters for helpful comments and suggestions. We benefited from discussions during seminars at Ghent University, Universitat Pompeu Fabra, University of Antwerp, National Bank of Hungary, and the conferences "The Macroeconomics of Price Setting" in Rimini, May 11-12 2007, "Computing in Economics and Finance" in Montréal, June 14-16 2007, "Inflation Dynamics in Japan, US and EU" in Tokyo, June 28 2007 and the "European Economic Association Annual Congress" in Budapest, August 27-31 2007. All errors are our own. The views expressed in this paper are those of the authors and do not necessarily reflect the views of the National Bank of Belgium.

[†] Corresponding author. National Bank of Belgium and SHERPPA, Ghent University, Maarten.Dossche@nbb.be, http://www.sherppa.be

[‡] SHERPPA, Ghent University, Freddy.Heylen@UGent.be, http://www.sherppa.be

[§] Marketing Department, Ghent University, Dirk.VandenPoel@UGent.be, http://www.crm.ugent.be

1 Introduction

A large literature documents the persistent effects of monetary policy on real output and inflation (Christiano et al., 1999, 2005; Peersman, 2004). To match this persistence micro-founded models with sticky prices were developed. A first approach was to introduce frictions to nominal price adjustment (e.g. Taylor, 1980; Calvo, 1983; Mankiw, 1985). However, as shown by several authors, the real effects of nominal frictions do not last much longer than the average duration of a price (Chari et al., 2000; Bergin and Feenstra, 2000). Taking into account recent microeconomic evidence that the mean price duration lies between 1.8 and 4 quarters for the United States (Bils and Klenow, 2004; Nakamura and Steinsson, 2007), and between 4 to 5 quarters for the euro area (Dhyne et al., 2006), nominal frictions alone fail to generate the persistence observed in the data.

The failure of nominal frictions alone to generate persistence has led to the development of models that combine nominal and so-called real price rigidities (Ball and Romer, 1990). Real rigidities refer to strategic complementarity in the price setting decision of firms. A firm is more reluctant to adjust its price in response to changes in the state of the economy the less other firms adjust their prices. Different frictions can generate this strategic complementarity. One option is the roundabout production structure of Basu (1995). Real price rigidity follows from the assumption that firms use the output of all other firms as materials in their own production (Bergin and Feenstra, 2000). A second option is to model firm-specific production factors.[1] In this case the marginal cost is a negative function of the relative price, which again dampens the incentive to change prices.

An alternative, and recently very popular, way to introduce strategic complementarity is the preference specification of Kimball (1995).[2] In contrast to the traditional Dixit and Stiglitz (1977) aggregator, Kimball (1995) no longer assumes a constant elasticity of substitution in demand. The price elasticity of demand becomes a function of the relative price. A key concept is the so-called curvature of the

---

[1] E.g. Galí and Gertler, 1999; Sbordone, 2002; Woodford, 2003; Altig et al., 2005; Burstein and Hellwig, 2007.

[2] See e.g. Bergin and Feenstra (2000), Coenen, Levin and Christoffel (2006), Eichenbaum and Fisher (2004), Smets and Wouters (2007), Dotsey and King (2005), Dotsey, King and Wolman (2006), Klenow and Willis (2006).

demand curve, which measures the price elasticity of the price elasticity. When the curvature is positive, Kimball's preferences generate a concave or smoothed "kinked" demand curve in a log price/log quantity framework. A price above the level of the firm's competitors increases the elasticity of demand for its product, so that the firm increasingly loses profits from relative price increases. Conversely, a price below the level of the firm's competitors reduces the elasticity of demand for its product, so that the firm again increasingly loses profits from relative price decreases. In this way the combination of small costs to nominal price adjustment and a concave demand curve generates slow adjustment to changes in the state of the economy.

Despite its attractiveness, the literature suffers from a lack of empirical evidence on the curvature of a typical demand curve. In Table 1 we report the parameter values for the price elasticity of demand and for the curvature as calibrated or estimated in recent models using macroeconomic data. Values for the (positive) price elasticity range from 3 to 20. Values for the curvature range from less than 2 to more than 400.

Table 1: Price Elasticity and Curvature of Demand in the Literature

	Price Elasticity	Curvature
Kimball (1995)	11	$471^{(a)}$
Chari, Kehoe and McGrattan (2000)	10	$385^{(a)}$
Eichenbaum and Fisher (2004)	11	10, 33
Coenen, Levin and Christoffel (2006)	$5-20$	10, 33
Smets and Wouters (2007)	3	10
Klenow and Willis (2006)	5	10
Woodford (2005)	7.67	$6.67^{(a)}$
Bergin and Feenstra (2000)	3	$1.33^{(a)}$

Note: Curvature is defined as the elasticity of the price elasticity of demand with respect to the relative price at steady state. Several authors characterize curvature differently. In Appendix 1 we derive the relationships between alternative definitions of curvature. The numbers indicated with (a) have been computed using these relationships. It is sometimes argued that Kimball (1995) would have imposed a curvature equal to 33 (see Eichenbaum and Fisher, 2004; Coenen, Levin and Christoffel, 2006). Our calculations show however that Kimball's curvature must be much larger.

Our contribution in this paper is twofold. First, we estimate the curvature of the demand curve. To do this, we use scanner data on both prices and quantities from a large euro area supermarket chain. The dataset contains information about prices and quantities sold of about 15,000 items in

2002-2005.[3] As is typical for studies with micro data, we find wide variation in the estimated curvature of demand among items/product categories. We observe both items with a convex and a concave demand curve. This result would ideally be matched with a model with heterogeneous firms that can match the entire distribution of curvatures. Our results also support the introduction of a kinked (concave) demand curve in a representative firm economy, but the median degree of curvature is much lower than currently calibrated. This finding is consistent with Klenow and Willis (2006) who find that the joint assumption of realistic idiosyncratic shocks and a curvature of 10 is not compatible with observed nominal and relative price changes in US data.

Second, we link the estimates for the curvature of the demand curve to statistics on nominal price adjustment. In case strategic complementarity affects price setting these should be correlated. We find no clear correlation between the estimated curvature and the observed size or frequency of nominal price adjustment in our data. The fact that our data stems from a multi-product retailer may explain this lack of correlation. Midrigan (2006) argues that the item-specific frequency and size of price adjustment in a multi-product firm are also a function of the shocks and price adjustment frictions of the entire product category to which the item belongs. This could explain why the relation between item-specific statistics of price adjustment and the estimated elasticities and curvatures is disturbed in our data.

Section 2 describes the dataset in detail. Section 3 of the paper presents a more rigorous econometric analysis of price elasticities and curvature parameters for individual items. To that end we extend the Almost Ideal Demand System (AIDS) of Deaton and Muellbauer (1980). Section 4 concludes the paper.

2 Basic Facts about the Data

2.1 Description of Dataset

We use scanner data for a sample of six outlets of an anonymous large euro area supermarket chain. This retailer carries a very broad assortment of about 15,000 different items (stockkeeping units). The products in the total dataset correspond to approximately 40% of the euro area CPI. The data that

---

[3] Note that the *items* that are sold by our retailer can be differently packaged goods of the same *brand.* All items and/or brands in turn belong to a particular *product category* (e.g. potatoes, detergent).

we use in this paper are prices and total quantities sold per outlet of 2274 individual items belonging to 58 randomly selected product categories. Appendix 2 describes these categories and the number of items in each product category. The time span of our data runs from January 2002 to April 2005. Observations are bi-weekly. Prices are constant during each period of two weeks. They are the same in each of the six outlets. The quantities are the number of packages of an item that are sold during a time period.

2.2 Nominal Price Adjustment

The nominal price friction in our dataset is that prices are predetermined for periods of at least two weeks. If they are changed at the beginning of a period of two weeks, they are not changed again before the beginning of the next period of two weeks, irrespective of demand. A second characteristic of our data is the high frequency of temporary price markdowns. We define the latter as any sequence of three, two or one price(s) that is below both the most left adjacent price and the most right adjacent price.[4] The median item is marked down for 8% of the time, whereas 27% of the median item's output is sold at times of price markdowns. In line with the previous, price markdowns are valid for an entire period, and not just for a few days.

Using the prices in the dataset, we can estimate the size of price adjustment, the frequency of price adjustment and median price duration as has been done in Bils and Klenow (2004) and Dhyne et al. (2006). Table 2 contains these statistics. The total number of items involved is 2274. Note that due to entry or exit we do not observe data for all items in all periods. We calculate price adjustment statistics including and excluding temporary price markdowns. When an observed price is a markdown price, we replace it by the last observed regular price (see also Klenow and Kryvtsov, 2005). We illustrate our procedure in Appendix 3.

Conditional on price changes taking place and including markdowns, we see in Table 2 that 25% of the items have an average absolute price change of less than 5%. At the other end, 25% have an average

---

[4] This definition puts us somewhere in between Klenow and Kryvtsov (2005) and Midrigan (2006).

absolute price change of more than 17%. The median item has an average absolute price change of 9%. Filtering out markdowns, the latter falls to 5%. As to price duration, the median item's price lasts 0.9 quarters when we include markdown periods. It lasts 6.6 quarters excluding markdown periods. Price duration in our data is only slightly longer than is typically observed in the US and the euro area (Bils and Klenow, 2004; Nakamura and Steinsson, 2007; Dhyne et al., 2006).

Table 2: Nominal Price Adjustment Statistics

	Incl. markdowns			Excl. markdowns		
Percentile	25%	50%	75%	25%	50%	75%
Average Absolute Size	5%	9%	17%	3%	5%	8%
Implied Median Price Duration (quarters)	0.4	0.9	2.8	2.4	6.6	∞

Note: The statistics reported in this table are based on bi-weekly price data for 2274 items belonging to 58 product categories from January 2002 to April 2005. The data show the average absolute percentage price change (conditional on a price change taking place) and the median price duration of the items at the 25th, 50th and 75th percentile, ordered from low to high.

2.3 Real Price and Quantity Adjustment

Table 3 presents summary statistics on real (relative) price and quantity changes over the six outlets in our dataset. All changes are again in comparison with the previous period of two weeks. The nominal price p_i of individual item i is common across the outlets. All the other data are different per outlet. Real (relative) item prices p_i/P^* have been calculated by deflating the nominal price of item i by the outlet-specific Stone price index P^* for the product category to which the item belongs.[5] The Stone price index is computed as

$$\ln P^* = \sum_{i=1}^{N} s_i \ln p_i \tag{1}$$

with N the number of items in the product category to which i belongs, $s_i = \frac{p_i q_i}{X}$ the outlet-specific share of item i in total nominal expenditures X on the product category, q_i the total quantity of item i sold at the outlet and $X = \sum_{i=1}^{N} p_i q_i$. Total outlet-specific real expenditures Q on the product category have been obtained as $Q = X/P^*$. Relative quantities q_i/Q show much higher and much more variable percentage changes than relative prices. Including markdowns, the average absolute percentage change

---

[5] As an alternative to the Stone index we have also worked with the Fisher index. The results based on this price index are available upon request. They confirm our main findings here.

in relative quantity equals 59% for the median item, with a standard deviation of 77%. The average absolute percentage relative price change for the median item equals only 9%, with a standard deviation of 12%.

Table 3: Real Price and Quantity Adjustment

	Including markdowns			Excl. markdowns		
Percentile	25%	50%	75%	25%	50%	75%
Average absolute $\Delta \ln(p_i/P^*)$	6%	9%	15%	5%	8%	15%
Average absolute $\Delta \ln(q_i/Q)$	39%	59%	80%	38%	59%	79%
Standard Deviation $\Delta \ln(p_i/P^*)$	7%	12%	21%	7%	12%	21%
Standard Deviation $\Delta \ln(q_i/Q)$	52%	77%	102%	51%	77%	101%

Note: The statistics reported in this table are based on changes in bi-weekly data for 2274 items belonging to 58 product categories in six outlets. Individual nominal item prices (p_i) are common across the outlets, all the other data (P^*, q_i, Q) can be different per outlet. For the statistical analysis we have excluded items that are mentioned in the supermarket's circular. For a proper interpretation, note that the median item can be different in each row of this table.

3 How Large is the Curvature?

There exist a number of mechanisms that can give rise to a concave demand curve. First, there can be loss aversion of consumers relative to a price reference point (Tversky and Kahneman, 1991; Heidhues and Köszegi, 2008). When a firm's price is higher than this reference point consumers perceive a loss, and will cut their consumption additionally due to loss aversion. Second, there can be customer search as in Okun (1981) and Bénabou (1988). In this model there is a long term relationship between the firm and the customer. If the firm increases its price, existing customers will feel being treated unfairly and leave, whereas when the firm decreases its price, existing customers stay, but do not buy more. This creates and asymmetric reaction to price increases versus price decreases. Third, the asymmetry in the demand curve can also simply come from preferences as assume Kimball (1995) and Dotsey and King (2005). All models have in common that they can generate a concave demand curve, but to find out which model could generate this concavity is beyond the scope of this paper. We here focus on the empirical question of how sensitive is the demand elasticity to changes in the relative price. To produce real price rigidity it is sufficient to know to what extent the demand elasticity is sensitive to changes in the relative price.

We estimate the price elasticity and the curvature of demand for a broad range of goods in our European scanner dataset. We extend the Almost Ideal Demand System (AIDS) developed by Deaton and Muellbauer (1980) to give room for the behavioral mechanisms described above. Our "behavioral" AIDS model allows for a more general curvature, which is necessary to answer our research question. The model still has the original AIDS nested as a special case. For several reasons we believe the AIDS is the most appropriate for our purposes: (i) it is flexible with respect to estimating own- and cross-price elasticities; (ii) it is simple, transparent and easy to estimate, allowing us to deal with a large number of product categories; (iii) it is most appropriate in a setup like ours where consumers may buy different items of given product categories; (iv) it is not necessary to specify the characteristics of all goods, and use these in the regressions. The latter three characteristics particularly distinguish the AIDS from alternative approaches like the mixed logit model used by Berry et al. (1995). Their demand model is based on a discrete-choice assumption under which consumers purchase at most one unit of one item of the differentiated product. This assumption is appropriate for large purchases such as cars. In a context where consumers might purchase several items, it may be less suitable. Moreover, to estimate Berry et al. (1995)'s mixed logit model, the characteristics of all goods/items must be specified. In the case of cars this is a much easier task to do than for instance for cement or spaghetti. Computational requirements of their methodology are also very demanding.

We follow the approach of Broda and Weinstein (2006) to cover as many goods as possible in order to get a reliable estimate for the aggregate curvature. In Section 3.1 we first describe our extension of the AIDS model. Section 3.2 discusses our econometric setup and identification and estimation. Section 3.3 presents the results. In Section 3.4 we discuss their robustness.

3.1 Model

Our extension of Deaton and Muellbauer's AIDS model is specified in expenditure share form as

$$s_i = \alpha_i + \sum_{j=1}^{N} \gamma_{ij} \ln p_j + \beta_i \ln \left(\frac{X}{P} \right) + \sum_{j=1}^{N} \delta_{ij} \left(\ln(\frac{p_j}{P}) \right)^2 \tag{2}$$

for $i = 1, ..., N$. In this equation X is total nominal expenditure on the product category of N items being analyzed (e.g. detergents), P is the price index for this product category, p_j is the price of the jth item within the product category and s_i is the share of total expenditures allocated to item i (i.e. $s_i = p_i q_i / X$). Deaton and Muellbauer define the price index P as

$$\ln P = \alpha_0 + \sum_{j=1}^{N} \alpha_j \ln p_j + \frac{1}{2} \sum_{j=1}^{N} \sum_{i=1}^{N} \gamma_{ij} \ln p_i \ln p_j \tag{3}$$

Our extension of the model concerns the last term at the right hand side of Equation (2). The original AIDS model has $\delta_{ij} = 0$. Although this model is generally recognized to be flexible, it is not flexible enough for our purpose. As we demonstrate below, the curvature parameter is not free in the original AIDS model. It is a restrictive function of the price elasticity, implying that in the original AIDS model it would not be possible to obtain a convex demand curve.

The implication of this is that relative price effects on the elasticity of demand should be accounted for in demand analysis. The added term $\sum_{j=1}^{N} \delta_{ij} \left(\ln(\frac{p_j}{P})\right)^2$ in Equation (2) allows us to capture these additional effects. Provided that standard adding up ($\sum_{i=1}^{N} \alpha_i = 1$, $\sum_{i=1}^{N} \gamma_{ij} = 0$, $\sum_{i=1}^{N} \beta_i = 0$, $\sum_{i=1}^{N} \delta_{ij} = 0$), homogeneity ($\sum_{j=1}^{N} \gamma_{ij} = 0$) and symmetry ($\gamma_{ij} = \gamma_{ji}$) restrictions hold, our extended equation is a valid representation of preferences. The definition of the (positive) uncompensated own price elasticity of demand for good i is:

$$\begin{aligned} \varepsilon_i &= -\frac{\partial \ln q_i}{\partial \ln p_i} \\ &= 1 - \frac{\partial \ln s_i}{\partial \ln p_i} \end{aligned} \tag{4}$$

where $q_i = s_i X / p_i$. Applied to our behavioral AIDS model, ε_i can then be derived from Equation (2) as

$$\varepsilon_{i(B-AIDS)} = 1 - \frac{1}{s_i} \left(\gamma_{ii} - \beta_i \frac{\partial \ln P}{\partial \ln p_i} + 2\delta_{ii} \ln(\frac{p_i}{P}) - 2 \sum_{j=1}^{N} \delta_{ij} \ln(\frac{p_j}{P}) \frac{\partial \ln P}{\partial \ln p_i} \right) \tag{5}$$

where we hold total nominal expenditure on the product category X as well as all other prices p_j ($j \neq i$) constant. In the AIDS model the correct expression for the elasticity of the group price P with respect to p_i is

$$\frac{\partial \ln P}{\partial \ln p_i} = \alpha_i + \sum_{j=1}^{N} \gamma_{ij} \ln p_j \tag{6}$$

However, since using the price index from Equation (3) often raises empirical difficulties (see e.g. Buse, 1994), researchers commonly use Stone's geometric price index P^*, given by (1). The model is then called the "linear approximate AIDS" (LA/AIDS). To obtain the own price elasticity for the LA/AIDS model, one has to start from Stone's P^* and derive

$$\frac{\partial \ln P^*}{\partial \ln p_i} = s_i + \sum_{j=1}^{N} s_j \ln p_j \frac{\partial \ln s_j}{\partial \ln p_i} \tag{7}$$

Green and Alston (1990) and Buse (1994) discuss several approaches to computing the LA/AIDS price elasticities depending on the assumptions made with regard to $\frac{\partial \ln s_j}{\partial \ln p_i}$ and therefore $\frac{\partial \ln P^*}{\partial \ln p_i}$. A common approach is to assume $\frac{\partial \ln s_j}{\partial \ln p_i} = 0$, such that $\frac{\partial \ln P^*}{\partial \ln p_i} = s_i$. Monte Carlo simulations by Alston et al. (1994) and Buse (1994) reveal that this approximation is superior to many others (e.g. smaller estimation bias). In our empirical work we will also use Stone's price index and this approximation. The (positive) uncompensated own price elasticity implied by this approach then is

$$\varepsilon_{i(LA/B-AIDS)} = 1 - \frac{\gamma_{ii}}{s_i} + \beta_i - \frac{2\delta_{ii} \ln(\frac{p_i}{P^*})}{s_i} + 2\sum_{j=1}^{N} \delta_{ij} \ln(\frac{p_j}{P^*}) \tag{8}$$

Equation (8) incorporates several channels for the relative price of an item to affect the price elasticity of demand. The contribution of our behavioral extension of the AIDS model is obvious from the presence of δ_{ii} in this equation. Since s_i is typically far below 1, observing $\delta_{ii} < 0$ will most likely imply a concave demand curve, with ε_i rising in the relative price $\frac{p_i}{P^*}$. When $\delta_{ii} > 0$, it is more likely to find convexity in the demand curve.

At steady state, for all relative prices equal to 1, the price elasticity becomes

$$\varepsilon_{i(LA/B-AIDS)(1)} = 1 - \frac{\gamma_{ii}}{s_i} + \beta_i \tag{9}$$

Finally, starting from Equation (8) we show in Appendix 4 that the implied curvature of the demand function at steady state is

$$\begin{aligned}
\epsilon_{i(LA/B-AIDS)} &= \frac{\partial \ln \varepsilon_i}{\partial \ln p_i} \qquad (10)\\
&= \frac{1}{\varepsilon_i}\left((\varepsilon_i - 1)\,(\varepsilon_i - 1 - \beta_i) - \frac{2\delta_{ii}(1-s_i)}{s_i} + 2(\delta_{ii} - s_i \sum_{j=1}^{N} \delta_{ij}) \right) \qquad (11)
\end{aligned}$$

Also in this equation the role of δ_{ii} is clear. For given price elasticity, the lower δ_{ii}, the higher the estimated curvature.

A simple comparison of the above results with the price elasticity and the curvature in the basic LA/AIDS model underscores the importance of our extension. Putting $\delta_{ii} = \delta_{ij} = 0$, one can derive for the basic LA/AIDS model that

$$\varepsilon_{i(LA/AIDS)} = 1 - \frac{\gamma_{ii}}{s_i} + \beta_i \qquad (12)$$

$$\epsilon_{i(LA/AIDS)} = \frac{(\varepsilon_i - 1)(\varepsilon_i - 1 - \beta_i)}{\varepsilon_i} \qquad (13)$$

With β_i mostly close to zero (and zero on average) the curvature then becomes a restrictive and rising function of the price elasticity, at least for $\varepsilon_i > 1$. Moreover, positive price elasticities ε_i almost unavoidably imply positive curvatures, which excludes convex demand curves. In light of our findings in Table 4 this is too restrictive.

3.2 Identification/Estimation

The sample that we use for estimation contains data for 28 product categories sold in each of the six outlets (supermarkets). The time frequency is a period of two weeks, with the time series running from the first bi-week of 2002 until the 8th bi-week of 2005. The selection of the 28 categories, coming from 58 in Section 2, is driven by data requirements and motivated in Appendix 2.

To keep estimation manageable we include five items per product category. Four of these items have been selected on the basis of clear criteria to improve data quality and make estimation possible. The fifth item is called "other". It is constructed as a weighted average of all other items. We include "other" to fully capture substitution possibilities for the four main items. Specifying "other" also enables us to deal with entry and exit of individual items during the sample period.[6] We discuss the selection of the four items and the construction of "other" in Appendix 2 as well. For each item i within a product category the basic empirical demand specification is:

$$\begin{aligned} s_{imt} &= \alpha_{im} + \sum_{j=1}^{5} \gamma_{ij} \ln p_{jt} + \beta_i \ln\left(\frac{X_{mt}}{P_{mt}^{*}}\right) + \sum_{j=1}^{5} \delta_{ij} \left(\ln(\frac{p_{jt}}{P_{mt}^{*}})\right)^2 + \sum_{j=1}^{5} \varphi_{ij} C_{jt} + \lambda_{it} + \varepsilon_{imt} \\ i &= 1, ..., 5 \qquad m = 1, ..., 6 \qquad t = 1, ..., 86 \end{aligned} \tag{14}$$

where s_{imt} is the share of item i in total product category expenditure at outlet m and time t, X_{mt} is overall product category expenditure at outlet m and time t, P_{mt}^{*} is Stone's price index for the category at outlet m and p_{jt} is the price of the jth item in the category. As we mentioned before, individual item prices are equal across outlets and predetermined. They are not changed during the period. This is an important characteristic of our data, which strongly facilitates identification of the demand curve (cf. infra). Furthermore, α_{im} captures item specific and outlet specific fixed effects.[7] Finally, we include dummies to capture demand shocks with respect to item i at time t which are common across outlets. Circular dummies C_{jt} are equal to 1 when an item j in the product category to which i belongs, is mentioned in the supermarket's circular. The circular is common to all outlets. For each item we also include three holiday dummies λ_{it} for New Year, Easter and Christmas. These dummies should capture shifts in market share from one item to another during the respective periods.

Our estimation method is SUR. The assumption underlying this choice is that prices p_{it} are uncorrelated with the error term ε_{imt}. For at least two reasons we believe this assumption is justified. Problems to identify the demand curve, as discussed by e.g. Hausman et al. (1994), Hausman (1997) and Menezes-Filho (2005), should therefore not exist. First, since our retailer sets prices in advance and does not change them to equilibrate supply and demand in a given period, prices can be considered predetermined with respect to Equation (14). Second, prices are equal in all six outlets. We assume

---

[6] The specification of "other" may also come at a cost. Including "other" imposes a number of restrictions on the regression. In Section 3.4. we briefly reconsider this issue.

[7] To control for item specific fixed effects, note that we have also de-meaned $\ln(\frac{p_{jt}}{P_{mt}^{*}})$ when introducing the additional term $\sum \delta_{ij}(\ln(\frac{p_{jt}}{P_{mt}^{*}}))^2$ in the regression.

that outlet specific demand shocks for an item do not affect the price of that item at the chain level.[8] Of course, against these explanations one could argue that the supplier may know in advance that demand will be high or low, so that he can already at the moment of price setting fix an appropriate price. We see no strong evidence for this hypothesis however. Important demand shocks should be captured by the circular dummies (C_{jt}) and the item specific holiday dummies (λ_{it}) in our regressions. They will not show up in the error term. In the same vein, the included fixed effect α_{im} captures the influence on expenditure shares of time-invariant product specific characteristics which will also affect the price charged by the retailer. Therefore, item specific characteristics will not show up in the error term of the regressions either. Robustness tests that we discuss in Section 3.4. provide further support for our assumption that prices p_{it} are uncorrelated with the error term ε_{imt}. Including additional dummies (seasonal dummies) to capture demand shifts related to the time of the year does not affect our results in any serious way. Also, using IV methods and instrumenting prices, we obtain very similar results as the ones reported below.

Following Hausman et al. (1994) we estimate Equation (14) imposing homogeneity and symmetry from the outset (i.e. $\sum_{j=1}^{5} \gamma_{ij} = 0$ and $\gamma_{ij} = \gamma_{ji}$). We also impose symmetry on the effects of the circular dummies (i.e. $\varphi_{ij} = \varphi_{ji}$). Finally, the adding up conditions ($\sum_{i=1}^{5} \alpha_{im} = 1, \sum_{i=1}^{5} \gamma_{ij} = 0$, $\sum_{i=1}^{5} \beta_{i} = 0$, $\sum_{i=1}^{5} \delta_{ij} = 0$, $\sum_{i=1}^{5} \varphi_{ij} = 0$) allow us to drop one equation from the system. We drop the equation for "other".

3.3 Results

Estimation of Equation (14) for 28 product categories over six outlets, with each product category containing four items, generates 672 estimated elasticities and curvatures. Since 6 of these elasticities were implausible, we decided to drop them, leaving 666 plausible estimates.[9]

---

[8] Hausman et al. (1994) and Hausman (1997) make a similar assumption. See our brief discussion in Section 3.4.

[9] These 6 price elasticities were lower than -10 (where our definition is such that the elasticity for a negatively sloped demand curve should be a positive number). Note that we do not include the estimated elasticities and curvatures for the composite "other" item in our further discussion. Due to the continuously changing composition of this "other" item over time, any interpretation of the estimates would be difficult.

First, as we cannot discuss explicitly the 666 estimated elasticities and curvatures, we present our results in the form of a histogram in Figures 1 and 2. In Appendix 5 we provide additional data on the distribution of related adjusted R^2 and Durbin-Watson test statistics, supporting the quality of our estimates. We find that the unweighted median price elasticity is 1.4. The unweighted median curvature is 0.8. If we weight our results with the turnover each item generates, we do not find very different results. We find a median weighted elasticity of 1.2 and a median weighted curvature of 0.8. Considering the values that general equilibrium modelers impose when calibrating their models, these are low numbers (see Table 1). The elasticities that we find are also a bit low in comparison with the existing empirical literature (see Bijmolt et al., 2005). Bijmolt et al. (2005) test various hypotheses explaining why estimated elasticities may be low. Among others, these relate to product category effects, effects from including advertising or promotion dummies and estimation method effects. The main reason for our relatively low price elasticity concerns the product categories that we could draw from our dataset. Food, which is typically less price elastic, is overrepresented (16 out of 28 categories). The median estimated elasticity among all items belonging to food categories in our dataset is 1.06. The median elasticity among all items belonging to 12 non-food categories is 1.95.[10] The fact that we include circular dummies in our regressions, and that advertisement in the circular most often goes along with price promotions, is much less of an explanation for low price elasticities in our dataset. Although the circular dummy might pick up part of the price effect, we hardly see this in our regressions. Excluding circular dummies implies higher elasticities, but the increase is very small (about +0.3). Estimation method effects do not seem to matter either for our results. Bijmolt et al. (2005) point to the possibility of positive correlation between demand shocks and prices. If the estimation method does not take this into account, estimated elasticities will be biased downward. For reasons mentioned above, and given our additional robustness checks in Section 3.4., we see no evidence for the hypothesis of correlation between prices and the error term in our regressions. Moreover, re-estimating Equation

---

[10] Distinguishing durable and non-durable goods categories reveils parallel differences, with elasticities being much higher for durable goods. In line with the high fraction of food categories, the share of durables in our dataset is relatively small.

(14) with IV-methods hardly affects the estimated elasticities. As a final test on the potential impact of estimation methods and the quality of estimation results, we calculated the median elasticity and curvature parameters conditional on good test statistics for autocorrelation and for the explanatory power of the model (R^2). Appendix 5 summarizes these results. Again, elasticity and curvature are hardly affected.

Figure 3 and Table 4 bring more structure in our estimation results. Excluding some extreme values for the curvature, Figure 3 reveals that the estimated price elasticity and curvature are strongly positively correlated. The correlation coefficient is 0.53.[11] In Table 4 we report the unweighted median elasticity and curvature, and their correlation, conditional on the elasticity taking certain values. The condition that the elasticity is strictly higher than 1 corresponds to the approach in standard macroeconomic models. When we impose this condition, the median estimated price elasticity is 2.4, the median estimated curvature 1.7. Estimated price elasticities between 3 and 6 go together with a median curvature of 3.5, etc.

We can now reduce the uncertainty around the curvature parameter in calibrated macro models. First, as we have summarized in Table 1, researchers typically impose price elasticities in the range from 3 to about 10. Our results in Table 4 reveal corresponding values for the curvature of the same order of magnitude, ranging respectively from about 2 to about 11. There does not seem to be any empirical ground for curvature parameters of 33 or more. Second, considering all the empirical evidence on price elasticities, even a curvature parameter of 10 would be hard to justify. The large survey of studies by Bijmolt et al. (2005) reveals a median price elasticity of about 2.2. Only 9% of estimated elasticities exceed 5. More or less in line with these results, the recent industrial organization literature reports price-cost mark-ups that are consistent with price elasticities between 3 and 6 (see e.g. Domowitz et al., 1988; Konings et al., 2001; Dobbelaere, 2004). Combining these results with our findings in Table

---

[11] Figure 3 excludes 38 observations with an estimated curvature higher than 40 or lower than -40. If we exclude only observations with a curvature above +60 or below -60, the correlation is 0.51. Note that most of the extreme estimates for the curvature occur when the estimated price elasticity is very close to zero. Relatively small changes in the absolute value of the elasticity then result into huge percentage changes in the elasticity and, according to our definition, high curvature.

4, a very sensible value to choose for the curvature would be around 4. Note that this value is fairly robust to changes in our selection of product categories. Our interpretation of Figure 3 and Table 4 allows us to overcome the bias on our median estimates that may result from an overrepresentation of low-elasticity product categories. Clearly, a value for the curvature of 4 is far below current practice (see again Table 1). Only Bergin and Feenstra (2000) impose a lower value. Our findings are fully consistent, however, with Klenow and Willis (2006) who observe that the joint assumption of realistic idiosyncratic shocks and a curvature of 10 is not compatible with actual nominal and relative price changes in US data.

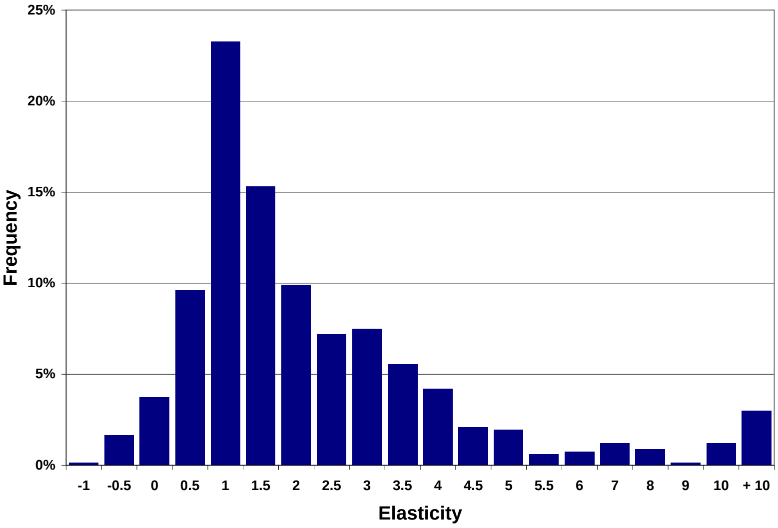


Figure 1: Estimation Results Elasticity

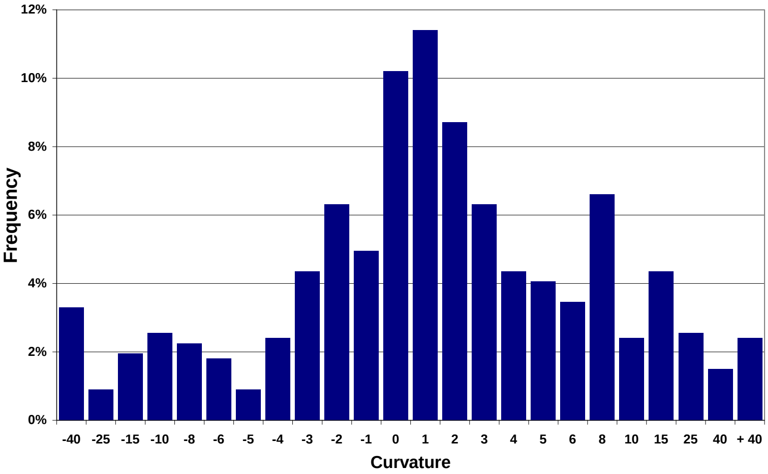


Figure 2: Estimation Results Curvature

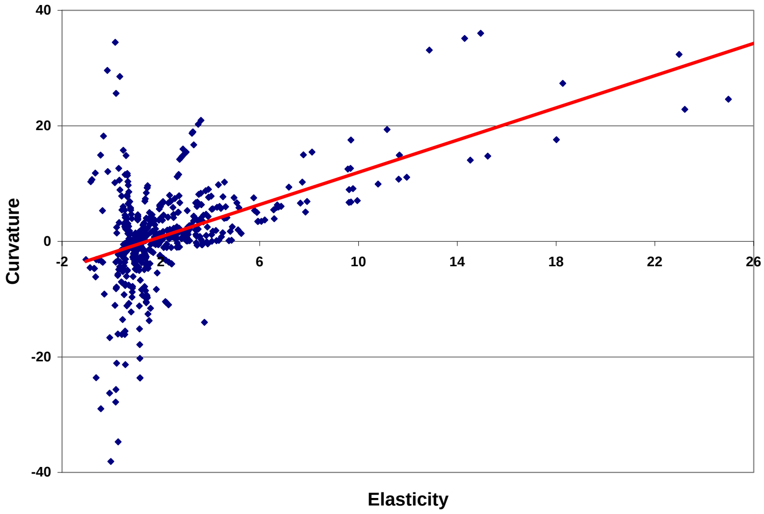


Figure 3: Correlation between Estimated Elasticity and Curvature

Table 4: Estimated Price Elasticity and Curvature

	Unconditional	Conditional				
		$\varepsilon > 1$	$2 < \varepsilon \leq 4$	$3 < \varepsilon \leq 6$	$4 < \varepsilon \leq 8$	$8 < \varepsilon \leq 12$
Median Elasticity	1.4	2.4	2.8	3.7	4.9	9.8
Median Curvature	0.8	1.7	2.0	3.5	5.4	11.1
Fraction $\epsilon < 0$	42%	26%	15%	8%	0%	0%
N.obs.	666	410	163	101	50	15

Second, our estimated curvatures show that the constant elasticity Dixit-Stiglitz (1977) benchmark is too simplistic. Over the broad range of product categories that we have studied, convex and concave demand curves coexist. We observe a negative curvature for 42% of the items. About 27% of our estimated curvatures are below -2, 38% are above +2. The high frequency of non-zero estimated curvatures, including many negative curvatures, supports our argument that the original AIDS model is too restrictive to answer our research question. A key parameter in our behavioral extension is δ_{ii} (see our discussion of Equation (8)). Additional tests show that this extension makes sense. We find the estimated δ_{ii} to be statistically different from zero at the 10% significance level for 43% of the items. Furthermore, a Wald test rejects the null hypothesis that $\delta_{11} = \delta_{22} = \delta_{33} = \delta_{44} = 0$ at the 5% significance level for two thirds of the included product categories. Appendix 6 provides details. A macroeconomic model that fits the microeconomic evidence well should thus ideally allow for sectors with differing elasticities and curvatures.

Third, in order to find out whether a concave demand curve gives rise to stickier prices, we check whether there is a link between our results on the curvature/elasticity and the size/frequency of price adjustment. In other words, does the supplier act differently for products with a high curvature compared to products with a low curvature, as the theory on strategic complementarity would suggest. We computed the correlation between the statistics on nominal price adjustment presented in Table 2 with the 666 estimated elasticities and curvatures. Table 5 reports the results. Only the correlation between the price elasticity of demand and the size of price adjustment is significantly negative for both the cases including and excluding markdowns. Correlation is very weak however. Furthermore, our estimated curvatures are not correlated with either the frequency or the size of price adjustment. This finding applies irrespective of including or excluding markdowns. It also applies irrespective of any condition on the level of the curvature (e.g. $\epsilon > 0$) or the elasticity (e.g. $\varepsilon > 1$). One must not overestimate the importance of this lack of correlation. An issue that might drive this result is the fact that our data refer to a multi-product firm. Midrigan (2006) documents that multi-product stores tend to adjust prices of goods in narrow product categories simultaneously. Price adjustment of individual items in a multi-product firm is also a function of the shocks and price adjustment frictions of the entire product category to which the item belongs. This kind of coordination will break the potential relation between individual items' curvatures and frequency and size of price adjustment.

Table 5: Correlation with Nominal Price Adjustment Statistics

	Including Markdowns		Excluding Markdowns	
	Frequency	Size	Frequency	Size
Elasticity	0.04	-0.09^*	-0.10^*	-0.15^*
Curvature	0.02	0.00	0.00	0.02

Note: The correlations in this Table are calculated using the 666 item elasticity/curvature estimates and their corresponding size and frequency of price adjustment. An asterisk signals that the correlation coefficient is significant at the 5% significance level. The column "Excluding Markdowns" indicates that the size and frequency of price adjustment were calculated discarding periods of temporary price markdowns.

3.4 Robustness

We test the robustness of our results in various ways. First, we have changed the estimation methodology. The assumption underlying the use of SUR is that prices p_{it} in Equation (14) are uncorrelated to the error term ε_{imt}. Although we believe we have good reasons to make this assumption, we drop it as a robustness check, and re-estimate our model using an IV method. Ideally, one can use information on costs, e.g. material prices, as instruments. However, data on a sufficient number of input prices with a high enough frequency is generally not available. Hausman et al. (1994) and Hausman (1997), who also use prices and quantities in different outlets, solve this problem by exploiting the panel structure of their data. They make the identifying assumption that prices in all outlets are driven by common cost changes which are themselves independent of outlet specific variables. Demand shocks that may affect the price of an item in one outlet are assumed not to affect the price of that item in other outlets. Prices in other outlets then provide reliable instruments for the price in a specific outlet. This procedure cannot work in our setup since prices are identical across outlets. As an alternative we use once to three times lagged prices p_i and once lagged relative prices $\frac{p_i}{P*}$ as instruments. Considering that autocorrelation is generally no problem in our basic regressions (see Appendix 5) lagged prices are valid instruments. Re-estimating our model for a large subset of the included product categories with the 3SLS methodology, we obtain very similar results for the elasticities and curvatures.

As a second robustness check we introduce seasonal dummies to capture possible demand shifts related to the time of the year. As we mentioned before, when suppliers are aware of such demand shifts they may fix their price differently. Not accounting for these demand shifts may then introduce correlation between the price and the error term, and undermine the quality of our estimates. Re-estimating our model with additional seasonal dummies does not affect our results in any serious way either.

Third, we allow for gradual demand adjustment to price changes by adding a lagged dependent variable to the regression. Although often statistically significant, we generally find the estimated parameter on this lagged dependent variable to be between +0.1 and -0.1. Gradual adjustment seems to be no important issue in our dataset.

Fourth, our results are based on the assumption that the aggregate price (P_t^*) is the relevant reference price when consumers make their choice. This assumption is in line with the approach in standard macro models. In the marketing literature, however, it is often assumed that reference prices are given at the time of choice (see e.g. Putler, 1992; Bell and Latin, 2000). As a fourth robustness test we have therefore assumed the reference price to be equal to the one-period lagged aggregate price P_{t-1}^*. Re-estimating our model for a subset of product categories we find that this alternative has no influence on the estimated price elasticities. It implies slightly higher estimated curvatures for most items, however without affecting any of our conclusions drawn above[12].

A final check on the reliability of our results considers potential implications of the way we specify and introduce "other". Although necessary to make estimation manageable, introducing "other" imposes a large number of restrictions on the regression. In Appendix 7 we report additional statistics showing that there is no correlation at all between the market share of "other" in a product category and the average estimated elasticity and curvature for the four items in that product category. The estimated elasticity and curvature are not correlated either with the total number of items in the category.

4 Conclusion

The failure of nominal frictions to generate persistent effects of monetary policy shocks has led to the development of models that combine nominal and real price rigidities. Many researchers recently introduce a kinked (concave) demand curve as an attractive way to obtain real price rigidities. However, the literature suffers from a lack of empirical evidence on the extent of curvature in the demand curve. This paper uses scanner data from a large euro area supermarket chain to estimate the curvature of a

---

[12] Assuming that the reference price equals P_{t-1}^* affects the equation for the curvature. Instead of Equation (11) it then holds that $\epsilon_i = \frac{\partial \ln \varepsilon_i}{\partial \ln p_i} = \frac{(\varepsilon_i - 1)(\varepsilon_i - 1 - \beta_i) - 2\delta_{ii}/s_i}{\varepsilon_i}$.

large number of items.

First, as is typical for studies with micro data, we find wide variation in the estimated curvature of demand among items/product categories. We observe both items with a convex and a concave demand curve. This result would ideally be matched with a model with heterogeneous firms that can match the entire distribution of curvatures. Our results also support the introduction of a kinked (concave) demand curve in a representative firm economy, but the median degree of curvature is much lower than currently calibrated. This finding is consistent with Klenow and Willis (2006) who find that the joint assumption of realistic idiosyncratic shocks and a curvature of 10 is not compatible with observed nominal and relative price changes in US data.

Second, exploiting the heterogeneity in the estimates, we do not find that items with a different curvature have a different frequency or size of nominal price adjustment in our data. In case strategic complementarity affects price setting these should be correlated. The fact that our data stems from a multi-product retailer may explain this lack of correlation. Midrigan (2006) argues that the item-specific frequency and size of price adjustment in a multi-product firm are also a function of the shocks and price adjustment frictions of the entire product category to which the item belongs. This could explain why the relation between item-specific statistics of price adjustment and the estimated elasticities and curvatures is disturbed in our data.

References

[1] Alston J., Foster A. and R.Green, 1994, Estimating Elasticities with the Linear Approximate Almost Ideal Demand System: Some Monte Carlo Results, *Review of Economics and Statistics*, 76, 351-356

[2] Altig D., Christiano L., Eichenbaum M. and J. Lindé, 2005, Firm-Specific Capital, Nominal Rigidities and the Business Cycle, *CEPR Discussion Paper*, No 4858

[3] Ball L. and D. Romer, 1990, Real Rigidities and the Non-Neutrality of Money, *Review of Economic Studies*, 57, 183-203

[4] Basu S., 1995, Intermediate Goods and Business Cycles: Implications for Productivity and Welfare, *American Economic Review*, 85, 512-531

[5] Benabou R., 1988, Search, Price Setting and Inflation. *Review of Economic Studies*, 55, 353-376

[6] Bell D.R. and J.R. Lattin, 2000, Looking for Loss Aversion in Scanner Panel Data: The Confounding Effect of Price Response Heterogeneity, *Marketing Science*, 19, 185-200

[7] Bergin P. and R. Feenstra, 2000, Staggered Price Setting, Translog Preferences and Endogenous Persistence, *Journal of Monetary Economics*, 45, 657-680

[8] Berry S., Levinsohn J. and A. Pakes, 1995, Automobile Prices in Market Equilibrium, *Econometrica*, 63, 841-890

[9] Bijmolt T., Van Heerde H. and R. Pieters, 2005, New Empirical Generalisations on the Determinants of Price Elasticity, *Journal of Marketing Research*, 42, 141-156

[10] Bils M. and P.J. Klenow, 2004, Some Evidence on the Importance of Sticky Prices, *Journal of Political Economy*, 112, 947-985

[11] Broda C. and D. Weinstein, 2006, Globalization and the Gains from Variety, *Quarterly Journal of Economics*, 121, 541-585

[12] Burstein A. and C. Hellwig, 2007, Prices and Market Shares in a Menu Cost Model, UCLA, *mimeo*

[13] Buse A., 1994, Evaluating the Linearized Almost Ideal Demand System, *American Journal of Agricultural Economics*, 76, 781-793

[14] Calvo G., 1983, Staggered Prices in a Utility-Maximizing Framework, *Journal of Monetary Economics*, 12, 383-398

[15] Chari V. Kehoe P. and E. McGrattan, 2000, Sticky Price Models of the Business Cycle: Can the Contract Multiplier Solve the Persistence Problem, *Econometrica*, 68, 1151-1179

[16] Christiano L, Eichenbaum M. and C. Evans, 1999, Monetary Policy Shocks: What Have We Learned and to What End?, *Handbook of Macroeconomics*,1A, eds, Michael Woodford and John Taylor, Elsevier Science

[17] Christiano L., Eichenbaum M. and Evans C., 2005, Nominal Rigidities and the Dynamic Effects of Shock to Monetary Policy, *Journal of Political Economy*, 113, 1-45

[18] Coenen G., Levin A. and K. Christoffel, 2006, Identifying the Influences of Nominal and Real Rigidities in Aggregate Price Setting Behavior, *Journal of Monetary Economics*, forthcoming

[19] Deaton A. and J. Muellbauer, 1980, An Almost Ideal Demand System, *American Economic Review*, 70, 312-326

[20] Dhyne E., Álvarez L., Le Bihan H., Veronese G., Dias D., Hoffman J., Jonker N., Lünnemann P., Rumler F., and J. Vilmunen, 2006, Price setting in the euro area: Some stylized facts from individual consumer price data, *Journal of Economic Perspectives*, 20, 171-192

[21] Dobbelaere S., 2004, Estimation of Price-Cost Margins and Union Bargaining Power for Belgian Manufacturing, *International Journal of Industrial Organization*, 22, 1381-1398

[22] Domowitz I., Hubbard G. and B. Petersen, 1988, Market Structure and Cyclical Fluctuations in US Manufacturing, *Review of Economics and Statistics*, 70, 55-66

[23] Dotsey M. and R. King, 2005, Implications of State-Dependent Pricing for Dynamic Macroeconomic Models, *Journal of Monetary Economics*, 52, 213-242

[24] Dotsey M., King R. and A. Wolman, 2006, Inflation and Real Activity with Firm-Level Productivity Shocks: A Quantitative Framework, *mimeo*

[25] Dixit A. and J. Stiglitz, 1977, Monopolistic Competition and Optimum Product Diversity, *American Economic Review*, 67, 297-308

[26] Eichenbaum M. and J. Fisher, 2004, Evaluating the Calvo Model of Sticky Prices, *NBER Working Paper*, No 10617

[27] Galí J. and M. Gertler, 1999, Inflation Dynamics: A Structural Econometric Analysis, *Journal of Monetary Economics*, 44, 195-222

[28] Golosov M. and R.E. Lucas Jr., 2003, Menu Costs and Phillips Curves, *NBER Working Paper*, No 10187

[29] Green R and J. Alston, 1990, Elasticities in AIDS Models, *American Journal of Agricultural Economics*, 72, 442-445

[30] Hausman J., 1997, Valuation of New Goods under Perfect and Imperfect Competition, in *The Economics of New Goods*, Bresnahan and Gordon, eds., Chicago Press

[31] Hausman J., Leonard G. and J.D. Zona, 1994, Competitive Analysis with Differentiated Products, *Annales d'Économie et de Statistique*, 34, 159-180

[32] Heidhues P. and B. Koszegi, 2008, Competition and Price Variation when Consumers Are Loss Averse, *American Economic Review*, 98, 1245-1268

[33] Kimball M., 1995, The Quantitative Analytics of the Basic Neomonetarist Model, *Journal of Money, Credit and Banking*, 27, 1241-1277

[34] Klenow P.J. and O. Kryvtsov, 2005, State-Dependent or Time-Dependent Pricing: Does It Matter for Recent U.S. Inflation?, *NBER Working Paper*, No 11043

[35] Klenow P.J. and J.L. Willis, 2006, Real Rigidities and Nominal Price Changes, *Research Working Paper*, Federal Reserve Bank of Kansas City, No 06-03

[36] Konings J., Van Cayseele P. and F. Warzynski, 2001, The Dynamics of Industrial Mark-Ups in Two Small Open Economies: Does National Competition Policy Matter? *International Journal of Industrial Organization*, 19, 841-859

[37] Mankiw N.G., 1985, Small Menu Costs and Large Business Cycles, *Quarterly Journal of Economics*, 100, 529-537

[38] Midrigan V., 2006, Menu Costs, Multi-Product Firms, and Aggregate Fluctuations, Ohio State University, *mimeo*

[39] Menezes-Filho N., 2005, Is the Consumer Sector Competitive in the U.K.? A Test Using Household-Level Demand Elasticities and Firm-Level Price Equations, *Journal of Business and Economic Statistics*, 23, 295-304

[40] Nakamura E. and J. Steinsson, 2007, Five Facts about Prices: A Reevaluation of Menu Cost Models, Harvard University, *mimeo*

[41] Okun A., 1981, Prices and Quantities, *The Brookings Institution*, Washington DC

[42] Peersman G., 2004, The Transmission of Monetary Policy in the Euro Area: Are the Effects Different Across Countries?, *Oxford Bulletin of Economics and Statistics*, 66, 285-308

[43] Putler D.S., 1992, Incorporating Reference Price Effects into a Theory of Consumer Choice, *Marketing Science*, 11, No 3, 287-309

[44] Sbordone A.M., 2002, Prices and Unit Labor Costs: A New Test of Price Stickiness, *Journal of Monetary Economics*, 49, 265-292

[45] Smets F. and R. Wouters, 2007, Shocks and Frictions in US Business Cycles: A Bayesian Approach, *American Economic Review*, 97, 586-606

[46] Taylor J., 1980, Aggregate Dynamics and Staggered Contracts, *Journal of Political Economy,* 88, 1-23

[47] Tversky A. and D. Kahneman, 1991, Loss Aversion in Riskless Choice : A Reference-Dependent Model, *Quarterly Journal of Economics*, 106, 1039-1061

[48] Woodford M, 2003, *Interest and Prices: Foundations of a Theory of Monetary Policy,* Princeton, Princeton University Press

[49] Woodford M., 2005, Firm-specific Capital and the New Keynesian Phillips Curve, *International Journal of Central Banking*, 1, September, 1-46

Appendix 1: Different Curvatures

Curvature is not defined homogeneously across the different papers in the literature on price rigidity. In this appendix we derive the relationships between the alternative definitions. These relationships underly some of the parameter values that we report in Table 1 in the main text. We use the following notation: $x_i = q_i/Q$ is firm i's relative output, p_i is its price, $\varepsilon(x_i)$ is the (positive) price elasticity of demand, $\mu(x_i) = \frac{\varepsilon(x_i)}{\varepsilon(x_i)-1}$ is the firm's desired markup. Assuming an aggregate price level equal to 1, p_i also indicates the firm's relative price.

Eichenbaum and Fisher (2004) and Smets and Wouters (2007) define curvature as we have done as the elasticity of the price elasticity of demand with respect to the relative price at steady state:

$$\epsilon = \left[\frac{\partial\varepsilon(x_i)}{\partial p_i}\frac{p_i}{\varepsilon(x_i)}\right]_{x_i=1} \tag{15}$$

Coenen, Levin and Christoffel (2006) define the curvature of the demand curve as the relative slope of the price elasticity of demand around steady state:

$$\epsilon = \left[-\frac{\partial\varepsilon(x_i)}{\partial x_i}\right]_{x_i=1} \tag{16}$$

It can be shown that in steady state both approaches are identical:

$$\frac{\partial\varepsilon(x_i)}{\partial p_i}\frac{p_i}{\varepsilon(x_i)} = \frac{\partial\varepsilon(x_i)}{\partial p_i}\frac{p_i}{\varepsilon(x_i)}\frac{\partial x_i}{\partial x_i}\frac{x_i}{x_i} = \frac{\partial\varepsilon(x_i)}{\partial x_i}\frac{p_i}{x_i}\frac{\partial x_i}{\partial p_i}\frac{x_i}{\varepsilon(x_i)} = -\frac{\partial\varepsilon(x_i)}{\partial x_i}\varepsilon(x_i)\frac{x_i}{\varepsilon(x_i)}$$

Evaluated at steady state ($x_i = 1$), this is equal to $-\frac{\partial\varepsilon(x_i)}{\partial x_i}$.

Kimball (1995) and Woodford (2005) characterize the curvature in the demand curve by the elasticity of the firm's desired markup with respect to relative output at steady state, i.e.

$$\xi = \left[\frac{\partial\mu(x_i)}{\partial x_i}\frac{x_i}{\mu(x_i)}\right]_{x_i=1} \tag{17}$$

The relationship between ϵ and ξ is as follows:

$$\begin{aligned}\xi &= \left[\frac{\partial\mu(x_i)}{\partial x_i}\frac{x_i}{\mu(x_i)}\right]_{x_i=1} = \left[\epsilon\frac{\partial\mu(x_i)}{\partial\varepsilon(x_i)}\frac{\partial p_i}{\partial x_i}\frac{x_i}{p_i}\frac{\varepsilon(x_i)}{\mu(x_i)}\right]_{x_i=1} \\ &= \left[\epsilon\frac{1}{(\varepsilon(x_i)-1)^2}\frac{1}{\varepsilon(x_i)}(\varepsilon(x_i)-1)\right]_{x_i=1} = \frac{\epsilon}{(\varepsilon(1)-1)\,\varepsilon(1)}\end{aligned}$$

Kimball (1995) assumes $\xi = 4.28$ and $\varepsilon(1) = 11$. Woodford imposes $\xi = 0.13$ and $\varepsilon(1) = 7.67$.

The approach in Chari et al. (2000) is very close to Eichenbaum and Fisher (2004), Coenen, Levin and Christoffel (2006) and Smets and Wouters (2007). Cost minimization by households buying differentiated products i to achieve optimal composite consumption Q yields the following first order condition for demand:

$$p_i = \frac{\lambda}{Q} G'(x_i)$$

with λ the Lagrangian lambda on the constraint relating household composite consumption Q to individual quantities q_i, G the Kimball (1995) aggregator function for composite consumption and (as defined before) $x_i = q_i/Q$. Rewriting this first order condition, we obtain the demand curve $x_i = D(p_i Q/\lambda)$ with $D = (G')^{-1}$. The price elasticity of demand equals

$$\varepsilon(x_i) = -\frac{D'(G'(x_i))G'(x_i)}{x_i}$$

Evaluated at steady state this is $\varepsilon(1) = -D'(G'(1))G'(1)$. The curvature of the demand curve at steady state can then be obtained as:

$$\epsilon = \left[-\frac{\partial \varepsilon(x_i)}{\partial x_i} \right]_{x_i=1} = D^{''}(G'(1))G^{''}(1)G'(1) + G^{''}(1)D^{'}(G^{'}(1)) - D^{'}(G^{'}(1))G^{'}(1)$$

Since $D'(G^{'}(1)) = 1/G^{''}(1)$ it follows that

$$\epsilon = \frac{D^{''}(G'(1))G'(1)}{D^{'}(G^{'}(1))} + 1 + \varepsilon(1)$$

Chari et al. (2000) define their curvature parameter χ as

$$\chi = -\frac{D^{''}(G'(1))G'(1)}{D^{'}(G^{'}(1))}, \tag{18}$$

from which the relationship with ϵ is:

$$\epsilon = -\chi + 1 + \varepsilon(1) \tag{19}$$

Chari et al. (2000) state a value of -289 for χ and 10 for $\varepsilon(1)$. According to Equation (19) this would imply $\epsilon = 300$. The discrepancy with the value of 385 that we report in Table 1 is due to the fact that

Chari et al. (2000) use a first order Taylor series expansion of the demand elasticity around the steady state to calculate their curvature parameter χ associated with the Kimball (1995) parameterisation. The exact value of χ would be -374.

Finally, Bergin and Feenstra (2000) derive a concave demand curve from assuming preferences with a translog functional form. The (positive) own price elasticity of demand is $\varepsilon_i = 1 - \frac{\gamma_{ii}}{s_i}$ with s_i the expenditure share of good i and $\gamma_{ii} = \partial s_i / \partial \ln p_i < 0$. Along the lines set out in Section 3.1. of this paper it can be derived that $\epsilon = \frac{(\varepsilon_i - 1)^2}{\varepsilon_i}$. Starting from the imposed $\varepsilon(1) = 3$, ϵ should be 1.33.

Appendix 2: Description of Dataset

Table 6 gives an overview of the 58 product categories that are in the dataset that we use in this paper. Between brackets we indicate the number of items within each category. The available data for all these categories have been used to compute the basic statistics in Section 2. Product categories in italic are also included in the econometric analysis in Section 3.

Table 6: Product Categories and Number of Items

Drinks: *tea* (67), coke (39), chocolate milk (9), *lemonade* (33), *mineral water* (66), *wine* (17) port wine (54), gin (21), *fruit juice* (54), beer (6), *whiskey* (82)
Food: *cornflakes* (49), tuna (46), *smoked salmon* (18), *biscuit* (9), *mayonnaise* (45), tomato soup (5), *emmental cheese* (56), gruyere cheese (19), *spinach* (29), *margarine* (62), *potatoes* (26), liver torta (98), *baking flour* (18), *spaghetti* (30), coffee biscuits (5), minarine (2)
Equipment: *airing cupboard* (61), knife (19), hedge shears (32), dishwasher (43), washing machine (36), tape measure (15), *tap* (24), dvd recorder (20), casserole (74), toaster (40)
Clothes and related: jeans (79), jacket (88)
Cleaning products: dishwasher detergent (43), *detergent* (43), soap powder (98), *floorcloth* (11) *toilet soap* (34)
Leisure and education: hometrainer (52), football (32), cartoon (86), dictionary (32), school book (34)
Personal care: *plaster* (33), *nail polish* (15), handkerchief (63), *nappy* (64), *toilet paper* (13)
Other: potting soil (33), *cement* (43), *bath mat* (48), *aluminium foil* (5)

Note: The number of items in a particular product category is stated in brackets. Only the product categories in italic are included in the econometric analysis in Section 3.

Our econometric analysis in Section 3 includes four items per product category and a composite of all other items in the category, called "other". Including more than four items could make sense from the perspective of covering a larger share of the market. However, it would also imply an inflation of coefficients to be estimated. Moreover, since the price of each item occurs as an explanatory variable in the expenditure share equation of all included items within the product category, raising the number of items could limit estimation capacity when additional items have shorter or non-overlapping data availability. Our criteria to select the four items per product category reflect these concerns. These criteria are (long) data availability and (relatively high) market share within the category.[13] More precisely, we ranked all items within the category on the basis of the total number of observations available (the maximum being 86), and chose those items with the highest number of observations.

---

[13] Note that both these criteria are strongly (positively) correlated.

Among items with an equal number of observations we selected those with the highest market share. If this procedure implied different selections among the six available outlets, we chose those products with the best ranking in most outlets.

The market share of "other" has been constructed as

$$s_{other} = \frac{X_{other}}{X} = \frac{\sum_{j \notin S4}^{N} p_j q_j}{X}$$

with $S4$ the selected four items, and all other variables as defined in the main text. The price index of "other" is the Stone index for all items included in "other".

$$p_{other} = \sum_{j \notin S4}^{N} s_j p_j$$

with $s_j = p_j q_j / X_{other}$. Due to different weights p_{other} will differ across the six outlets.

The reduction to 28 product categories in the econometric analysis in Section 3, coming from 58, has been driven by the following criteria. For a category to be included in the econometric analysis we required (i) data availability in all six outlets, (ii) the four selected items to have a total market share of at least 20% in their product category and (iii) the four selected items to show sufficient price variation. Over the whole time span the four items together should show at least 20 price changes of at least 5%, where we counted the typical V-pattern of a price markdown as 1 price change. At least 3 of these price changes should be regular price changes. The minimum market share requirement should make certain that the chosen four items are important within their category. This should raise the relevance of our estimates. Sufficient price variation is an obvious requirement if one wants to estimate a demand curve accurately.

Appendix 3: Identification of Markdowns

Figures 4 and 5 illustrate the identification of markdowns for an individual item of potatoes and lemonade. We define a markdown as a sequence of three, two or one price(s) that are/is below both the most left adjacent price and the most right adjacent price. To calculate our "excluding markdowns" statistics in Section 2, we have filtered out markdown prices. We have replaced them by the last observed regular price.

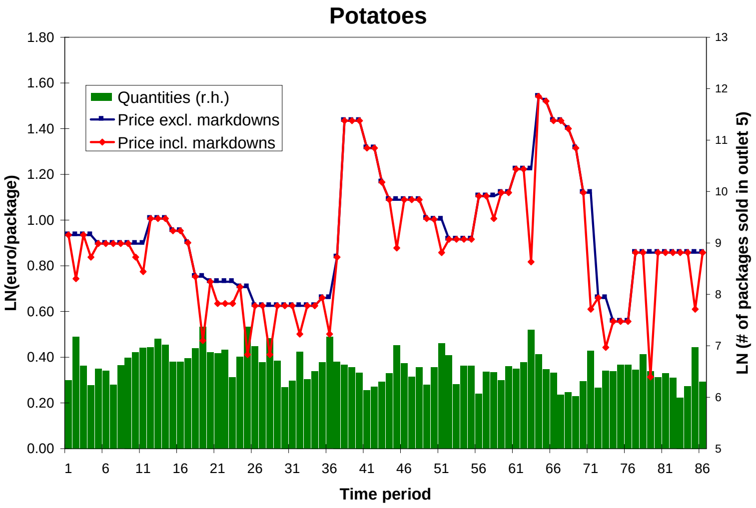


Figure 4: Price for Potato Item Including and Excluding Temporary Markdowns and Quantities

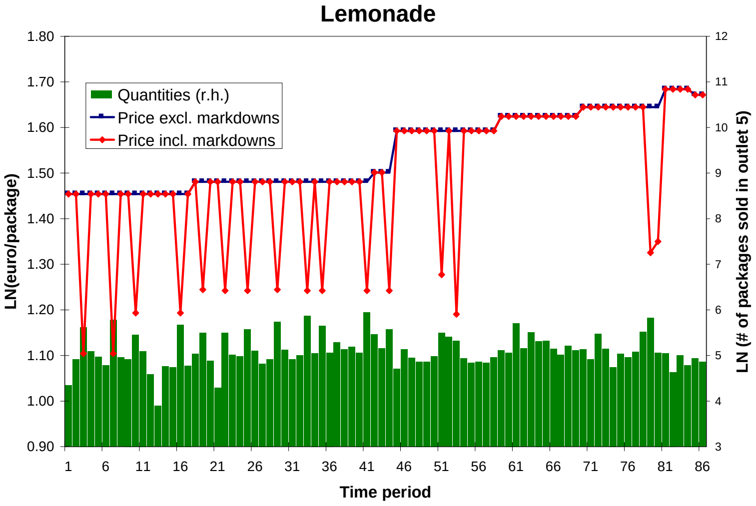


Figure 5: Price for Lemonade Item Including and Excluding Temporary Markdowns and Quantities

Appendix 4: Derivation of Curvature in the Behavorial AIDS Model

Starting from Equation (8)

$$\varepsilon_{i(LA/B-AIDS)} = 1 - \frac{\gamma_{ii}}{s_i} + \beta_i - \frac{2\delta_{ii}\ln(\frac{p_i}{P^*})}{s_i} + 2\sum_{j=1}^{N}\delta_{ij}\ln(\frac{p_j}{P^*})$$

the derivation of the curvature goes as follows:

$$\begin{aligned}
\epsilon_{i(LA/B-AIDS)} &= \frac{\partial \ln \varepsilon_i}{\partial \ln p_i} \\
&= -\frac{1}{\varepsilon_i}\frac{\partial\left(\frac{\gamma_{ii}+2\delta_{ii}\ln(\frac{p_i}{P^*})}{s_i} - 2\sum_{j=1}^{N}\delta_{ij}\ln(\frac{p_j}{P^*})\right)}{\partial \ln p_i} \\
&= -\frac{1}{\varepsilon_i}\left(\frac{2\delta_{ii}(1-s_i)s_i - (\partial s_i/\partial \ln p_i)(\gamma_{ii} + 2\delta_{ii}\ln(\frac{p_i}{P^*}))}{{s_i}^2} - 2(\delta_{ii} - s_i\sum_{j=1}^{N}\delta_{ij})\right) \\
&= -\frac{1}{\varepsilon_i}\left(\frac{2\delta_{ii}(1-s_i)}{s_i} + (\varepsilon_i - 1)\left(1 - \varepsilon_i + \beta_i + 2\sum_{j=1}^{N}\delta_{ij}\ln(\frac{p_j}{P^*})\right) - 2(\delta_{ii} - s_i\sum_{j=1}^{N}\delta_{ij})\right)
\end{aligned}$$

In the third line we again use the (empirically supported) assumption that $\frac{\partial \ln P^*}{\partial \ln p_i} = s_i$. The fourth line relies on the definition that $-\frac{\partial s_i/s_i}{\partial \ln p_i} = (\varepsilon_i - 1)$ and the result derived from Equation (8) that $\frac{\gamma_{ii}}{s_i} + \frac{2\delta_{ii}\ln(\frac{p_i}{P^*})}{s_i} = 1 - \varepsilon_i + \beta_i + 2\sum_{j=1}^{N}\delta_{ij}\ln(\frac{p_j}{P^*})$. Rearranging and imposing the steady state assumption that all relative prices are 1, we find for the curvature that

$$\epsilon_{i(LA/B-AIDS)} = \frac{1}{\varepsilon_i}\left((\varepsilon_i - 1)(\varepsilon_i - 1 - \beta_i) - \frac{2\delta_{ii}(1-s_i)}{s_i} + 2(\delta_{ii} - s_i\sum_{j=1}^{N}\delta_{ij})\right)$$

Appendix 5: Distribution of adjusted R^2 and Durbin Watson

The two figures below and Table 7 show the distribution of the adjusted R^2 and the Durbin Watson statistic over our 666 estimated regressions (28 product categories, 4 items per category, 6 outlets and excluding 6 observations with an elasticity below -10). For a very large majority of our estimates the null hypothesis of autocorrelation in the error term can be rejected.

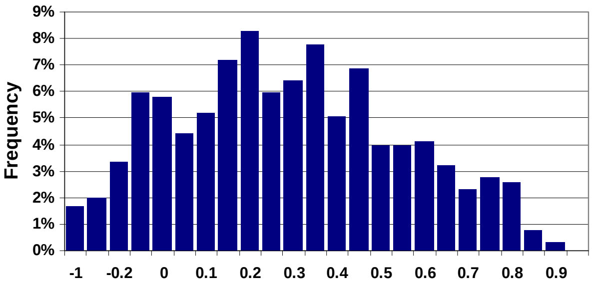


Figure 6: Adjusted R-square

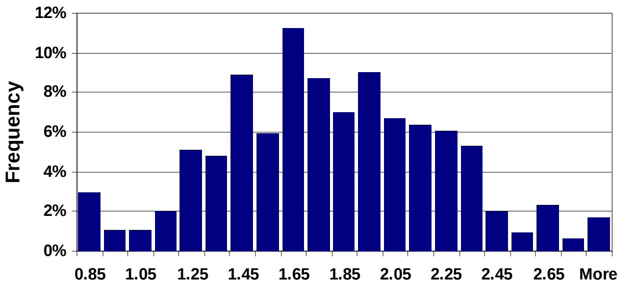


Figure 7: Durbin Watson statistic

Table 7: Estimated Price Elasticity and Curvature

	25%	50%	75%	90%
Adjusted R^2	0.07	0.26	0.45	0.63
DW	1.43	1.72	2.06	2.30

Note: The data show the adjusted R^2 and the Durbin Watson statistic of the regressions (among 666) at the 25th, 50th and 75th percentile, ordered from low to high.

Table 8 summarizes our estimates for the price elasticity and the curvature conditional on 'good' test statistics for the adjusted R^2 and the Durbin Watson statistics. Conditioning on better test statistics hardly affects our results for the median estimated elasticity and curvature. At best, we see a rise in the estimated elasticity with increasing R^2, but this rise is small.

Table 8: Estimated Price Elasticity and Curvature

	Unconditional	Conditional			
		$AdjR^2 > 0$	$AdjR^2 > 0.2$	$AdjR^2 > 0.4$	$1.5 < DW < 2.5$
Median Elasticity	1.4	1.4	1.6	1.8	1.4
Median Curvature	0.8	0.5	0.7	0.5	0.6

Appendix 6: Estimation Results for δ_{ii}

The two figures below show the distribution of the 112 (=28x4) estimated values for δ_{ii} and the distribution of the related absolute t-values. The table contains the results of a Wald test for each of the 28 product categories of the joint hypothesis that $\delta_{11} = \delta_{22} = \delta_{33} = \delta_{44} = 0$. The results are briefly discussed in the main text.

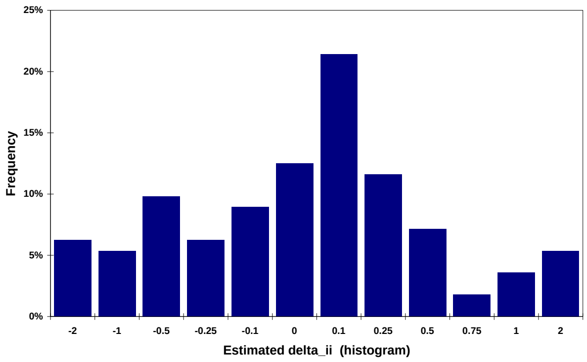


Figure 8: Point Estimates δ_{ii}

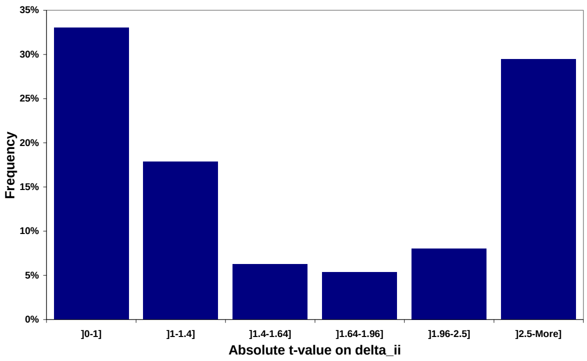


Figure 9: t-values δ_{ii}

Table 9: Wald Test for $\delta_{11} = \delta_{22} = \delta_{33} = \delta_{44} = 0$

p-value	$p \leq 0.05$	$0.05 < p \leq 0.1$	$0.1 < p \leq 0.2$	$0.2 < p$
Number of product categories	19	2	4	3

Appendix 7: Size of "Other" and Estimation Results

This appendix reveals that there is no specific relationship between our estimation results for the elasticity and the curvature in a product category and the number of items *not* included in the regressions. The table below contains all relevant correlation coefficients, the figures illustrate two of the results involving curvature.

Table 10: Pairwise Correlation Coefficients over 28 Product Categories

	Market Share "Other"	Number of Items	Median Elasticity	Median Curvature
Market Share "Other"	1	-	-	-
Number of Items	0.61	1	-	-
Median Elasticity	-0.06	-0.19	1	-
Median Curvature	-0.03	0.06	0.56	1
Median δ_{ii}	0.12	-0.19	-0.29	-0.78

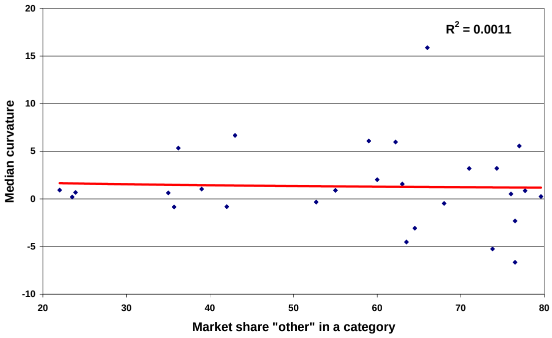


Figure 10: Curvature vs. Market Share "Other"

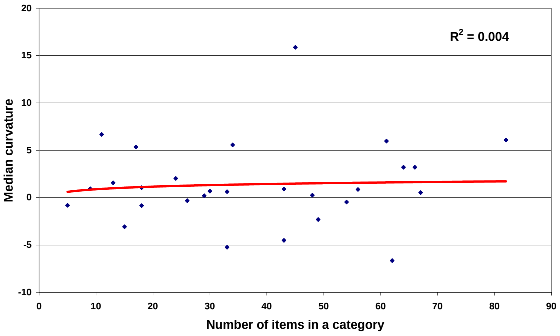


Figure 12: Curvature vs. # Items in Product Category

Optimal Inflation, Imperfect Competition and Labor Taxes

Maarten Dossche*

November 28, 2008

Abstract

In this paper I show that in an economy with sticky prices and high labor taxes, optimal inflation volatility is significantly higher than for an economy with low labor taxes. Because the marginal revenue decreases in the level of labor taxes, the Ramsey planner needs to raise taxes more to finance the same adverse government spending shocks. This creates a larger tax distortion than under a low level of labor taxes. To minimize overall distortions the planner changes taxes less than is needed to entirely finance the increase in spending and generates a surprise inflation to raise revenue from inflating the nominal public debt.

JEL classification: E30, E50, E60
Keywords: optimal fiscal and monetary policy, sticky prices, labor tax distortion

---

[*] National Bank of Belgium, Boulevard de Berlaimont 14, 1000 Brussels, Belgium, and Ghent University. E-mail: maarten.dossche@nbb.be. I started this paper while I was visiting the Economics Department of Universitat Pompeu Fabra, Barcelona, Spain. I acknowledge financial support from the Research Foundation - Flanders. I am grateful to Fabrice Collard, Nils Gottfries, Freddy Heylen, Robert Kollmann, Jurek Konieczny, Morten Ravn, Pedro Teles, Thijs Van Rens and Raf Wouters for helpful comments. The views expressed in this paper are my own, and do not necessarily reflect the views of the National Bank of Belgium. All errors are my own.

1 Introduction

It is a well known fact that in Europe labor taxes are much higher than in the United States. Prescott (2002, 2004) argues that high labor taxes can largely explain the low labor market participation in Europe. In this paper I ask the question whether the level of labor taxes can affect the way fiscal and monetary policy should be conducted.

Schmitt-Grohé and Uribe (2004b) and Siu (2004) study optimal fiscal and monetary policy in environments with nominal rigidities, imperfect competition, nominal non-state-contingent government debt and distortionary income taxes. In this environment the Ramsey planner faces a trade-off in choosing the path of inflation in response to government spending shocks. On the one hand, the planner likes to use unexpected inflation as a non-distorting tax on nominal wealth. In this way, the fiscal authority can minimize the need to vary distortionary income taxes over the business cycle. On the other hand, changes in the rate of inflation come at a cost, for firms face nominal rigidities. They find that under plausible calibrations of the degree of price stickiness, this trade-off is robustly resolved in favor of price stability. This is exactly the opposite of the result of Chari et al. (1991) who assume flexible prices. With flexible prices they find that it is optimal to use inflation as a tax on nominal wealth to finance government spending shocks. This is intuitive because price adjustment is costless so that the planner does not face a trade-off between labor taxes and inflation.

These results are all obtained for an economy like the United States where average labor taxes are around 30%, compared to Europe where average labor taxes are around 40%. Moreover, a lot of European countries have average labor tax rates close to 50%. Trabandt and Uhlig (2007) document that because labor taxes in Europe are higher than in the United States, Europe is much closer to the peak of the labor tax Laffer curve. Close to the peak of the Laffer curve the slope is much flatter than at lower levels of taxation. This implies that the marginal revenue of a 1% tax increase is much lower. The planner needs to raise taxes much more to collect the same amount of revenue. This creates a larger tax distortion than under low labor taxes. The planner then prefers to change taxes less than is required to finance the increase in spending and prefers to generate a surprise inflation to raise revenue from inflating the nominal public debt. The policy recommendation under sticky prices (Schmitt-Grohé and Uribe, 2004b) is to a large extent reverted back to the one made under flexible prices (Chari et al, 1991). I find that the volatility of inflation for an economy with high labor taxes and sticky prices is about half that of an economy with low taxes and flexible prices. The volatility of inflation for an economy with low taxes and sticky prices is negligible.

Siu (2004) finds that for wartime or large shocks to government spending the optimal policy is to inflate the nominal public debt, but arrives at the same conclusion as Schmitt-Grohé and Uribe (2004b) for peacetime or small shocks to government spending. Again this is for a calibration of an economy with a relatively low level of labor taxes. In this paper I do not compare two economies with a different size of shocks. I compare two economies with the same size of shocks, but with different levels of labor taxes. So instead of a wartime vs. peacetime comparison for the United States, this paper is a comparison of optimal policy for peacetime United States and Europe.

Section 2 presents the model and explains how the interaction between the degree of monopolistic competition and the level of labor taxes results into a Laffer curve. Section 3 shows how the level of labor taxes affects the optimal Ramsey policy. Section 4 concludes.

2 Model

I use the same model as Schmitt-Grohé and Uribe (2004b), except for the price setting mechanism. Instead of Rotemberg (1982) adjustment costs I use Calvo (1983) price setting. There are three distortions in the model. First, the distortion from labor taxes, second the distortion from transaction costs, third the relative price distortion. I choose a time unit of one quarter of a year. This is the usual choice in the business cycle literature on monetary policy. One could argue that for the way fiscal policy is conducted today this time unit is too small. Still, ministers meet as regularly as central bankers to decide on policy. The level of government spending is assumed to be exogenous. It is the outcome of a democratic process that is beyond the control of the policy maker. I restrict the presentation of the model to the key equations. Details on the first order conditions characterizing the private decisions of households and firms, as well as the optimal policy of the Ramsey planner are in Appendix A.

2.1 Households

Households maximize expected intertemporal utility as a function of consumption C_t and labor H_t. The intertemporal discount factor is β.

$$E_0 \sum_{t=0}^{\infty} \beta^t U\left(C_t, H_t\right) \tag{1}$$

Consumption purchases are subject to a proportional transaction cost $s(v_t)$ that depends on the household's money-to-consumption ratio.

$$v_t = \frac{P_t C_t}{M_t}$$

This gives the households a reason to hold money. If money were not needed to do consumption purchases, households would not be willing to hold a money stock on which they do not receive any interest. Households purchase one-period nominal government bonds B_t and pay a proportional tax τ_t on their wage. The flow budget constraint of the household is then given by:

$$P_t C_t \left[1 + s\left(v_t\right)\right] + M_t + B_t = M_{t-1} + R_{t-1} B_{t-1} + \left(1 - \tau_t\right) W_t H_t$$

The household is subject to a borrowing constraint that prevents it from engaging in Ponzi schemes:

$$\lim_{j \to \infty} E_t q_{t+j+1} \left(R_{t+j} B_{t+j} + M_{t+j}\right) \geq 0$$

at all dates. The variable q_t represents the period-zero price of one unit of currency to be delivered in period t and is given by

$$q_t = \frac{1}{R_1 R_2 ... R_{t-1}}$$

with $q_0 \equiv 1$.

2.2 Firms

A retailer bundles a continuum of goods $i \in (0,1)$ into an aggregate good Y_t that can be used for either private consumption C_t or government spending G_t:

$$Y_t = \left[\int_0^1 Y_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right]^{\frac{\varepsilon}{\varepsilon-1}} \text{ with } 1 < \varepsilon < \infty$$

where ε is the elasticity of substitution between varieties. The technology function for a variety i is linear in labor input $H_t(i)$:

$$Y_t(i) = Z_t H_t(i)$$

Labor $H_t(i)$ to produce the specific varieties is hired from a perfectly competitive labor market. The monopolist sets the price of the good it supplies, taking as given the level of aggregate demand. Once the price is set the monopolist is constrained to satisfy demand at that price so that:

$$Y_t(i) \geq \left(\frac{P_t(i)}{P_t} \right)^{-\varepsilon} Y_t$$

where ε is the demand elasticity and is the same as the elasticity of substitution in the production function of the retailer. Price adjustment is à la Calvo (1983). The probability that a firm cannot reset its price is θ. The aggregate price level then has the form:

$$P_t = \left[\theta P_{t-1}^{1-\varepsilon} + (1-\theta)\left(P_t^*\right)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}$$

The price setting problem of the firm i is to maximize future discounted profits/dividends:

$$\max_{P_t^*(i)} \left\{ \sum_{k=0}^{\infty} \theta^k \left\{ Q_{t,t+k} \left(P_{t+k}^*(i) Y_{t+k}(i) - W_{t+k} H_{t+k}(i) \right) \right\} \right\}$$

The variable $Q_{t,t+k}$ is defined as:

$$Q_{t,t+k} = \beta \left\{ \frac{U_1\left(C_{t+k}, H_{t+k}(i)\right)}{U_1\left(C_t, H_t(i)\right)} \frac{P_t}{P_{t+k}} \right\}$$

2.3 Government

The government faces a stream of public spending, denoted G_t, that is exogenous, stochastic and unproductive. These expenditures are financed by levying labor income taxes at the rate τ_t, by printing money, and by issuing one-period, risk free nominal bonds, denoted B_t. The government's flow budget constraint is then given by:

$$M_t + B_t + \tau_t W_t H_t = M_{t-1} + R_{t-1} B_{t-1} + P_t G_t$$

There is no perfect Ricardian equivalence in this model as the government can only raise revenue with distortionary taxes. If the government could raise revenue with lump sum taxes, then the timing of debt would be irrelevant (Barro, 1979). I keep the government sector in my model deliberately simple. First, this is to keep the model comparable to the model used in Schmitt-Grohé and Uribe (2004b), and second to keep the intuition behind the result as simple as possible.

2.4 Equilibrium

In equilibrium the following market clearing conditions need to hold:

Goods market clearing:

$$Y_t = s\left(v_t\right) C_t + G_t$$

Labor market clearing:

$$H_t = \int_0^1 H_t\left(i\right)$$

The price level is defined as:

$$P_t = \left[\theta P_{t-1}^{1-\varepsilon} + \left(1-\theta\right)\left(P_t^*\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}$$

2.5 Parameterization and Functional Forms

Most of the parameters I take from Schmitt-Grohé and Uribe (2005) for a quarterly model frequency. This paper mainly aims at illustrating the mechanism that generates higher optimal average inflation and a higher optimal standard deviation of inflation. It is not my aim to match the European and American data in all their dimensions.

Government spending is the only source of uncertainty.[1] Government spending G_t is assumed to

---

[1] Schmitt-Grohé and Uribe (2004b) also consider technology shocks. In the interest of clarity I only focus on government spending shocks.

Table 1: Parameterization

Symbol	Value	Description
δ	2.9	Preference parameter
A	0.0267	Transaction cost parameter
B	0.1284	Transaction cost parameter
β	0.99	Discount factor
ε	4	Elasticity of substitution
ρ_G	0.87	Persistence government spending shock
ρ_Z	0.85	Persistence technology shock
σ_G	0.016	Standard deviation gov't spending shock
σ_Z	0.0064	Standard deviation technology shock
b/Y	0.42	Steady state debt-to-GDP ratio (quarterly)
θ	0.75	Calvo price adjustment parameter

follow an AR(1) process in its logarithm,

$$\ln G_t = (1-\rho_G)\ln \overline{G} + \rho_G \ln G_{t-1} + \varepsilon_t^G \qquad \text{with } \varepsilon_t^G \sim N(0, \sigma_{\varepsilon^G}^2)$$

As in Schmitt-Grohé and Uribe (2004b) I use the utility function:

$$U(C_t, H_t) = \ln C_t + \delta \ln(1 - H_t)$$

and the transaction cost function:

$$s(v_t) = Av_t + \frac{B}{v_t} - 2\sqrt{AB}$$

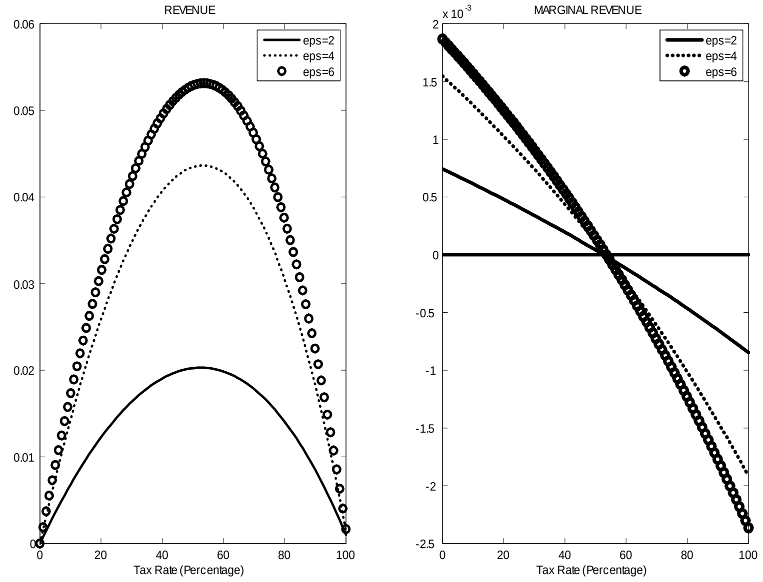
2.6 Laffer Curve

The model implies a Laffer curve for labor taxes. This happens through the interaction between imperfect competition and labor taxes. Abstracting from consumption transaction costs, the steady state labor H^* is determined by the equation below:

$$\begin{aligned} H^* &= \frac{(1-\tau)\frac{\varepsilon-1}{\varepsilon}}{\left[\delta\left(1-\frac{\tau(\varepsilon-1)}{\varepsilon}\right)+(1-\tau)\frac{\varepsilon-1}{\varepsilon}\right]} \\ H^*_{\varepsilon=\infty} &= \frac{(1-\tau)}{[\delta(1-\tau)+(1-\tau)]} = \frac{1}{1+\delta} \end{aligned}$$

In the case of perfect competition ($\varepsilon = \infty$), the presence of labor taxes does not distort the equilibrium labor allocation $H^*_{\varepsilon=\infty}$. The income and substitution effect of higher taxes exactly cancel out. It is only in the presence of imperfect competition that labor taxes distort the labor supply. Because of the imperfect competition distortion the income effect of higher labor taxes does not fully compensate the negative substitution effect of higher labor taxes. That is because households receive monopoly profits, so that with higher labor taxes their income does not fall to the same extent as their after tax wage. This can also be seen in Figure 1, that illustrates how different degrees of competition affect the shape of the Laffer curve, and thus the level of marginal tax revenue. So even though I use preferences consistent with balanced growth, due to the presence of monopolistic competition I find a negative effect of higher labor taxes on labor supply. Jonsson (2007) investigates the steady state welfare costs of imperfect competition and distortionary taxes for the United States. He finds that the combination of imperfect competition and distortionary taxes creates a much higher welfare cost than the sum of the welfare costs when both distortions occur in isolation. This is in line with the presence of a Laffer curve here.

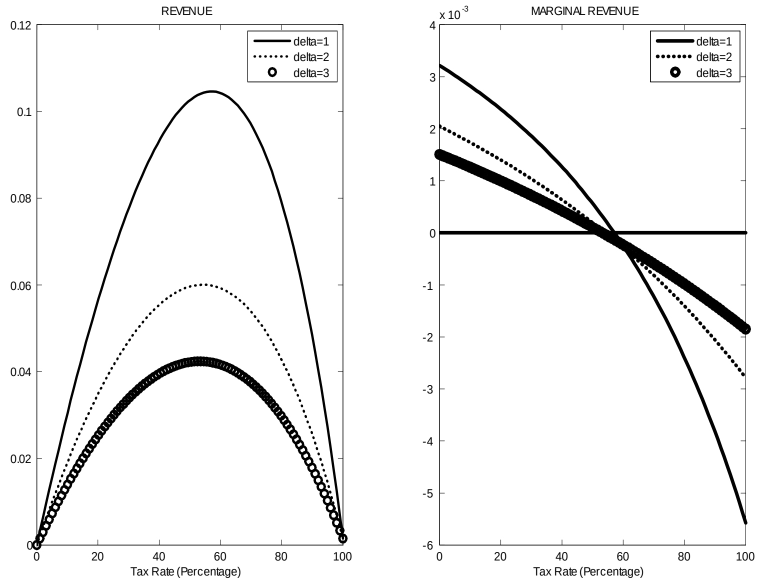
Figure 1: **Laffer Curve and Demand Elasticity**



So it should be clear that it is not the choice of the utility function that generates the Laffer curve. As long as preferences have the balanced growth property, there will only emerge a Laffer curve when there is some degree of imperfect competition in the goods market. Another issue is how my results might be affected by the size of the labor supply elasticity. Exploring different parameter values for δ

in Figure 2 I find that only the level of the Laffer curve is affected. The elasticity of labor supply does not substantially change the location of the tax rate that maximizes the tax revenue, which is what counts for my result.

Figure 2: **Laffer Curve and Labor Supply Elasticity**



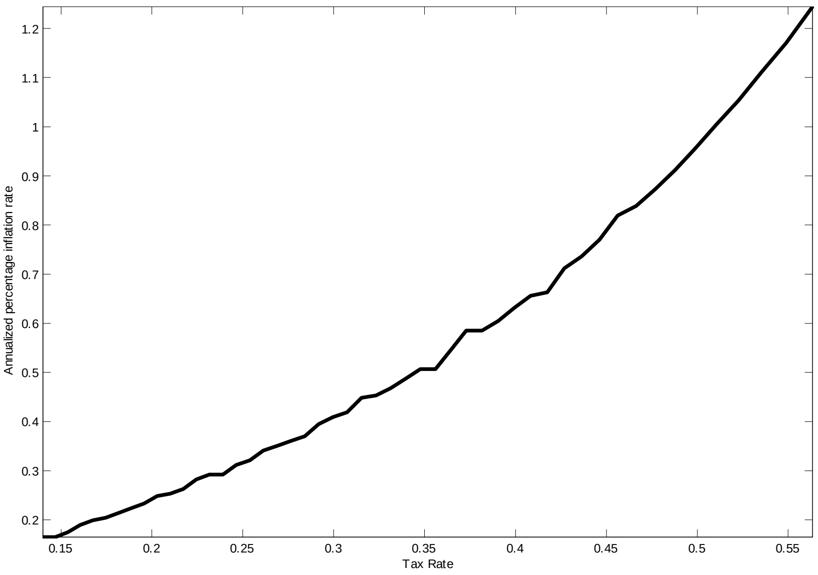
Finally, it is justified to ask how the assumption on government spending affects the shape of the Laffer curve. Rogerson (2007) and Dhont and Heylen (2008) point out that taking into account more elaborate, and thus more realistic, government taxation and spending can change the effects of taxation on hours worked. This will also affect the location of the peak of the Laffer curve. Introducing government transfers would shift the peak of the Laffer curve to the left, strengthening the relevance of this paper. Introducing productive government spending (e.g. investment in public goods) would shift the peak of the Laffer curve to the right, weakening the relevance of this paper. As in reality governments spend their money on both transfers and productive government spending, it seems reasonable to assume unproductive government spending.

3 Optimal Fiscal and Monetary Policy

In this Section I analyze the Ramsey (1927) policy for the economy I outlined in the previous Section. The Ramsey policy maximizes intertemporal utility given the decisions of households and firms. The problem can be summarized in Lagrangian form by taking the FOCs of the private economy as constraints for the Ramsey solution. I refer to Appendix A for the details on the Ramsey problem and its solution. I use a second order approximation to solve the model numerically with a perturbation method. I use the software Dynare.

3.1 Optimal Long-Run Policy

Figure 3: **Labor Taxes and Optimal Average Inflation**



In Figure 3 I show that optimal steady state inflation is increasing in the steady state labor tax rate. This is due to the fact that financing the government spending becomes increasingly distortionary through labor taxes. It is optimal to use higher inflation, which acts as an indirect tax on consumption, to finance government spending. This is in line with Schmitt-Grohé and Uribe (2004a) who explain that the intuition behind the breakdown of the Friedman rule under imperfect competition is the following: In the imperfectly competitive economy, part of income takes the form of pure monopoly rents. By definition, the labor income tax rate cannot tax profits. As a result, the social planner resorts to the inflation tax as an indirect way to tax profit income. When the household transforms profit income into consumption, it must use fiat money, which is subject to the inflation tax.

There is again a trade-off though. As inflation increases, the relative price distortion will also increase. But this is balanced by the higher labor tax distortion. In steady state there can be no taxation of nominal wealth through inflation, as by definition there is no surprise inflation. The nominal interest rate will reflect the higher inflation rate.

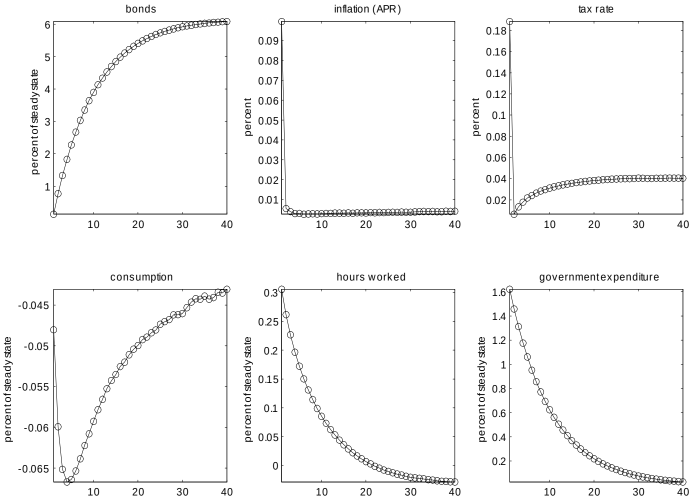
3.2 Optimal Cyclical Policy

In this Section I present the results of a simulation exercise. The impulse response functions in Figure 4 and 5 show exactly the point of this paper. For low levels of labor taxes the Ramsey planner replicates the result of Schmitt-Grohé and Uribe, and finances the government spending shock with higher taxes and accumulates debt over time. For the case with high labor taxes the Ramsey planner increases inflation and in this way deflates the real outstanding government debt. In the latter case inflation reacts more than in the first case. This explains the result in Figure 6 where the optimal standard deviation of inflation increases with the level of labor taxes. Note that I rescale the standard deviation of the government spending shock as the size of the government gets bigger. To keep the different economies comparable I choose the same level size of shocks to government spending instead of the percentage size of shocks. That is why the percentage change in government spending is smaller for the case with high labor taxes.

The policy recommendation under sticky prices (Schmitt-Grohé and Uribe, 2004b) is to a large extent reverted back to the one made under flexible prices (Chari et al, 1991). I find that the volatility of inflation for an economy with high labor taxes and sticky prices is about half that of an economy with low taxes and flexible prices. The volatility of inflation for an economy with low taxes and sticky prices is negligible.

The (peak of the) Laffer curve acts as an upper bound on taxes, similar to the lower bound on

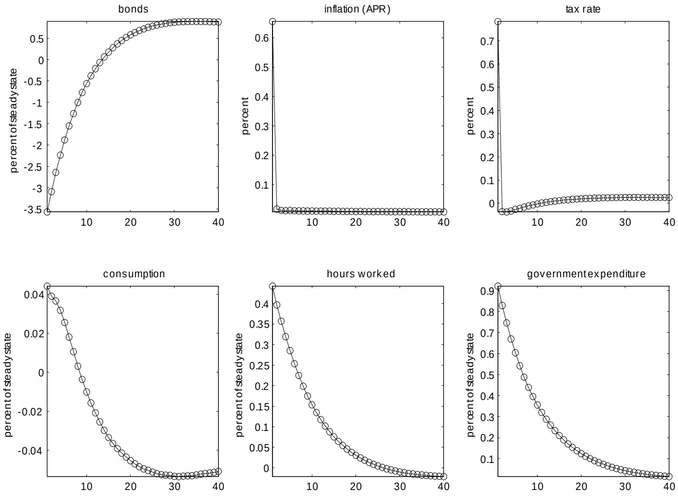
Figure 4: **Impulse Responses Low Labor Taxes**



Note: Impulse responses to a government spending shock for a low level of labor taxes (29%).

nominal interest rates. Just like an economy with low inflation rates will be more likely to hit the lower bound on nominal interest rates, will an economy with high labor taxes be more likely to hit this upper bound on taxes than an economy with low labor taxes. Upon reaching the peak of the Laffer curve the policymaker will have to use rather unorthodox policy.

Figure 5: **Impulse Responses High Labor Taxes**



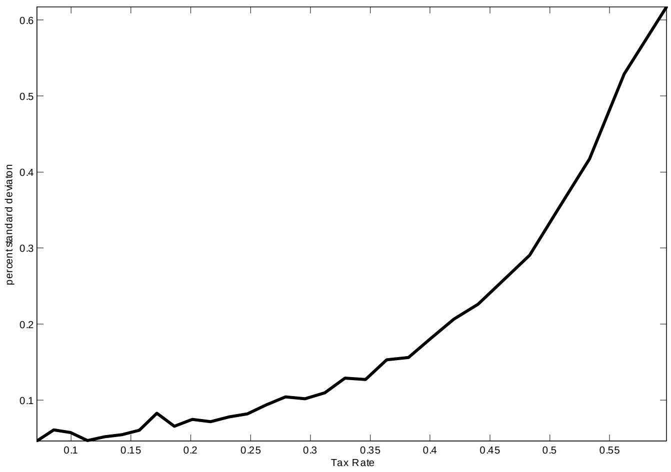
Note: Impulse responses to a government spending shock for a high level of labor taxes (60%).

4 Conclusion

Schmitt-Grohé and Uribe (2004b) and Siu (2004) study optimal fiscal and monetary policy in environments with nominal rigidities, imperfect competition, nominal non-state-contingent government debt and distortionary income taxes. They find that under plausible calibrations of the degree of price stickiness, this trade-off is robustly resolved in favor of price stability.

These results are all obtained for an economy like the United States where average labor taxes are about 30%. However, Trabandt and Uhlig (2007) document that because labor taxes in most European countries are higher than in the United States, European countries are close to the peak of their labor tax Laffer curves. Close to the peak of the Laffer curve the slope is much flatter than at lower levels of taxation. The planner then needs to raise taxes much more to collect the same amount of revenue. This creates a larger tax distortion than under low labor taxes. The planner then prefers to change taxes less than is required to finance the increase in spending and prefers to generate a surprise inflation to raise revenue from inflating the nominal public debt. The policy recommendation under sticky prices (Schmitt-Grohé and Uribe, 2004b) is to a large extent reverted back to the one made under flexible

Figure 6: **Labor Taxes and Optimal Inflation Variability**



prices (Chari et al, 1991). I find that the volatility of inflation for an economy with high labor taxes and sticky prices is about half that of an economy with low taxes and flexible prices. The volatility of inflation for an economy with low taxes and sticky prices is negligible.

References

[1] Barro R., 1979, On the Determination of the Public Debt, *Journal of Political Economy*, 87, 940-971

[2] Calvo G., 1983, Staggered Prices in a Utility-Maximizing Framework, *Journal of Monetary Economics*, 12, 383-398

[3] Chari V., L. Christiano and P. Kehoe, 1991, Optimal Fiscal and Monetary Policy: Some Recent Results, *Journal of Money, Credit, and Banking*, 23, 519-539

[4] Dhont T. and F. Heylen, 2008, Why Do Europeans Work Much Less? It is Taxes and Government Spending, *Economic Inquiry*, 46, 197-207

[5] Jonsson M., 2007, The Welfare Cost of Imperfect Competition and Distortionary Taxation, *Review of Economic Dynamics*, 10, 576–594

[6] Prescott E., 2002, Prosperity and Depression, *American Economic Review*, 92, 1-15

[7] Prescott E., 2004, Why Do Americans Work So Much More Than Europeans?, *Federal Reserve Bank of Minneapolis Quarterly Review*

[8] Ramsey F., 1927, A Contribution to the Theory of Taxation, *Economic Journal*, 37, 47-61

[9] Rogerson R, 2007, Taxation and Market Work: Is Scandinavia an Outlier?, *NBER Working Papers*, n° 12890

[10] Rotemberg J., 1982, Sticky Prices in the United States, *Journal of Political Economy*, 90, 1187-1211

[11] Schmitt-Grohé S. and M. Uribe, 2004a, Optimal Fiscal and Monetary Policy under Imperfect Competition, *Journal of Macroeconomics*, 26, 183-209

[12] Schmitt-Grohé S. and M. Uribe, 2004b, Optimal Fiscal and Monetary Policy under Sticky Prices, *Journal of Economic Theory*, 114, 198-230

[13] Schmitt-Grohé S. and M. Uribe, 2005, Optimal Fiscal and Monetary Policy in a Medium-Scale Macroeconomic Model, *NBER Macroeconomics Annual 2005*, eds M. Gertler and K. Rogoff, MIT Press

[14] Siu H., 2004, Optimal Fiscal and Monetary Policy with Sticky Prices, *Journal of Monetary Economics*, 51, 575-607

[15] Trabandt M. and H. Uhlig, 2007, How Far are We from the Slippery Slope? The Laffer Curve Revisited, Sveriges Riksbank and University of Chicago, *mimeo*

Appendix A: Optimality Conditions

Note that I here express all optimality conditions in real terms. I use small letters for nominal variables that have been divided by the price level P_t.

Competitive Equilibrium

The competitive equilibrium is characterized by the 14 constraints below. They comprise the FOCs of the households and the firms and the aggregate market clearing conditions.

(C_t)

$$\frac{1}{C_t} = -\lambda_t \left[1 + \left(A \left(\frac{C_t}{m_t} \right) + \frac{B}{\left(\frac{C_t}{m_t} \right)} - 2\sqrt{AB} \right) + \left(A - \frac{B}{\left(\frac{C_t}{m_t} \right)^2} \right) \frac{C_t}{m_t} \right] \tag{2}$$

(m_t)

$$1 - \left(A - \frac{B}{\left(\frac{C_t}{m_t} \right)^2} \right) \left(\frac{C_t}{m_t} \right)^2 = \beta \frac{\lambda_{t+1}}{\lambda_t} \frac{1}{\pi_{t+1}} \tag{3}$$

(b_t)

$$R_t = \frac{1}{\beta} \frac{\lambda_t}{\lambda_{t+1}} \pi_{t+1} \tag{4}$$

(H_t)

$$\frac{-\delta}{(1 - H_t)} - \lambda_t (1 - \tau_t) w_t = 0 \tag{5}$$

(λ_t)

$$\begin{aligned} 0 \;=\; & C_t \left[1 + A \left(\frac{C_t}{m_t} \right) + \frac{B}{\left(\frac{C_t}{m_t} \right)} - 2\sqrt{AB} \right] + m_t + b_t - \frac{m_{t-1}}{\pi_t} - \frac{R_{t-1} b_{t-1}}{\pi_t} \\ & - (1 - \tau_t) w_t H_t - d_t \end{aligned} \tag{6}$$

(p_t^*)

$$\varepsilon x_t^1 = (\varepsilon - 1) x_t^2 \tag{7}$$

(x_t^1)

$$x_t^1 = (p_t^*)^{-\varepsilon} Y_t \frac{w_t}{Z_t} + \theta \beta \frac{\lambda_{t+1}}{\lambda_t} \left(\frac{p_t^*}{p_{t+1}^*} \frac{1}{\pi_{t+1}} \right)^{-\varepsilon} x_{t+1}^1 \tag{8}$$

$\left(x_t^2\right)$

$$x_t^2 = \left(p_t^*\right)^{-\varepsilon} Y_t p_t^* + \theta\beta \frac{\lambda_{t+1}}{\lambda_t} \left(\frac{p_t^*(i)}{p_{t+1}^*(i)} \frac{1}{\pi_{t+1}} \right)^{1-\varepsilon} x_{t+1}^2 \tag{9}$$

Aggregate goods market clearing:

$$Y_t = \left(1 + Av_t + \frac{B}{v_t} - 2\sqrt{AB} \right) C_t + G_t \tag{10}$$

and labor market clearing:

$$H_t = \frac{Y_t s_t}{Z_t} \tag{11}$$

and the price level:

$$1 = \left[\theta \left(\frac{1}{\pi_t} \right)^{1-\varepsilon} + (1-\theta) \left(p_t^*\right)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}} \tag{12}$$

dividends from sticky sector:

$$d_t = Y_t - \frac{w_t}{Z_t} Y_t s_t \tag{13}$$

and:

$$s_t = (1-\theta) \left(p_t^*\right)^{-\varepsilon} + \theta \left(\pi_t\right)^{\varepsilon} s_{t-1} \tag{14}$$

Ramsey Policy

The Ramsey planner maximizes intertemporal utility (1) subject to the 13 constraints of the competitive equilibrium just described in conditions (2) – (**??**). The problem in Lagrangian form looks like:

$$\mathcal{L} = E_0 \sum_{t=0}^{\infty} \beta^t \left[\begin{array}{c} U\left(C_t, H_t\right) \\ +\xi_{1,t}\left[2\right] + \xi_{2,t}\left[3\right] + \xi_{3,t}\left[4\right] + \xi_{4,t}\left[5\right] + \xi_{5,t}\left[6\right] \\ +\xi_{6,t}\left[7\right] + \xi_{7,t}\left[8\right] + \xi_{8,t}\left[9\right] + \xi_{9,t}\left[10\right] + \xi_{10,t}\left[11\right] \\ +\xi_{11,t}\left[12\right] + \xi_{12,t}\left[13\right] + \xi_{13,t}\left[14\right] \end{array} \right]$$

This results in 13 additional Lagrange multipliers and 15 additional FOCs. Together with the competitive equilibrium conditions this results in 28 constraints and 28 variables. I do not explicitly write down the Ramsey FOCs here as these are automatically derived in my Matlab programs using the code of Levin et al. (2005).