Do Menu Costs Make Prices Sticky?*

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Abstract

This paper studies whether menu costs are large enough to explain why firms are so reluctant to change their prices. Without actually estimating menu costs, we can infer their significance for firms’ price setting decisions indirectly from observed pricing behaviour around a currency changeover. Using data from the Euro-changeover, the paper estimates that menu costs can explain a stickiness of around 35 days which is considerably less than the 7 to 18-month stickiness we observe in retailing. The reluctance of firms to adjust prices more frequently appears to be caused by factors other than menu costs.

Keywords: menu cost, price stickiness
JEL classification: E30

1 Introduction

At a currency changeover, firms have to reprint their price tags (menus) independently of whether or not they want to change prices and if this is costly firms will try to make the changeover coincide with a change in prices. This behavior will be reflected in the data. Using data from the euro-changeover in January 2002, this paper estimates that menu costs can explain a stickiness of around 35 days which is considerably less than the stickiness of 7 to 18 months that we observe in consumer prices. The reluctance of firms to adjust prices more frequently seems to be caused by factors other than menu costs.

Before reviewing the related literature, it will be useful to sketch the idea of the paper and to give an example of how the changeover affected firms’ price setting. Consider a market in which firms are price setters and suppose that the market price has a trend as in figure 1a. If changing prices is costly, firms do not adjust every period but will keep their prices constant for some time before making a larger adjustment. The individual firm’s price will increase in steps, but aggregating over many firms conceals the steps, making the index

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Figure 1: This figure shows the effect of a currency changeover on prices. The changeover takes place at $t_0$. Period 2 (3) is defined as the period immediately before (after) the changeover where we expect the index to be flat if menu costs are sufficiently large.

smooth as in the figure. Now suppose that there is a currency changeover at time $t_0$ (see figure 1b). At $t_0$ firms have to reprint their menu independently of whether or not they want to change prices so that, in order to save costs, firms will postpone price adjustments to make the price changes coincide with the changeover. Postponing price changes makes the index flat for some time before the changeover. Similarly, other firms will anticipate their price changes making the index flat for some time after $t_0$. Postponing and anticipating causes the price index to jump at the changeover.

The idea of this paper is to use the fact that the lengths of the flat periods are functions of menu costs. The higher the costs of adjusting prices, the earlier firms will start postponing. Not observing that firms postpone is a strong indicator that menu costs do not play a significant role in firm’s price setting decisions.

The notion that the cost of changing prices is an important cause of money non-neutrality has some intuitive appeal especially for restaurant prices where a price change requires the restaurant to print new menus. On average, restaurant prices are kept constant for a period between one and two years and interestingly, restaurant prices increased noticeably in some of the euro-countries when the new currency was introduced. Since menu costs can explain such a jump, there are a number of papers that conclude that this increase was caused by menu costs (Hobijn, Ravenna, and Tambalotti 2005 and Gaiotti and Lippi 2005).

Figure 2 shows the index of restaurant prices in Germany for the four-year period around the changeover. The smaller figure in the upper-left corner shows the same data for a period of 12 years. The increase of the index at the changeover is striking and note that just as we would expect, the index is constant before it jumps at the changeover. Note, however, that the index is
constant for only one month and if the stickiness of 1 to 2 years that we observe in this sector was in fact caused by menu costs we should expect the index to be flat for a significantly longer period. As there are firms that start postponing earlier than others, the model in the next section predicts a reduction in inflation before the index is constant. But inflation in the year before the changeover is significantly higher than in any of the other five years earlier - the opposite of what we should expect if menu costs constitute an important part in firms’ price setting decision.³

Until only a few years ago, our main information about pricing behaviour was based on studies of a few specific goods (Cecchetti 1986, Lach and Tsiddon 1992, 1996, Kashyap 1996). Recently, however, the statistical offices of several countries provided access to the micro-level price data that underlie the consumer price indices. In Europe, several countries participated at the Inflation Persistence Network (IPN) of the European Central Bank. Summaries of the main findings can be found in Alvarez et al. (2005) and Dhyne et al. (2006). The average duration of price spells, which captures how long prices tend to remain unchanged, is between 6 and 11 months. As mentioned above, services prices are kept unchanged for a longer period. Here, the estimates range from 14 to 24 months. For the U.S., Nakamura and Steinsson (2007) estimate a median duration of consumer prices in the U.S. of 8 to 11 months and 12 to 18 months

Fig. 2: The figure shows German restaurant prices in the four years around the changeover. The changeover is indicated by the vertical line. Upper left corner: same data for a longer horizon. Dashed line: regression line using data from January 1996 - December 2000.

¹In order to illustrate the increase in inflation in the year before the changeover I ran a regression for the years from January 1996 until December 2000. The regression line, extended for the full sample period, is shown in figure 2.
Pricing patterns as analyzed in the literature cited in the previous paragraph reveals at most indirect information about the reason for firms’ reluctance to adjust prices more frequently. In order to shed some light on the underlying reason, Levy, Bergen, Dutta and Venable (1997) estimated the magnitude of menu costs. The key insight from this study is that menu costs are large enough to be regarded a non-trivial factor in the price-setting decision of firms. The authors estimate that menu costs make up around 0.7% of revenues of U.S. supermarkets (more than $100,000 per year per store or $0.50 per price change). A drawback of the papers that estimate the magnitude of menu costs is that an estimate of the magnitude of menu costs does not reveal for how long menu costs constrain firms to hold back price adjustments. Concerning the time-span a firm keeps its price constant because of menu costs, these studies remain inconclusive.

Another important field in the literature are survey studies on how firms set their prices. See for example Blinder (1991), Hall (1999) and Apel (2002). Rather than construct new models or econometric tests, these authors survey business people about their price-setting practices and their opinions of academic theories. One of the question firms were asked was of the following type: “Are you reluctant to change your price because of X?”, where X is a theory of price stickiness economists use in their theoretical work. Menu costs receive only fairly low support in these surveys but this does not appear to have had a strong impact on the popularity of the menu cost assumption in economic modelling. For a thorough methodological discussion of the strengths and weaknesses of survey studies see Blinder (1998).

The nice feature of the approach taken in the present paper is that it reveals directly whether it is menu costs that cause the price stickiness we observe in the data. This can be done without actually estimating the magnitude of menu costs but rather by looking at firms’ pricing behaviour in the run-up to a currency changeover.

The paper is organized as follows. The next section presents the model. The model’s predictions are tested in section 3. Since I rely on aggregate data when testing, section 3 starts with a discussion of the consequences of such an approach. Section 3 also includes various robustness tests. A general discussion about the implications of the findings in section 4 concludes the paper.

### 2 Model

The purpose of the model is first to describe firms’ price setting problem in the presence of menu costs and second to study how the optimization problem is

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2Nakamura and Steinsson (2007), for example, interpret their findings in the context of a simple menu costs model and conclude that some of their stylized facts are consistent with menu costs while others are not.
altered when there is a currency changeover. The last subsection analyzes the stability of the model’s predictions.

2.1 The Basic Framework

As in any model with menu costs, firms are assumed to be price setters. The number of firms is assumed to be large enough to abstract from strategic considerations. Let \( p^* \) be the firm’s optimal price and assume for simplicity that \( p^* \) is rising over time at a rate \( \pi^* = \frac{dp^*}{dt} \). In order to keep the model simple, \( p^* \) and \( \pi^* \) are exogenous. Let \( k \) be the costs of changing prices (the "menu costs"). As long as \( k > 0 \) firms will not adjust prices every period but keep their prices constant for some time before changing prices again.

Positive and negative deviations from the optimal price are treated symmetrically (are equally costly) so that the optimal path will be to fluctuate around \( p^* \) as shown in the figure above. The figure also defines a new variable, \( s \), which is the length of a cycle, that is, the time span between two consecutive price changes. The length of a cycle will depend on the costs of adjusting \( (k) \) and the costs of deviating from the optimal prices (denoted by \( r \)).

With these definitions, we can now set up the firm’s problem. Firms minimize costs. The firm’s cost function has two parts. First, the menu costs, which is \( k \) times the number of price changes, \( \frac{\pi^*}{\Delta P} \), and second, the costs of deviating from the optimal prices. From the figure above it is clear that the average deviation equals \( \frac{A\Delta P}{A} \). The firm’s problem is thus given by the following problem.

\[
\min_{\Delta P} TC = k \frac{\pi^*}{\Delta P} + r \frac{\Delta P}{4}
\]

From the first order conditions, we can derive the optimal length of a cycle.

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s = \frac{\Delta P}{\pi^*} = 2 \sqrt{\frac{k}{r \pi^*}}
\]

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\(^3\)The model has some formal similarities with models of inventory management. These types of model been used in monetary economics before, see for example Baumol (1952) and Tobin (1954).
Here I used the fact that \( s = \frac{1}{n} \), where \( n \) is the number of price changes during a given period (to be exact, it is the number of price changes over the period in which \( p^* \) increases by \( \pi^* \)). The length of a cycle increases

- as the menu cost increase (\( k \uparrow \)),
- as the cost of deviating decrease (\( r \downarrow \)), and
- as inflation decreases (\( \Delta p^* \downarrow \)).

### 2.2 The Optimization Problem During a Currency Changeover

During a currency changeover, the firm has to change its price and in order to save costs, the firm will try to make the changeover coincide with a price change. This behaviour makes the problem that of a finite horizon. The following proposition states the problem.

**Proposition 1** As long \( k > 0 \), the firm will try to make the currency changeover coincide with a price change and will re-optimize its price-setting path immediately after the announcement.

The proof of the proposition is delegated to the appendix. The driving force behind the proposition is the convexity of the firm’s cost function. The convexity also implies that all cycles are of equal length.

The figure above illustrates the firm’s problem and defines the initial and the final cycle. Note that in contrast to the previous figure, only deviations from the optimal price are shown. Let the initial cycle be the cycle in which the changeover was announced and let the final cycle be the cycle in which it takes place. With these two definitions we can now analyse the firm’s problem.

The firm has two possibilities to make the changeover coincide with a price change: postponing and anticipating. Which possibility the firm chooses is

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Footnote: Given the convexity of the firm’s costs, the second order conditions are satisfied.
decided by the final cycle. It will be useful to state the firm’s problem in terms
of triangles. Each cycle consists of two triangles (one above and one below the
horizontal line). Let $m$ be the number of triangles between the announcement
and the changeover when the firm postpones. In the case of anticipating, the
number of triangles increases to $m + 2$.

First consider the final cycle (see figure above). In order to describe the firm’s
optimal choice, we need to introduce a new variable. Let $\sigma \in [0, 2]$ indicate the
exact moment of the changeover. When $\sigma = 0$, the changeover coincides with
the price change at the beginning of the cycle and the firm does not need to
re-optimize. The same holds when $\sigma = 2$, that is, when the changeover coincides
with the price change at the end of the final cycle. The following proposition
states when it is optimal to postpone and when it is optimal to anticipate.

**Proposition 2** For $\sigma$ close to 0 it will be optimal for firms to postpone and for $\sigma$ close to 2 it will be optimal to anticipate. The firm will be indifferent between postponing and anticipating when

$$\sigma_{\text{indiff}} = m \left( \sqrt{\frac{m + 2}{m}} - 1 \right) < 1.$$ 

The proof is delegated to the appendix. Note that $\lim_{m \to \infty} \sigma_{\text{indiff}} = 1$. The
fact that $\sigma_{\text{indiff}} < 1$ means that it is more likely for a firm to anticipate than to
postpone. An intuition for this result is again the convexity of the firm’s cost
function. Postponing means that the firm increases its cycle which implies that
the length of the triangles increases. The firm’s costs, however, increase in the
square of the cycle length. This means that increasing the cycle by one unit
is more expensive than what is saved when the cycle is shortened by one unit.
This, in turn, causes more firms to shorten the cycle, that is, to anticipate.

What remains to be calculated is the length of the new cycles. The technical
details are delegated to the appendix. First consider the case where a firm
postpones. Postponing means that the new cycles are larger than the original
cycles. This implies that the firm’s reaction to the announcement is independent
of the exact moment of the announcement; there is only one result. The new
cycle when postponing, $s_P$, equals
\[ s_P = s\left(1 + \frac{\sigma}{m}\right). \]

Intuitively, what the firm does is to take whatever is left over in the final cycle \((\sigma)\) and distribute it equally among all the \(m\) triangles between the announcement and the changeover.

The case of anticipating is more difficult to analyze. Here we will have more than one result. Anticipating means that the new cycle is shorter than the old one. When the announcement falls into the first part of the initial cycle, the firm will simply set the new cycle length, \(s_A\) equal to

\[ s_A = s\left(1 - \frac{2 - \sigma}{m + 2}\right). \]

Again, the result is quite intuitive. In the case of anticipating, what is left-over in the final cycle is \(2 - \sigma\). And recall that in the case of anticipating, there are \(m + 2\) triangles between the announcement and the changeover. The firm distributes whatever is left-over in the final cycle among the \(m + 2\) triangles between the announcement and the changeover.

Towards the end of the initial cycle, the firm’s reaction will be to change prices immediately after the announcement. This means that there are infinitely many different cycle lengths. For our analysis, however, we only need to calculate the shortest cycle. This is given by

\[ s_{AC} = s\left(1 - \frac{2 - \sigma}{m + 1}\right) < s_A. \]

The figure above summarized the model’s predictions. The model predicts that when menu costs are sufficiently large, there will be a period before the changeover \((t_0)\) in which firms keep their prices constant (period \(2b\) in the figure). Given that not all firms stop changing prices at the same time, there will be a transition period, denoted by period \(2a\) in the figure. The variable \(s_P\) tells us when the first firms stop adjusting and the variable \(s_{AC}\) tells us when the last firm will stop changing prices.
Table 1 provides some numerical examples. A firm that keeps its price constant for 18 months (a restaurant for example), would stop changing prices between 14.99 and 21.05 months before the changeover. All this if, and this is an important if, the 18 month stickiness is caused by menu costs. The table shows more examples. It is interesting that as $s$ gets smaller, the length of the transition period decreases even in relative terms. In the case of firms that keep prices constant for one month because of menu costs, the first stop changing 1.01 months before the changeover and the last 0.99 months before.

We can also turn the argument around: observing that firms do not keep prices constant for several months before the changeover implies that menu costs are not very large. Large here is measured in relative terms, relative to the benefit of changing prices. In terms of the model, the data show that the ratio of the costs of changing prices over the cost of not changing price ($\frac{k}{r}$) is not very large. Returning to the case of restaurants, if we do not observe that firms stop changing prices nearly one year before the changeover (the model predicts more than 14 months), then the stickiness of 18 months that we observe in this sector cannot be caused by menu costs. Restaurants stopped changing prices one months before so that menu costs appear to play some role in firms’ consideration to adjust prices, but it also means that menu costs in this sector can only explain a stickiness of somewhat between 1 and 2 months. The stickiness of 18 months we observe in the sector appears to be caused by other factors.

### 2.3 Stability of the Prediction

The model’s prediction are quite strong and we will see in the next section that there is barely an industry in which firms keep prices constant for more than one month before the changeover. A possible explanation might be that production costs increased unexpectedly a few weeks before the changeover and firms had to react to these increases and adjust prices. For small increases in production costs, it seems reasonable that the firm would still keep prices constant but for increases sufficiently large firms will adjust. The goal of this subsection is to calculate what "sufficiently" means, that is, to calculate the stability of the predictions of the previous subsection. Production costs do not enter the model but can be incorporated by increases in the optimal price $P^*$. 
The figure above illustrates the argument. Shown is the final cycle with length $s$. The optimal price increases unexpectedly a fraction $\delta$ of $s/2 = b$ before the changeover. For simplicity, I assume that inflation $\pi^*$ stays constant so that we can model the increase in $P^*$ by a parallel upward shift. The size of the increase is indicated by $\eta$ and the additional costs of this increase are shown by the area $B$.

**Proposition 3** After an unexpected increase in the optimal price $P^*$, the firm will keep its price constant as long $\eta < \frac{1}{s^2}$.

The proof is straightforward and delegated to the appendix. Graphically, the firm compares the additional costs (area $B$) with the area $A = A_1 + A_2$. As long $B < A$, it is optimal to keep the price constant despite the increase in costs. An example helps to illustrate this result. Consider again a restaurant that keeps its price constant for one and a half years because of menu costs and suppose that two months before the changeover, the optimal price of a cup of coffee increases unexpectedly. In this case we find that $\eta = \frac{1}{\frac{1}{3} \times \frac{1}{2}} = 6$. The difference between the optimal price $P^*$ and the originally planned price just before the changeover $P$ needs to increase six-fold for the firm to change the price. Let the optimal price of a cup of coffee at the changeover be 5.€ and the originally planned price 4.50 euros so that the planned difference is 50 cents. The result shows that as long this difference does increase less than six-fold, the firm will keep its price constant. Stated differently, in order for the firm to change prices two months before the changeover, the optimal price of a cup of coffee needs to increase from 5.€ to 8.€. This example illustrates how large menu costs need to be if they were the true reason behind the 18-month stickiness in the restaurant sector.

### 3 Estimation Results and Discussion

The model predicts that if menu costs are large, firms would not change prices in the run-up to the changeover. This, then, causes the index to jump when the
new currency is introduced. Depending on the overall trend of the index, the jump might be upward or downward. This section will have a look at the data. In section 3.2 I will discuss how I analyze the data and discuss the difficulties but before that I will provide some comments about the problems using aggregate data in section 3.1.

At this point, another comment is necessary about the data. In the model, we have assumed that firms needed to reprint their menus at the moment of the changeover. This was, however, not necessarily the case in practice. The regulation in all Euro-countries was such that up to the changeover all prices had to be denoted in the old, national currency, while starting with January 1st 2002 all prices had to be denoted in euros. By using dual price tags (price tags on which the price is denoted in both the old and the new currency) firms were able to postpone or anticipate the printing for some time and the assumption we imposed is violated. Using German data allows us to bypass this problem. Price setting in Germany was regulated in the following way. Until the introduction of Euro coins and banknotes, prices had to be denoted in Deutsch-Marks. To make people acquainted with the new currency, double price tags were encouraged by the authorities but not compulsory. With the changeover, prices had to be denoted in Euros. There was a two months transition period in which payments could be made both in Euros and Marks. In this transition period double price tags were still allowed but only until February 28th 2002. This means that all menus (price tags) had to be reprinted within the eight-week transition period.\(^5\) Below I will argue that in practice most firms re-printed prices already in the first days of the year but even if we control for this complication, the menu cost theory is still strongly rejected by the data.

3.1 Using Aggregated Data

In the paper I rely on publicly available series of eurostat’s HICP data. The HICP basket contains 94 individual series ranging from basic food items to services. An example of such a series is the index of "restaurants, cafés and the like" shown in figure 2 above. Two issues arise here, the first might be called "causality" and the second concerns the heterogeneity of firms.

\[ P_f \rightarrow P_{ag} \]

Studying aggregate data and deducing characteristics of the underlying individual series might appear faulty and in fact, causality clearly goes from the

\(^5\)For more about the legal aspects of price setting around the Euro changeover see the article of the German Chamber of Commerce (2001).
individual firms to the aggregate (see figure above). If the individual firms keep their prices constant, the aggregate will be constant as well but the converse does not hold as there might be some firms that increased and others decreased leaving the average unchanged. What we need in this exercise is, however, something like the "contrapositive". Not observing that the aggregate is constant implies that there are firms that adjusted prices and this observation is all that is required in this exercise.

Heterogeneity on the other hand is a more subtle issue and I need to make an assumption on the data, though I believe that the assumption is not too strong. The assumption is that firms that are aggregated within one of the 94 indices have comparable pricing costs. The restaurants, for example, that are aggregated in the index shown in figure 2 need to have comparable menu costs and comparable costs of deviating from the optimal price. It would skew the results if, for example, half the restaurant have menu costs so high, that it forces them to keep prices constant for 24 months and the other half menu costs so low that they can adjust every week. Nonetheless, even with significant heterogeneity, the model predicts a reduction in inflation which is as well a testable result and which restaurant, for example, do not show.

3.2 Do Menu Costs Make Prices Sticky?

My goal in this paper is to show that menu costs are not large enough to explain the stickiness we observe in the data. In order to do this I have to take any pattern in the data that could be caused by menu costs as evidence in favour of the theory I want to reject. Take for example the restaurant series we have seen in figure 2. Here we observe that prices are constant for one month. This might have been just by coincidence but since I cannot reject that this shape was caused by menu costs I will assume that it was in fact caused by menu costs.

Searching for a constant price index before the changeover, I will ignore the jump and only look at the period before the changeover. The reason for this is that it is difficult to define what a "jump" is. Requiring a series to jump requires defining the size of a jump and the correct direction. In order to avoid any arbitrary definitions I have decided to take any flat period before the changeover as evidence for menu costs. This comes at the expense of interpreting many more patterns as caused by menu costs while in fact the pattern was caused by other factors. But since I want to reject the menu cost theory, this expense seems worthwhile.

As already mentioned above, the data I am using are the individual series of eurostat’s HICP basket. The basket contains 94 series of which 9 are considered as administered. Since I am interested in firms’ pricing behaviour I need to exclude these. I will also exclude tobacco so that I am left with 84 series.
Figure 3: The figure shows the percentage of HICP items whose index stays constant in a given month. The changeover is indicated by the dashed line.

Table 2 shows the number of indices (out of 84) that are constant before the changeover for at least the number of months in the left column. Out of 84 series, 35 are constant for at least one month. 19 out of these are constant for at least 2 months and so on. Only five out of 84 are constant for four or more months and recall that if menu costs were the reason behind the stickiness in the data, we should observe flat indices before the changeover for a significantly longer period.

The evidence in favour of menu costs becomes even weaker if we compare the numbers in table 2 with other months. Figure 3 shows the percentage of series with a zero inflation rate in a given month. The 35 series we found before is above average, though still within the range one would expect from such a distribution. Figure 3 nicely shows the high number of price changes (a low column) in January 2002, when the new currency was introduced.

This impression that the month before the changeover does not display an unusual number of series with no inflation is confirmed by the histogram in
Figure 4: The histogram shows the distribution of observations with zero-inflation. The mode is 29 and the maximum is 41. Ten out of 84 series are above the 35 observed at the changeover.

...figure 4. At the changeover we observed that 35 out of 84 series have a zero inflation rate. Even if 35 is above the average of 28, there are still 10 out of 84 that are above.

Some of the series in the HICP basket are constant for one or more months before the changeover, though no clear pattern appears, only that in the case of services, menu costs might be somewhat higher. An interesting statistic is the average stickiness that can be explained by menu costs. This number can be calculated as follows. The data are collected in mid-month so that any stickiness of less than 15 days will not show up in the data. For all indices that are not constant for one or more months before the changeover I assume a stickiness of 15. Similarly, if an index is constant for 1 month, I add 15 days so that I assume that in this sector, menu costs can explain a stickiness of 45 days. Doing this for all sectors and weighting the numbers by their weights in the HICP basket, gives an average of 35 days. That is, menu costs can explain a stickiness of 35 days on average. Again, this is an average, so that there are some sectors where menu costs seem to be higher (such as in the case of restaurants). But in general, the data strongly reject the notion that prices are sticky because of menu costs.

So far I assumed that all price tags were replaced on the weekend of the changeover, but remember that there was a transition period of 2 months. There is some evidence that most were replaced within the days of the changeover.
But suppose they were not, suppose that all firm waited until the end of the transition period. In this case, a stickiness of less than 3 months would not be observable so that rather than 35 days, we would have somewhat more than 4 months that can be explained by menu costs. A stickiness of 8 or even 18 months as observed in the restaurant sector can still not be explained by menu costs. But again, there is strong evidence that the majority of prices have been replaced within the days after the changeover so that my initial assumption does not seem to be very strong.

An interesting feature of the HICP basket is that most prices are sold at "pricing points", or threshold prices such as 1.99 or 24.90. Depending on how one defines pricing points, the estimates range from 72 to 95 percent of the data (see Holdershaw et al. 1997, Fengler and Winter 1980, Bergen et al. 2003, Alvarez and Jareno 2002, Aucremanne and Cornille 2001). This and the fact that the exchange rate from Deutschmarks to Euros was 1.95583 \( \frac{DM}{Euro} \) means that firms not only needed to reprint new price tags but also needed to decide whether to round up or down to the new pricing point or whether to keep an "odd" price that is a threshold price in Marks but not in Euros. The Bundesbank (2003) reports that a few weeks after the changeover, nearly 60 percent of the prices were already quoted at pricing points. What makes this observation interesting for the exercise in this paper is that the menu costs we estimate do not only include the cost of printing new price tags but also the managerial costs. This is an important point because the managerial costs are likely to make up a large part of menu costs in general.

4 Concluding Remarks

The goal of this paper is to study whether menu costs are large enough to explain why firms are so reluctant to change their prices. Depending on the sector, prices are kept constant for between 7 and 12 months. This stickiness is significantly higher in the case of services prices that are kept unchanged for between 12 and 18 months on average. An important question for monetary policy is whether this stickiness is caused by menu costs or by other factors such as sticky information as emphasized by Mankiw and Reis (2002).

Rather than estimating the size of menu costs, this paper infers their importance in firms’ price setting from observed pricing behaviour in the run-up to a currency changeover. At a currency changeover, firms have to reprint their price tags (menus) independently of whether or not they want to change prices and if this is costly firms will try to make the changeover coincide with a change in prices. This behavior will be reflected in the data.

A nice feature of the approach taken in this paper is that it tells us directly whether firms care much about the costs of changing prices. In this sense, the results here are somewhat more informative than estimates of the size of menu costs. On average, menu costs can explain a stickiness of around 35 days. This number should be considered an upper bound because I imposed relatively conservative assumptions on its estimation.
Given the prevalence of "psychological" or threshold prices in retailing, the measure of menu costs includes both the costs of printing and the managerial costs. This is an important point because the managerial costs are likely to make up a large part of menu costs in general.

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A Appendix

This appendix shows the proofs of all three propositions in section 2. For convenience, the variables of the model are repeated here.

- $p$: actual price, set by the firm
- $p^*$: optimal price
  - the optimal price is assumed to increase over time at a constant rate
  - $p^* = p^* (t)$ with $\frac{dp^*(t)}{dt} = \pi^* > 0$
- $k$: menu costs
- $r$: cost of deviating from optimal price
- $s$: length of cycle and $b$: length of a triangle ($2b = s$)
- $m$: number of triangles
- $n$: number of cycles in $T$, where (do I need this variable?)
- $\sigma \in [0, 2]$ indicates exact position of the changeover in the last cycle
- $T$: time span from announcement to actual changeover. In the figures, $T$ also indicates the exact moment of the changeover.
- $\bar{T}$: defined below

Without loss of generality, assume that $m$ is even. In the optimum, the menu costs $(k)$ will be a function of the cost of deviating $(r)$ the length of a cycle $(b)$ and $\alpha$ which is a function of the inflation rate $\pi^*$:

$$k = rb^2 \tan \alpha.$$  

Let $C_A$ ($C_P$) be the cost when a firm anticipates (postpones). It is straightforward to show that

$$C_A = r \frac{\tan \alpha}{2} b^2 \left( \frac{m^2 + 2 \sigma m + \sigma^2}{m + 2} + m + 2 \right)$$  \hspace{1cm} (1)

$$C_P = r \frac{\tan \alpha}{2} b^2 \left( 2m + 2\sigma + \frac{\sigma^2}{m} \right).$$  \hspace{1cm} (2)
A.0.1 Proof of Proposition 1

As long \( k > 0 \), the firm will try to make the currency changeover coincide with a price change and will re-optimize its price-setting path immediately after the announcement.

**Proof:**

Let \( C_N \) be the cost of not aligning.

\[
C_N = r \frac{\tan \alpha}{2} b^2 \left[ 2m + 3 - (1 - \sigma)^2 \right]
\]

Comparing these costs with \( C_A \) and \( C_P \) given in (1) and (2), it can be shown that

\[
C_N > C_P \text{ and } C_N > C_P.
\]

The fact that the firm will re-optimize immediately after the announcement is a result of the convexity of the firm’s problem. Technically, the earlier the firm reacts, the lower \( C_A \) and \( C_P \). This implies that the earlier the announcement, the lower are the firm’s additional costs from the changeover.

\[\blacksquare\]

A.0.2 Proof of Proposition 2

For \( \sigma \) close to \( 0 \) it will be optimal for firms to postpone and for \( \sigma \) close to \( 2 \) it will be optimal to anticipate. The firm will be indifferent between postponing and anticipating when

\[
\sigma_{\text{indiff}} = m \left( \sqrt{\frac{m+2}{m}} - 1 \right) < 1.
\]

**Proof:** Calculating \( C_P - C_A = 0 \)

\[
(m + 2) \left( \left( 1 - \frac{\eta}{m + 2} \right)^2 + 1 \right) = m \left( \left( 1 + \frac{\sigma}{m} \right)^2 + 1 \right)
\]

\[
(m + 2) \left( 1 - \frac{\eta}{m + 2} \right)^2 + m + 2 = m \left( 1 + \frac{\sigma}{m} \right)^2 + m
\]

\[
\frac{(m + 2 - \eta)^2}{m + 2} + 2 = \frac{(m + \sigma)^2}{m}
\]

\[
\frac{(m + 2 - \eta)^2}{m + 2} + 2 = \frac{(m + \sigma)^2}{m}
\]

This is the first relationship between \( \sigma \) and \( \eta \). The second one is \( 2 = \sigma + \eta \).
Using this, we get
\[
\frac{(m + 2 - \eta)^2}{m + 2} + 2 = \frac{(m + \sigma)^2}{m}
\]
\[
\frac{(m + \sigma)^2}{m + 2} + 2 = \frac{(m + \sigma)^2}{m}
\]
\[
m(m + \sigma)^2 + (m + 2)m^2 = (m + 2)(m + \sigma)^2
\]
\[
(m + 2)m^2 = 2(m + \sigma)^2
\]
\[
\sqrt{m(m + 2)} - m = \sigma
\]
or
\[
\sigma_{\text{indiff}} = m \left( \sqrt{\frac{m + 2}{m}} - 1 \right)
\]

Note that \(\lim_{m \to \infty} \sigma_{\text{indiff}} = 1\). Applying l’Hopital’s rule:
\[
\lim_{m \to \infty} m \left( \sqrt{\frac{m + 2}{m}} - 1 \right) = \lim_{m \to \infty} \frac{\left( \sqrt{\frac{m + 2}{m}} - 1 \right)}{\frac{1}{m}}
\]
\[
= \lim_{m \to \infty} \frac{1}{\sqrt{1 + \frac{2}{m}}} = 1
\]

\section{A.0.3 Proof of Proposition 3}
After an unexpected increase in the optimal price \(P^*\), the firm will keep its price constant as long \(\eta < \frac{1}{\pi}\).

\textbf{Proof:} Remember that at the changeover \(k = 0\) which makes it convenient to change prices at that time. Above we calculated that \(k = r(A_1 + A_2) = rA = r \frac{a}{2} = r \frac{\Delta p}{b}\). The area \(B = \eta a \times \delta b\) in the figure above is proportional to the additional costs triggered by the price increase. By not adjusting, the firm saves \(k\). The firm is, therefore indifferent between adjusting or not when
\[
\frac{A}{a} = B
\]
\[
\frac{\Delta p}{2} = \eta a \times \delta b.
\]
Solving for \(\eta\) yields
\[
\eta = \frac{1}{2 \delta b}.
\]
A.1 Deriving $s_A$, $s_{AC}$ and $s_P$.

- First note that with the exception of the complication in the case of anticipating described above, we might simply assume that the announcement takes place in the center of the initial cycle.
- $T$: time span from announcement to changeover
- $\bar{T}$: time span from center of initial cycle to changeover
- Then we have that
  \[ b_P = \frac{b}{1 + \frac{\sigma}{m}} \]
  \[ b_A = \frac{b}{1 - \frac{\eta}{m+2}} = \frac{b}{1 - \frac{2 - \sigma}{m+2}} \]

- This comes from
  \[ \bar{T} = mb_P \]
  \[ \bar{T} = mb + h = b(m + \sigma) \]

and

  \[ \bar{T} = (m + 2) b_A \]
  \[ T = (m + 2) b - \eta b = b(m + 2 - \eta) \]

A.1.1 The Complication when Anticipating ($b_{AC}$)

- Shortest cycle will be at the right point of the anomaly (point D in the figure).
The time span from there to the changeover is $\bar{T} - b$

\[
\bar{T} - b = (m + 2) b_A - b \\
= \left( (m + 2) \left( 1 - \frac{\eta}{m + 2} \right) - 1 \right) b \\
= (m + 2 - \eta - 1) b \\
= (m + 1 - \eta) b
\]

- Number of cycles is $(m + 2)$
- $\rightarrow$ the shortest cycle length is then

\[
b_{AA} = b \left( \frac{m + 1 - \eta}{m + 1} \right) = b \left( 1 - \frac{\eta}{m + 1} \right)
\]

- note that $b_{AA} = b \left( 1 - \frac{\eta}{m + 1} \right) < b_A = b \left( 1 - \frac{\eta}{m + 2} \right)$

\[
b - b_{AA} = b \frac{\eta}{m + 2} \\
= 2 - m \left( \sqrt{\frac{m + 2}{m}} - 1 \right) \\
= b \frac{2}{m + 2} - b \sqrt{m + 2} - m \\
= b \left( 1 - \frac{\sqrt{m}}{\sqrt{m + 2}} \right) < b
\]