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The analyses, opinions and findings of these papers represent the views of the authors, they are not necessarily those of the Banco de Portugal or the Eurosystem

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Why are some prices stickier than others? Firm-data evidence on price adjustment lags*

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Abstract

Infrequent price changes at the firm level are now well documented in the literature. However, a number of issues remain partly unaddressed. This paper contributes to the literature on price stickiness by investigating the lags of price adjustments to different types of shocks. We find that adjustment lags to cost and demand shocks vary with firm characteristics, namely the firm's cost structure, the type of pricing policy, and the type of good. We also document that firms react asymmetrically to demand and cost shocks, as well as to positive and negative shocks, and that the degree and direction of the asymmetry varies across firms.

JEL classification codes: C41, D40, E31.

Key Words: Firm heterogeneity, Panel-ordered probit, Real rigidities, Survey data.

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1. INTRODUCTION

Price stickiness has a central role in macroeconomics and, besides a vast theoretical literature, it has generated numerous empirical studies trying to explain its origins and gauge its importance.¹ A consensual finding of this work is that prices at the micro level may remain unchanged for periods that can last up to several months. Studies documenting this stylised fact include, among many others, Bils and Klenow (2004), Klenow and Kryvtsov (2008), and Nakamura and Steinson (2008), who study consumer prices in the United States (US), and Dhyne *et al.* (2006) and Vermeulen *et al.* (2007), who give a synthesis of studies carried out for the Euro Area (EA). For example, using comparable micro data on consumer prices, Dhyne *et al.* (2006) find that the estimated monthly frequency of price changes is around 15 percent in the EA and 25 percent in the US, and that the implied average duration of a price spell is 13 months in the EA and 6.7 months in the US. These results are consistent with evidence from survey data: according to Fabiani *et al.* (2006), the median frequency of price changes is one per year in the EA, lower than the estimated 1.4 price changes per year in the US reported in Blinder *et al.* (1998).

The empirical literature investigating the reasons for such infrequent price changes at the firm-level is, however, scantier. Dhyne *et al.* (2008) have recently made an important contribution to the understanding of this phenomenon by distinguishing between “intrinsic price rigidity” (price rigidity that is inherent to the price-setting mechanism), and “extrinsic rigidity” (price rigidity that is induced by a low degree of volatility of shocks to the marginal cost and/or the desired mark-up). They find that the differences across products in the frequency of price changes do not strictly correspond to differences in intrinsic price rigidity, i.e., the frequency of price changes also depends, in a significant way, on the frequency and magnitude of the shocks to the unobserved optimal price. Thus, as Blinder (1991, p. 94) puts it: “From the point of view of macroeconomic theory, frequency of price change may not be the right question to ask, for it depends as much

¹See, among many others, Taylor (1980), Calvo (1983), Sheshinski and Weiss (1977, 1983), Caplin and Spulber (1987), Caballero and Engel (1993, 2007), Caplin and Leahy (1991, 1997), Danziger (1999), Dotsey *et al.* (1999), Golosov and Lucas (2007), Klenow and Kryvtsov (2008), and Woodford (2009).

on the frequency of shocks as on the firms' pricing strategies. We are more interested to know how long price adjustments lag behind shocks to demand and cost."

Therefore, rather than looking into the reasons for infrequent price changes, as done in most of the previous literature on price stickiness (see, e.g., Munnick and Xu, 2007, Vermeulen *et al.*, 2007, Dhyne *et al.*, 2006, and the references therein), in this paper we directly investigate the deeper and more meaningful question of the determinants of the speed of price adjustments to demand and cost shocks. In particular, we use survey data on price adjustment lags reported by Portuguese firms to investigate how they adjust their prices in response to changes in market conditions. The advantage of using such data is that, in order to study the intrinsic price rigidity, we do not need to match price changes decisions with market conditions, which is usually a difficult task.

Other papers have studied the speed of price reactions to demand and costs shocks; see, e.g., Kwapil *et al.* (2004) for Austria, Loupias and Ricart (2004) for France, Alvarez and Hernando (2005) for Spain, Fabiani *et al.* (2004) for Italy, and Small and Yates (1999) for the United Kingdom. However, a major distinguishing feature of our approach is that we use much more detailed information on the speed of price adjustments, and consequently we are able to identify more precisely the effect of the covariates in our model. Specifically, we explore the available information on price adjustment lags using a six-categories panel-ordered probit model to study the link between price adjustment lags and various firm characteristics. This type of model provides great efficiency gains relatively to the binary models commonly used in the literature.

There are also other dimensions in which our dataset set is richer than those previously used to investigate price-stickiness. In particular, we have detailed data on an extensive list of characteristics of more than 900 firms and on the reaction time of each firm to four types of shock. In total, therefore, we can use more than 3600 observations on a varied set of firms. Naturally, this also increases the precision of our estimates, allowing us to identify significant effects of regressors that often appear as not statistically significant in previous studies. It is also worth pointing out that, unlike previous studies in the area, we investigate not only the statistical significance of the regressors, but we also compute marginal effects on probabilities to gauge the economic relevance of each covariate.

A potential disadvantage of the type of data we use is that it does not distinguish between aggregate and idiosyncratic shocks. Indeed, the economic literature has stressed that the reaction of firms to shocks may depend on whether these are aggregate or idiosyncratic (Lucas, 1973), and recently Mackowiak and Wiederholt (2009) developed a model in which firms' prices react quickly to idiosyncratic shocks, but only slowly to aggregate shocks. The fact that our data has no information on whether the firm sees the shock as aggregate or idiosyncratic is an important limitation of our data.² In any case, we do not expect this fact to seriously limit the interpretation of our results because, since we have four observations of each firm, our panel data model will to some extent account for the heterogeneity resulting from firms interpreting the nature of the shock in different ways.

In this paper we tackle several interesting questions. Do prices respond with different lags to demand and cost shocks? Do prices respond differently to shocks implying a price increase than to shocks implying a price decrease? Does the cost structure matter for price stickiness? Are prices stickier when a firm operates in a less competitive industry? Does price stickiness depend on how long firms have been dealing with their customers? Is the services sector structurally different from the manufacturing sector?

We find that adjustment lags to cost and demand shocks (either positive or negative), vary significantly with firm characteristics such as the cost structure, type of pricing policy, and the type of good, among others. Interestingly, and in contrast to what one could expect, measures of the importance of explicit and implicit contracts – two of the most cited sticky-price theories in firms' surveys – do not emerge as having significant implications for the speed of price reaction to demand or cost shocks. Overall, these results are consistent with the idea that differences in price stickiness across firms depend on the sensitivity of their profits to deviations from the optimal price and on the costs of changing nominal prices. The evidence also suggests that firms react differently to

²Another potential disadvantage of this type of data is that these are reported, not actual, lags and it is impossible to know whether the answers provided are close to reality. However, the fact that in our model we only use the ordinal information in the answers given by the firms will significantly mitigate potential measurement errors.

demand and cost shocks, as well as to positive and negative shocks, and that the degree and direction of these asymmetries vary with the characteristics of the firms.

The rest of the paper is organised as follows. Section 2 presents the theoretical background which underlies the estimated model. Section 3 describes the novel dataset used in the paper and presents the results of a preliminary data analysis. Section 4 presents the estimated model and discusses the main results. Section 5 contains some concluding remarks and, finally, two appendices provide technical details on the specification and estimation of the econometric model used in the empirical part of this paper, as well as an explanation of how the different variables were constructed.

2. THEORETICAL BACKGROUND

Individual firms do not continuously adjust their prices in response to shocks that hit the economy. To model this fact, the economic literature considers mainly two types of pricing behaviour: time dependent and state dependent pricing rules. According to the former, firms are assumed to change their prices periodically using either a deterministic (Taylor, 1980) or a stochastic (Calvo, 1983) process of price adjustment, i.e., the timing of the price changes is exogenous and does not depend either on the state of the economy or on the timing of the shocks.

Firms following state-dependent pricing rules are usually assumed to review their prices whenever relevant shocks hit the economy but, due to the existence of fixed costs of changing prices (e.g., the cost of printing and distributing new price lists), they change their prices only when the difference between the actual and target prices is large enough (see, for example, Sheshinski and Weiss, 1977, Caplin and Spulber, 1987, Caballero and Engel, 1993, Dotsey *et al.*, 1999). Thus, a company facing these menu costs will change its price less frequently than an otherwise identical firm without such costs.

Some authors have, however, argued that the main benefit of infrequent price changes is not lower menu costs, but reduction of the costs associated with information collection and decision-making. Obtaining this benefit necessarily means that the timing of the occasions upon which prices are reconsidered may be largely independent of current market conditions (see Woodford, 2003, Zbaracki *et al.*, 2004). In the same vein, Ball

and Mankiw (1994a) argue that “the most important costs of price adjustment are the time and attention required of managers to gather the relevant information and to make and implement decisions.”

In addition to menu costs and/or information costs, economic theory has suggested a large number of other potential explanations for the existence of price rigidities, of which the theories of explicit and/or implicit contracts, cost-based pricing, coordination failure, and pricing thresholds, are notable examples.

With explicit contracts, firms aim at building long-term relationships with their customer in order to stabilise their future sales. Customers, on the other hand, are attracted by a constant price because it makes their future costs more predictable and helps to minimize transaction costs (e.g., shopping time). In turn, the theory of implicit contracts is based on the idea that firms try to win customer loyalty by changing prices as little as possible. The idea that explicit contracts may be central for price stickiness was first introduced in the economic literature through wage contracts (see, for instance, Fisher, 1977), while the idea of implicit contracts goes back to Okun (1981), who distinguishes between price increases due to cost shocks and those that are due to demand shocks. He argues that higher costs are an accepted rationale for rising prices, while increases in demand are viewed as unfair. Consequently, firms hold prices constant in the face of demand shocks, as they do not want to jeopardise customer relations. The idea that consumers wish to buy from firms whose prices are “fair” is also stressed, for example, by Rotemberg (2005) and Anderson and Simester (2010).

Rather than emphasizing the firm-customer relation, the theory of coordination failure focuses on the interaction between firms as the explanation for sticky prices. Like in the case of explicit contracts, the idea was first introduced for the analysis of the labour market (see, for instance, Clower, 1965). After a shock, a firm might want to change its price, but only if the other firms change their prices too. Without a coordinating mechanism which allows the firms to move together, the prices might remain unchanged.

As regards the cost-based pricing theory, the idea is that input costs are an important determinant in firms’ pricing decision, and that if costs do not change, prices will not change either. Basically, this means that prices do not change because other prices

(input costs) do not change (see Hall, 1986).³ Finally, some firms set their prices at psychologically attractive thresholds. This pricing strategy can cause price stickiness because, in face of small shocks calling for small price changes, firms might not react and postpone price adjustments until new events justify a price change to the next pricing threshold.

The different sticky-price theories discussed above have informed most of the empirical research on the existence and significance of infrequent price changes, and the present work is no exception to this trend. A useful way of looking at these sticky-price theories is to think of them as reflecting the existence of both real and nominal rigidities. As Ball and Romer (1990) noticed, nominal price stickiness depends not only on the costs of changing nominal prices (nominal frictions) but also on the benefits of changing prices (real rigidities). Thus, as a general principle, we may expect that the less profits change when firms set their prices away from the optimum, the smaller will be the benefits from quickly adjusting towards the optimum, and vice-versa. In this paper we look into the factors that may explain why some firms adjust their prices more rapidly than others. For that purpose, we will look into the factors that might reflect differences in the relative importance of the alternative sticky-price theories at the firm-level, i.e., factors that might reflect differences in the firms' adjustment costs, or that might be expected to make profits more or less sensitive to sub-optimal prices.

3. THE DATA

3.1. Data sources

Most of the data used in this study come from a survey about price setting practices carried out by the Banco de Portugal.⁴ In this survey, firms were asked how long they would take to react to significant cost and demand shocks. More specifically, they were asked the following four questions: 1) "After a significant increase in demand how much time on average elapses before you raise your prices?"; 2) "After a significant increase

³This reason for not changing prices relates directly to the concept of "extrinsic price rigidity" introduced in Dhyne *at al.* (2008), and discussed above.

⁴For further details on this survey, see Martins (2010).

in production costs how much time on average elapses before you raise your prices?"; 3) "After a significant fall in demand, how much time on average elapses before you reduce your prices?"; and 4) "After a significant decline in production costs how much time on average elapses before you reduce your prices?". The responses to these questions, which will be the dependent variable in our model, are recorded as continuous interval data with six categories: 1 - less than one week; 2 - from one week to one month; 3 - from one month to three months; 4 - from three to six months; 5 - from six months to one year; 6 - the price remained unchanged. With the expression "significant increase" or "significant decline" the authors of the survey had in mind inducing respondents to interpret the shock as significant enough to lead firms to react to it by changing their price. Therefore, we interpret option 6 as indicating that the price will eventually change, but the adjustment lag is longer than one year.⁵

Besides the questions on price adjustments lags, the survey also contains information on a large set of firms' characteristics. These include information on the main market of the firm (internal versus external market), main destinations of sales (wholesalers vs. retailers, private vs. public sector), number of competitors, relations with customers (long-term vs. short-term), type of product competition (price vs. quality, differentiation vs. after sales service), price discrimination (same price for all customers vs. decided on a case-by-case basis), price setting decisions (own company vs. external entity, main customers vs. main competitors), and reasons for postponing price changes (the risk that competitors do not follow, existence of implicit or written contracts, cost of changing prices, costs of collecting information, absence of significant changes in variable costs, preference for maintaining prices at psychological thresholds, etc.).

The information from the survey is supplemented with data from two other sources. From *Central de Balanços*, a comprehensive dataset maintained by Banco de Portugal in which the balance sheets and income statements of most Portuguese firms are registered, we obtain data on the number of employees, the share of sales that are made abroad, and the shares of labour, inputs, and financial costs. Finally, we obtain information about

⁵As a robustness check, we also estimated models grouping categories 5 and 6 together and found that the results change very little.

the proportion of domestic and foreign capital of the firm from *Quadros de Pessoal*, a large administrative database collected by the Ministry of Employment and Social Security, which, among other, includes information about all the Portuguese firms with wage earners (size, ownership, location, etc.).

By combining the three datasets through the individual tax identification number of each firm, we are able to obtain detailed information on 903 firms from different branches of activity. More specifically, our sample includes firms with 20 or more employees, from which almost 90 percent belong to Manufacturing (NACE - classification of economic activities - 15 to 37) and the remaining to Services (NACE 60 to 64, 80 and 85 - Transport, Storage and Communication, Education and Healthcare). Sectors such as agriculture, construction, or wholesale and retail trade are not included.

3.2. Preliminary data analysis

As mentioned above, the four survey questions about price adjustment lags are our variates of interest. Table 1 summarises the information on these variables by displaying the distribution of the observed price adjustment lags for each type of shock. These results suggest that, in general, firms in the sample are quicker to react to cost shocks, in particular when they are positive, than to demand shocks. For example, only around 10 percent of the firms keep their prices unchanged in the first year after a positive cost shock, while the fraction of firms that hold their prices unchanged in response to a positive demand shock is around 35 percent. Interestingly, firms in the sample seem to react more quickly to positive than to negative cost shocks, but to be slower to react to positive than to negative demand shocks.⁶ Formal tests for the hypotheses that the reaction time is the same both for positive and negative shocks, and for demand and cost shocks, will be performed in the next section.

⁶Similar results concerning the relative speed of price adjustment to cost and demand shocks using survey data were obtained for Austria, Italy, France, Luxembourg, Spain and the US (see, respectively, Kwapil *et al.*, 2004, Fabiani *et al.*, 2004, Loupias and Ricart, 2004, Lünnemann and Mathä, 2006, Alvarez and Hernando, 2005, Blinder, 1998).

Table 1: Speed of price response to demand and cost shocks

Price adjustment lag	Cost shocks		Demand shocks	
	Positive	Negative	Positive	Negative
1 - less than one week	4.7	3.5	2.8	4.8
2 - from one week to one month	16.8	15.2	12.2	16.8
3 - from 1 month to 3 months	25.0	25.7	19.3	23.4
4 - from 3 to 6 months	17.6	15.0	13.4	13.7
5 - from 6 months to one year	26.3	21.2	17.7	14.0
6 - the price remained unchanged	9.6	19.5	34.7	27.4
Total	100.0	100.0	100.0	100.0

Table 2: Percentage of firms that do not change their prices in the first year after the shock

	Cost shocks		Demand shocks	
	Positive	Negative	Positive	Negative
Manufacturing	8.5	17.5	33.0	25.1
Services	20.0	37.8	50.0	47.8
Small firms	9.0	18.7	35.2	27.1
Large firms	13.5	24.1	31.6	28.6
Total	9.6	19.5	34.7	27.4

Small and large firms are firms with up to 250 employees and more than 250 employees, respectively. The percentages in the table are computed as a proportion of the total number of firms in the corresponding sector or firm type.

The results of this preliminary analysis, however, are not informative about the possible effect of the characteristics of the firms on the speed of adjustment, and may hide important heterogeneity in firms' responses to shocks. As an illustration of the importance of this heterogeneity, Table 2 gives the breakdown by sector and firm size of the proportion of firms that do not adjust the price in the first year after the shock. Clearly, the speed of price adjustment varies with firm sizes and across sectors. Naturally, all

these findings will be taken into account in the econometric analysis we present in the next section.

As in similar studies, the survey data also contains information on the reasons why firms may delay price changes. Specifically, firms were asked to rank the main sticky-price theories according to their importance in explaining why firms sometimes avoid or postpone price changes in the face of changes in the relevant economic environment. Respondents were asked to indicate the degree of importance attached to each theory in a scale ranging from 1 (unimportant) to 4 (very important). Table 3 summarises these results by ranking theories by mean scores.

Table 3: Theories of price stickiness (mean scores)

Theory	Total	Sectors		Size	
		Manufacturing	Services	Small	Large
Implicit contracts	3.2	3.2	3.1	3.2	3.0
Coordination failure	2.8	2.8	2.7	2.8	2.8
Cost-based pricing	2.7	2.7	2.9	2.7	2.6
Explicit contracts	2.6	2.6	2.9	2.5	2.8
Temporary shock	2.5	2.5	2.1	2.5	2.5
Quality signal	2.3	2.3	2.3	2.3	2.2
Menu costs	2.0	2.0	2.1	2.0	1.8
Costly information	1.7	1.7	1.7	1.7	1.6
Pricing thresholds	1.6	1.6	1.8	1.7	1.6

The results in Table 3 are in line with the findings of similar surveys. For example, implicit contracts, explicit contracts, cost-based pricing and coordination failure, also emerge as the top four theories for the EA (Fabiani *et al.*, 2006), while coordination failure, cost-based pricing, implicit contracts and explicit contracts rank first, second, fourth and fifth, respectively, for the US (Blinder *et al.*, 1998). Similar results were obtained for Sweden (Apel *et al.*, 2005) and the UK (Hall *et al.*, 1997). The results for the lower part of the ranking are also similar across countries. In these surveys, menu costs and information costs systematically rank very poorly as explanations for

price rigidities. For example, menu costs rank eighth and information costs ninth out of ten alternative explanations in the EA (Fabiani *et al.*, 2006), and similar results were obtained for other countries such as the UK, Canada and Sweden (Hall *et al.*, 1997, Almirault *et al.*, 2006, Apel *et al.*, 2005).

In the literature, the rankings of sticky-price theories have been used either directly, as a way of ranking the importance of the different sticky-price theories (see, among others, Fabiani *et al.*, 2006, and the references therein), or indirectly through regression analyses, to explain the frequency of price changes (see, for instance, Munnick and Xu, 2007). However, although these rankings provide evidence on the causes of the existence of price adjustment lags, they tell us little about the length of the lags and on how these vary across firms, which is the main purpose of this paper. For this reason, in the model to be presented in the next section, the rankings of the sticky-price theories as reported by the firms are not used as covariates. Rather, and for the reasons explained above, we will look into the factors that might reflect differences in the relative importance of the alternative sticky-price theories at the firm-level by identifying the factors that might affect the firms' adjustment costs, or that are expected to affect the sensitivity of profits to deviations from the optimal price.

4. AN ECONOMETRIC MODEL FOR PRICE ADJUSTMENT LAGS

The model we use to gauge the impacts of the different covariates on the lags of price adjustments takes into account both the interval nature of the data and the fact that each firm contributes to the sample with four observations. Specifically, we model the latent variable $y_{i,j}$, which represents the time firm i takes to react to a shock of type j , as a function of a set of firm characteristics and of a firm-specific random-effect. Because $y_{i,j}$ is not fully observable, and due to the potential existence of reporting errors, our model uses only the ordinal information provided by the firms.⁷ That is, the dependent variable in our model is $\tilde{y}_{i,j} = m$, where $m = 1, 2, \dots, 6$ indicates one of the six possible

⁷Because the lags of price adjustments are reported in the form of known time intervals, one could have used this information to estimate an interval-regression model with known cut-off parameters. However, we do not follow this approach as it would require much stronger assumptions on the functional

response categories. We therefore use a panel-ordered probit model that allows for the presence of unobserved firm-specific effects.⁸

Because the preliminary data analysis suggests that the speed of price adjustment is shock specific, we estimate a model which allows for the possibility of different coefficients for each type of shock, including different cut-off parameters and different variances for the non-observed stochastic components. This is almost equivalent to estimating four different models, one for each type of shock, with the difference being that in our case the models are linked by the unobserved heterogeneity component, which is assumed to be common to the four shocks.⁹ A more detailed description of the model is provided in Appendix A.

To complete the model specification it is necessary to define the set of regressors to use. As mentioned above, this choice was guided by the literature on the sticky-price theories briefly reviewed in Section 2. Ultimately, the importance of the different sticky-price theories at the firm-level may be captured by the characteristics of the firm itself, the good that is produced, or the sector in which the firm operates. For this reason, we have chosen as regressors sectoral, product, and firm-level characteristics, that may be related directly to the above discussed sticky-price theories, or may be expected to make profits more or less sensitive to shocks. Appendix B describes the different regressors and provides some summary statistics.

form of the model (see further details in Appendix A). Instead, we opted for estimating the cut-off parameters freely in the context of a very general ordered probit model.

⁸To the best of our knowledge, all the papers in the empirical literature that have looked at the speed of price reactions to demand and costs shocks have estimated binary probit models. As mentioned before, being able to use much more detailed data on the speed of price adjustments is a major distinguishing feature of our work, and the model we use explores more fully the richness of the data than the simple probit models used so far in the literature.

⁹Qualitatively, the results do not change if the model is estimated without the random effects or assuming that the random effects are independent across the four equations.

4.1 Estimation results

Table 4 presents the results of the estimated model,¹⁰ and Table 5 reports the marginal effects of the covariates on the probability that the price adjustment does not take place in the first year after the shock.¹¹ Specifically, the first line of Table 5 reports the estimated probability, for a firm in the reference group, that the price adjustment does not take place in the first year after the shock, and the remaining lines give the change to this probability from setting to 1 the corresponding regressor. These differences to the baseline group, for a generic covariate d and shock j ($j = 1, \dots, 4$), are computed as $\Pr[\tilde{y}_{i,j} = 6 \mid \bar{x} = 0, d = 1] - \Pr[\tilde{y}_{i,j} = 6 \mid \bar{x} = 0, d = 0]$, where \bar{x} denotes the fixed values of all other covariates in the model.

For ease of presentation we grouped the covariates in our model into the following six categories: 1) Price setting practices, 2) Cost structure, 3) Market environment, 4) Source of competitiveness, 5) Type of good, and 6) Other characteristics.

¹⁰Given the definition of the categorical variables (see Appendix B), the reference or baseline group is composed of firms for which: a) the proportion of sales under written contracts is less than 50 percent; b) the relationship with customers is essentially of a short-term nature; c) the price charged is the same for all customers (absence of price discrimination) and there are no quantity discount prices; d) the price of the product is set by the firm itself and not by an external entity, including the main competitors or main customers; e) the share of labour and input costs are below the corresponding median share; f) the number of competitors is less than 5; g) exports represent more than 50 percent of their main product sales; h) price, quality and delivery time are not considered very important factors for the competitiveness of the main product; i) the sector of activity is manufacturing; j) the production is essentially for final consumption (the main destination market is composed of wholesalers, retailers or final consumers), as opposed to intermediate consumption; k) the number of employees is equal or less than 250, and l) the share of domestic capital is equal or less than 50 percent.

¹¹It is well-known (see, e.g., Winkelmann and Boes, 2006) that in models for ordered data the signs of the partial effects of the covariates are unambiguous only for the first and last category ($\tilde{y}_{i,j} = 1$ and $\tilde{y}_{i,j} = 6$, in our case). For the intermediate categories, it is possible to see how a covariate changes the probability of a firm being in a given category, but that is not informative about whether that variable has a positive or negative impact on the value of the underlying latent variable. We focus on the category $\tilde{y}_{i,j} = 6$ (i.e., price adjustment does not take place in the first year after the shock), as it is more meaningful than the category $\tilde{y}_{i,j} = 1$ (i.e., price adjustment takes place in the first week after the shock).

Table 4: Panel-ordered probit estimates for the price adjustment lags

Covariates	Cost shocks		Demand shocks	
	Positive	Negative	Positive	Negative
Constant	3.455** (0.325)	4.639** (0.444)	3.327** (0.318)	3.555** (0.379)
Explicit contracts	0.044 (0.127)	-0.033 (0.154)	0.075 (0.123)	0.124 (0.146)
Implicit contracts	-0.142 (0.148)	-0.113 (0.180)	0.102 (0.143)	-0.195 (0.171)
Price discrimination	-0.395** (0.163)	-0.386* (0.198)	-0.568** (0.160)	-0.633** (0.190)
Quantity discount	-0.428** (0.152)	-0.304* (0.184)	-0.405** (0.149)	-0.440** (0.176)
Price set by customers	0.417** (0.181)	-0.214 (0.219)	0.113 (0.174)	-0.137 (0.206)
Price set by competitors	0.315* (0.163)	-0.079 (0.197)	-0.408** (0.156)	-0.673** (0.187)
Labour costs	0.417** (0.122)	0.394** (0.149)	0.411** (0.119)	0.508** (0.141)
Intermediate input costs	-0.253** (0.126)	-0.292* (0.153)	-0.052 (0.122)	0.036 (0.144)
Competition	-0.358** (0.136)	-0.365** (0.165)	-0.304** (0.132)	-0.409** (0.157)
Domestic market	-0.032 (0.127)	-0.071 (0.154)	0.043 (0.123)	0.223 (0.146)
Price competitiveness	-0.026 (0.113)	-0.239* (0.137)	-0.213* (0.110)	-0.409** (0.131)
Quality competitiveness	0.271** (0.130)	0.204 (0.157)	0.313** (0.125)	0.488** (0.150)
Delivery competitiveness	-0.091 (0.111)	-0.106 (0.134)	0.268** (0.108)	0.302** (0.128)
Services	1.031** (0.205)	1.108** (0.253)	0.559** (0.199)	0.949** (0.238)
Intermediate goods	-0.262** (0.124)	-0.423** (0.151)	-0.418** (0.120)	-0.419** (0.143)
Size	0.356** (0.158)	0.525** (0.193)	-0.131 (0.152)	0.174 (0.181)
Capital structure	-0.392** (0.171)	-0.448** (0.208)	-0.119 (0.165)	-0.174 (0.195)
$\tau_{2,j}$	1.443** (0.113)	1.793** (0.166)	1.367** (0.126)	1.586** (0.131)
$\tau_{3,j}$	2.605** (0.139)	3.263** (0.221)	2.418** (0.148)	2.873** (0.174)
$\tau_{4,j}$	3.386** (0.158)	4.064** (0.256)	2.994** (0.159)	3.578** (0.200)
$\tau_{5,j}$	4.973** (0.206)	5.302** (0.308)	3.675** (0.173)	4.304** (0.227)
σ_j	1.060** (0.087)	1.429** (0.129)	0.964** (0.081)	1.304** (0.111)

Standard errors computed from analytical second derivatives are in parenthesis; **marks significance at 5%; *marks significance at 10% level; $\tau_{k,j}$ ($k = 2, \dots, 5$) are the cut-off parameters, and σ_j is the shock-specific impact of the random-effects (see Appendix A for details).

Table 5: Probability estimates for the category $\tilde{y}_{ij} = 6$ for the baseline group, and differences with respect to this group

	Cost shocks		Demand shocks	
	Positive	Negative	Positive	Negative
Baseline group	0.1614** (0.0262)	0.3568** (0.0716)	0.4045** (0.0443)	0.3305** (0.0422)
Explicit contracts	0.0069 (0.0202)	-0.0068 (0.0313)	0.0203 (0.0334)	0.0265 (0.0317)
Implicit contracts	-0.0208 (0.0207)	-0.0229 (0.0368)	0.0277 (0.0389)	-0.0398 (0.0339)
Price discrimination	-0.0528** (0.0196)	-0.0751* (0.0387)	-0.1410** (0.0361)	-0.1191** (0.0317)
Quantity discount	-0.0565** (0.0181)	-0.0598 (0.0366)	-0.1033** (0.0357)	-0.0861** (0.0317)
Price set by customers	0.0735** (0.0363)	-0.0427 (0.0430)	0.0305 (0.0474)	-0.0282 (0.0416)
Price set by competitors	0.0539* (0.0310)	-0.0160 (0.0396)	-0.1039** (0.0375)	-0.1255** (0.0311)
Labour costs	0.0736** (0.0250)	0.0839** (0.0315)	0.1128** (0.0326)	0.1131** (0.0325)
Intermediate input costs	-0.0357** (0.0166)	-0.0577* (0.0311)	-0.0139 (0.0323)	0.0077 (0.0306)
Competition	-0.0485** (0.0170)	-0.0713** (0.0324)	-0.0788** (0.328)	-0.0805** (0.0288)
Domestic market	-0.0049 (0.0192)	-0.0145 (0.0314)	0.0117 (0.0332)	0.0483 (0.0324)
Price competitiveness	-0.0039 (0.0171)	-0.0476* (0.0274)	-0.0559** (0.0279)	-0.0804** (0.0242)
Quality competitiveness	0.0456* (0.0242)	0.0427 (0.0326)	0.0857** (0.0346)	0.1086** (0.0345)
Delivery competitiveness	-0.0136 (0.0161)	-0.0215 (0.0271)	0.0732** (0.0297)	0.0661** (0.0288)
Services	0.2124** (0.0519)	0.2406** (0.0525)	0.1535** (0.0543)	0.2163** (0.0550)
Intermediate goods	-0.0368** (0.0163)	-0.0818** (0.0284)	-0.1065** (0.0287)	-0.0822** (0.0262)
Size	0.0617** (0.0357)	0.1127** (0.420)	-0.0345 (0.0396)	0.0375 (0.0398)
Capital structure	-0.0525** (0.0205)	-0.0864** (0.0410)	-0.0316 (0.0431)	-0.0356 (0.0389)

Standard errors computed from analytical second derivatives are in parenthesis; **marks significance at 5%; *marks significance at 10% level.

Price setting practices

This category includes six regressors deemed to affect directly the ability of the firm to change its price in the event of a shock: the proportion of sales under written contracts, information on whether the relation with the customers is essentially of a long- or short-term nature, information on whether the firm practices price discrimination and/or

quantity discounts, and, finally, information on whether the price is significantly affected by the firm's main customers or main competitors.

The first variable measures how important explicit contracts are for firms' regular operations, while the second may be seen as a proxy for the existence of implicit contracts. As we have seen in Section 2, economic theory suggests that the existence of explicit and/or implicit contracts may be an important source of price stickiness, and the results in Section 3 confirm that indeed this is an important reason for the existence price adjustment lags. In contradistinction, the results in Table 4 show that the coefficients on "Explicit contracts" and "Implicit contracts" are not statistically different from zero for either of the four shocks. Thus, although these variables may play a role in explaining the existence of price adjustment lags following significant demand or cost shocks, they do not seem to have a bearing on the length of these lags.

In contrast, the type of pricing policy (single price versus price discrimination and existence of quantity discounts) emerges as playing an important role in determining the speed of price adjustments. Firms that decide the price on a case-by-case basis, or do quantity discounts, tend to be faster to adjust to both cost and demand shocks. In particular, from Table 5 we see that, for a firm that sets its price on a case-by-case basis, the probability of adjusting its price in response to a demand shock more than one year after the shock is 12 to 14 percentage points (pp) lower than the probability for an otherwise identical firm (approximately 8 to 10 pp lower in the case of a firm that does quantity discounts). These results can be interpreted as reflecting the fact that firms with such flexible pricing practices are likely to face relatively low information, managerial, or menu costs, which also allow them to react more quickly to shocks.

Finally, we consider two variables related to the firms' lack of autonomy in setting their own prices (as opposed to cases in which the price is set by the firm itself). We find that the "price set by customers" variable has a positive and significant impact only in the case of positive cost shocks, suggesting that for these firms customers have enough power to delay the firms' reaction when costs push prices up. Regarding the "price set by competitors" variable, our results show that firms that have their prices significantly affected by the main competitors are faster to respond to demand shocks

than firms that set their own prices. According to Table 5, the probability of such a firm adjusting the price more than one year after the shock is 10 to 13 pp lower than for a firm in the reference category. This suggests that firms whose prices are set by the main competitors may be acting as market followers in a market where the presence of market leaders helps reducing, or even eliminating, potential coordination problems.

Cost structure

In order to test whether the cost structure matters for explaining the differences in price adjustment lags, we included two variables that measure the importance of labour costs and other input costs (intermediate inputs). From Tables 4 and 5 we see that the shares of labour and intermediate input costs emerge as important factors in explaining the price adjustment lags. Irrespective of the type of shock, firms with a labour share above the median tend to be slower to react to shocks.¹² In contrast, firms with a share of intermediate input costs above the median tend to react more quickly to cost shocks than otherwise similar firms.

Cost structure is an important determinant of how firms react to cost shocks. Under very general conditions, profit maximizing firms would like to set their price equal to the marginal cost plus a mark-up. Thus, for firms following mark-up rules, the higher the volatility of input prices, the higher will be the frequency with which they change their prices. If input costs are relatively stable, such as wages which are changed on average once a year, prices can also be expected to be relatively stable. On the contrary, if input costs are highly volatile, in particular the price of some raw materials, the frequency of price changes could be much higher. Thus, *ceteris paribus*, one may expect firms with higher labour cost shares to change their prices less frequently than firms with higher shares of intermediate inputs with more volatile prices. Our findings suggest that this result translates into the speed of price adjustment to cost shocks: firms with a higher share of labour cost tend to be slower to react, while firms with a higher share of intermediate input costs tend to be faster (see also Altissimo *et al.*, 2006).

¹²This is a very robust result that has been extensively documented in the literature for the frequency of price adjustments (see, among other, Altissimo, Ehrmann and Smets, 2006, and the references therein). Our results show that the same result is valid for the speed with which firms react to shocks.

As for demand shocks, we may expect a similar result. Infrequent wage changes give rise to flatter product supply curves for firms with higher shares of labour costs, making their optimal price less sensitive to demand shocks. Thus, we may expect firms with higher shares of labour costs to react slowly to demand shocks. This is confirmed by our findings. In particular, from Table 5 we see that, for a firm with a share of labour costs above the median, the probability of taking more than one year to adjust its price after a cost shock is about 7 to 9 pp higher than the corresponding probability for an otherwise identical firm. This difference in the probabilities increases to 11 to 12 pp in the face of demand shocks.

Market environment

To characterize the market environment in which firms operate, we use a direct measure of market competition (number of competitors equal to 5 or more), and information on the main destination market (domestic vs. foreign market). According to the estimated model, the degree of competition is a relevant factor in determining the speed of price adjustment. Firms in more competitive environments tend to be faster to react to shocks. Indeed, it is known that the more competitive a sector is, the more sensitive profits are to sub-optimal prices. Thus, for given nominal adjustment costs (due for instance to the presence of information or menu costs), stronger competition may be expected to translate into quicker responses to shocks (see, for instance, Martin, 1993). From Table 5 we see that, in the face of a demand shock (either positive or negative), the probability of a firm adjusting the price more than one year after the shock is reduced by around 8.0 pp for firms with five or more competitors.

Regarding the market destination variable, we find that the coefficients of the covariate that measures the importance of the domestic market are not statistically significant for any of the four shocks. Thus, whether the firm sells their products in the domestic market or abroad does not seem to make a difference for the speed with which firms react to shocks.

Source of competitiveness

In order to investigate if the different competitiveness factors affect the speed with which firms respond to shocks, we distinguish between price, quality, and delivery period,

as alternative sources of competitiveness. We may think of these factors as reflecting different product characteristics which translate into different demand elasticities (higher demand elasticity for firms for which price is an important factor, and lower elasticity for firms that value more the quality of the product or the delivery period).¹³ According to Tables 4 and 5, firms that consider price as an important factor of competitiveness tend to adjust prices more quickly, while firms that value more the quality of the product or the delivery period as competitiveness factors tend to adjust their prices at a slower pace in response to shocks (specially so, in face of demand shocks).

Type of good

In the data we have information regarding the sector where firms operate (manufacturing or services), and the destination of the product (final vs. intermediate consumption). As earlier results suggested (see Table 2), from Table 4 and 5 we find that firms that operate in the services sector are substantially slower to react to shocks than firms that operate in the manufacturing sector. In fact, for each of the four shocks, the covariate "Services" shows up in Table 5 as the one with the largest impact on the estimated probabilities, with marginal effects ranging from 15 to 24 pp. These results are consistent with previous evidence on the frequency of price changes which suggested a significantly higher degree of price stickiness in the services sector.

The speed of price adjustment also varies according to the type of market for the product. Firms that sell their products to other firms (intermediate goods) tend to be quicker to adjust their prices than firms whose products are mainly for final demand (whose main destinations are wholesalers, retailers or consumers). These results may reflect the fact that services and final goods are typically more differentiated than manufacturing and intermediate goods, respectively, and thus face a less elastic demand.

Other characteristics

The last group of variables we considered as potentially relevant to explain the differences in the lags of price adjustment are the firm size and the capital structure. In line

¹³Martin (1993) showed that the speed of price adjustment increases with the elasticity of demand, that is, firms react faster to shocks when the demand schedule facing them is flatter. This same idea was used by Gopinath and Itskhoki (2009) to show the link between the frequency of price adjustment and exchange rate pass-through.

with the findings from the previous section, size matters for the speed of price adjustment. In the face of cost shocks, large firms tend to be slower at adjusting their prices than small firms. This finding probably indicates that firm size is capturing some remaining firm characteristics not explained by the included covariates, like the flexibility of the decision-making process.

As regards the capital structure, we find that firms with a higher share of domestic capital tend to adjust faster in the face of shocks (especially so in the face of cost shocks), probably because, in contrast to what can be expected for foreign firms, the decision making process of domestic firms resides inside the country allowing a prompter reaction to shocks.

4.2 Symmetric or asymmetric response lags?

Because the consequences of monetary policy shocks might differ depending on the direction of the shock, it is interesting to study whether the lags of price adjustments to cost and demand shocks are symmetric or asymmetric. There is now a vast theoretical literature that focus on the question of whether prices are more sticky in response to a shock that warrants a price decrease or to shocks in the opposite direction. Such asymmetries may arise because of strategic behaviour (Hansen *et al.*, 1996, Kavenock and Widdows, 1998, Bhaskar, 2002, Devereux and Siu, 2007), adjustment costs under trend inflation (Tsiddon, 1993, Ball and Mankiw, 1994b, Ellingsen *et al.*, 2006), search models (Lewis, 2004, Yang and Ye, 2008, Bayer and Ke, 2009), capacity constraints (Finn, 1996, Laxton *et al.*, 1996, Loertscher, 2005), inattentive consumers (Chen *et al.*, 2008), or customer anger (Okun, 1981, Rotemberg, 2005, Anderson and Simester, 2010). Importantly, there seems to be no theoretical unanimity as to whether prices will be more sticky when moving up or down.

According to the preliminary analysis in Section 3, and in line with results found in other countries, some asymmetry is expected because firms seem to react more quickly to positive than to negative cost shocks, and more slowly to positive than negative demand shocks. However, tests of possible asymmetric reaction times were not performed in Section 3, and therefore it is important to investigate this issue formally. In the context

of our model, testing for symmetry entails comparing not only the coefficients of the different covariates in the equations for the different shocks, but also all other parameters that are shock specific.

Table 6 presents the results of the two tests for symmetry within shocks – positive and negative cost shocks, and positive and negative demand shocks. The null of symmetry is clearly rejected in both cases and therefore it can be concluded that firms react differently to negative and positive shocks. Table 6 also reports the results of two tests for symmetry between shocks – positive shocks to costs and demand, and negative shocks to costs and demand. Again, the null of symmetry is clearly rejected, suggesting that firms adjust differently to positive cost and demand shocks, as well as to negative cost and demand shocks.

Table 6 - Tests of symmetry

Symmetry within shocks		Symmetry between shocks	
Positive and negative cost shocks	Positive and negative demand shocks	Positive cost and demand shocks	Negative cost and demand shocks
$\chi^2(23) = 88.33$	$\chi^2(23) = 78.29$	$\chi^2(23) = 300.0$	$\chi^2(23) = 95.88$
($p = 0.000$)	($p = 0.000$)	($p = 0.000$)	($p = 0.000$)

$\chi^2(23)$ stands for the Wald test statistic with 23 degrees of freedom and p for the corresponding p-value.

Combining the results of these formal tests with the evidence in Section 3, one may be led to conclude that prices adjust more quickly upwards than downwards following cost shocks, but more slowly upwards than downwards in reaction to demand shocks. However, the results in Section 3 revealed strong heterogeneity in the way firms react to shocks and therefore the direction of the asymmetry may vary with the characteristics of the firms. In order to investigate this issue, we computed for firms in the baseline group the differences between the probability that the adjustment to different shocks will take more than a year, as well as the differences-in-differences for each covariate relative to the baseline group (obtained from Table 5). These results, which are displayed in Table 7, allow us to discuss the sources and direction of asymmetries within shocks (positive

vs. negative cost or demand shocks) and between shocks (cost vs. demand positive or negative shocks).

Table 7: Estimates of the difference between probabilities for the category $\tilde{y}_{ij} = 6$ for the baseline group, and differences with respect to this group.

	Within shocks		Between shocks	
	Positive - Negative		Cost - Demand	
	Cost shock	Demand shock	Positive shock	Negative shock
Baseline group	-0.1955** (0.0763)	0.0740 (0.0535)	-0.2431** (0.0545)	0.0263 (0.0828)
Explicit contracts	0.0137 (0.0252)	-0.0063 (0.0312)	-0.0134 (0.0290)	-0.0334 (0.0268)
Implicit contracts	0.0020 (0.0294)	0.0674* (0.0347)	-0.0485 (0.0333)	0.0169 (0.0298)
Price discrimination	0.0223 (0.0322)	-0.0218 (0.0334)	0.0882** (0.0323)	0.0440 (0.0318)
Quantity discount	0.0033 (0.0307)	-0.0172 (0.0329)	0.0467 (0.0319)	0.0263 (0.0301)
Price set by customers	0.1162** (0.0360)	0.0588 (0.0423)	0.0430 (0.0425)	-0.0145 (0.0355)
Price set by competitors	0.0698** (0.0332)	0.0216 (0.0339)	0.1578** (0.0349)	0.1096** (0.0323)
Labour costs	-0.0103 (0.0268)	-0.0003 (0.0312)	-0.0392 (0.0299)	-0.0292 (0.0275)
Intermediate input costs	0.0220 (0.0255)	-0.0216 (0.0301)	-0.0218 (0.0281)	-0.0654** (0.0264)
Competition	0.0227 (0.0272)	0.0017 (0.0300)	0.0302 (0.0291)	0.0093 (0.0271)
Domestic market	0.0096 (0.0251)	-0.0366 (0.0312)	-0.0166 (0.0286)	-0.0628** (0.0269)
Price competitiveness	0.0437** (0.0221)	0.0245 (0.0254)	0.0520** (0.0242)	0.0328 (0.0228)
Quality competitiveness	0.0029 (0.0269)	-0.0229 (0.0329)	-0.0401 (0.0308)	-0.0658** (0.0286)
Delivery competitiveness	0.0079 (0.0218)	0.0071 (0.0280)	-0.0868** (0.0257)	-0.0876** (0.0239)
Services	-0.0282 (0.0490)	-0.0628 (0.0536)	0.0589 (0.0546)	0.0243 (0.0471)
Intermediate goods	0.0450* (0.0237)	-0.0242 (0.0265)	0.0697** (0.0254)	0.0005 (0.0244)
Size	-0.0510 (0.0349)	-0.0720* (0.0379)	0.0963** (0.0361)	0.0752** (0.0350)
Capital structure	0.0338 (0.0341)	0.0040 (0.0391)	-0.0210 (0.0377)	-0.0508 (0.0343)

Standard errors computed from analytical second derivatives are in parenthesis; **marks significance at 5%; *marks significance at 10% level.

When we compare the speed of adjustment to positive and negative cost shocks for the baseline firm, we find evidence of asymmetric response; the difference between the probability that the adjustment takes more than a year for positive and negative shocks is equal to -0.1955 , and significantly different from zero. This means that these firms react significantly faster to positive than to negative cost shocks. Nevertheless, this result is only strictly valid for the baseline firm we use. For example, if in our baseline group we had included firms whose price is set by customers, consider price as an important factor of competitiveness, and produce intermediate goods, we would have obtained a value very close to zero: $0.0094 = 0.1162 + 0.0437 + 0.0450 - 0.1955$. What we take from these results is that there is evidence of asymmetric response to cost shocks, but the degree and direction of this behaviour varies significantly across firms.

For demand shocks, the asymmetry tests in Table 6 above, combined with the evidence in Table 2, suggest that prices move more quickly in response to negative than to positive shocks. However, the results in Table 7 do not provide clear evidence to support this asymmetry, and do not identify covariates with a strong effect on it. This suggests that differences in the probability that the price is adjusted more than one year after the shock is not a good measure of the degree of asymmetry in this particular case.

Turning, finally, to the difference between cost and demand shocks (see the last two columns in Table 7), we conclude that the probability of a firm in the baseline group adjusting the price more than one year after the shocks is significantly lower for a positive cost shock than for a positive demand shock, but that the difference is not significant in the case of negative shocks. However, again, the direction of the asymmetry may be reversed for firms with particular characteristics, with several regressors being able to contribute to this.

In summary, because the direction and magnitude of the asymmetries vary from firm to firm, the relevance of the different types of firms in the economy will ultimately determine whether prices adjust more quickly upwards or downwards, or if they are quicker to react to cost or demand shocks. To the best of our knowledge, the result that the sign and magnitude of the asymmetry depends on the characteristics of the firms, on the market structure considered, and on the nature of the shock, is new in the

literature and may explain the lack of unanimity of the current economic models with respect to this issue.

5. CONCLUSIONS

This paper investigates firm-level price rigidities by using survey data to look into the origins of lags of price adjustments to demand and cost shocks. Price adjustment lags are a direct measure of intrinsic price rigidity and therefore may be seen as a better measure of price stickiness than the commonly used frequency of price changes.

By estimating a panel-ordered probit model, we find that the lags of price adjustments vary with the sector, product, and firm characteristics, namely the cost structure of the firm, the type of pricing policy, the competitive environment, the different factors of competitiveness, or the type of good. These factors, using the terminology in Ball and Romer (1990), affect directly the degree of real rigidities, which in turn, determines the speed at which firms adjust their prices, for a given level of nominal adjustment costs (or nominal frictions). In contrast to what one could expect, the fact that the firm has a large proportion of sales under written contracts, or whether the relation with the customers is essentially of a long-term nature, does not have implications for the speed with which firms adjust prices following significant demand or cost shocks. Overall, the findings in this paper are consistent with the idea that differences in the speed of price adjustments depend on the costs of changing nominal prices, as well as on the sensitivity of the firms' profits to deviations from the optimal price.

Both for demand and cost shocks, statistical tests indicate that firms react differently to positive and negative shocks. Similarly, for shocks of the same sign, the evidence shows that firms react differently to cost and demand shocks. However, because these asymmetries depend on the characteristics of the firms, their general direction and magnitude will depend on the relative importance of different types of firms in an economy.

A first implication of our results is related to the identification of inflation leading indicators. Because it is possible to identify the characteristics of the firms that are faster to react to shocks, it should be possible to identify inflation risks earlier by

monitoring closely the sectors where this type of firms predominate, and thus construct useful leading indicators of inflation.

More important, however, are the implications of our results for macroeconomic models. Indeed, our findings suggest that monetary models should try to accommodate the fact that the degree of price stickiness varies across firms and that firms react differently to different types of shocks. In particular, our results suggest that these models could benefit from explicitly incorporating some of the characteristics of the firms, namely the structure of the market where they operate (services vs. manufacturing, intermediate goods vs. final consumption goods) and their cost structure, as these are important determinants of the degree of price stickiness. Consideration of these factors may help to better understand the heterogeneous effects of monetary policy across regions and sectors, as well as providing some information about possible changes of the effectiveness of monetary policy as a result of structural changes in the fabric of the economy.

APPENDIX A

In this appendix we explain in detail the panel-ordered probit with random effects used in Section 4.

We are interested in modelling the response of each firm to four different shocks. These four responses are likely to depend on common unobserved firm characteristics, suggesting the use of a panel data set-up in which the four seemingly unrelated equations are linked by a common random effect representing the unobserved firm characteristics. However, because we let different covariates have different coefficients in different equations, we allow the impact of the random effects to be shock-specific. Besides providing potential efficiency gains, the inclusion of the random effects with a flexible distribution makes the model more general and therefore less sensitive to distributional assumptions.

The resulting model is very similar to a standard ordered probit with the only difference being the fact that we take into account the panel structure of the data. As in the common ordered probit, we assume that there is a latent variable, $y_{i,j}$, which represents the time firm i takes to react to a shock of type j . Recall that the different types of shocks are: 1) positive demand shock; 2) positive cost shock; 3) negative demand shock; and 4) negative cost shock. We also assume that $y_{i,j}$ is related to a set of firm characteristics by

$$y_{i,j} = \Lambda_j (x_i' \beta_j + \sigma_j v_i + \varepsilon_{i,j}), \quad (\text{A1})$$

where $\Lambda_j(\cdot)$ is a strictly increasing invertible function that is specific to shocks of type j ; x_i is a set of firm characteristics whose impact, measured by vectors β_j , is shock specific; v_i is a non-observed firm-effect whose impact, measured by σ_j , is shock specific; and $\varepsilon_{i,j}$ is a non-observed stochastic term that is firm and shock specific.

Equation (A1) implies that $w_{i,j} = \Lambda_j^{-1}(y_{i,j})$ is related to the firm characteristics by the linear model

$$w_{i,j} = x_i' \beta_j + \sigma_j v_i + \varepsilon_{i,j}.$$

In our data, $y_{i,j}$ is not fully observed and instead we observe $\tilde{y}_{i,j}$, which is related to $w_{i,j}$ as follows. For $m = 1, 2, \dots, 6$,

$$\tilde{y}_{i,j} = m \quad \text{if} \quad \tau_{m-1,j} < w_{i,j} < \tau_{m,j}, \quad (\text{A2})$$

where the constants $\tau_{m,j}$ are the limits of the intervals into which the domain of $w_{i,j}$ is partitioned due to the fact that $y_{i,j}$ is observed as interval data.

At this point, two approaches can be followed. Because the price lags are reported in the form of known time intervals, we could specify the form of $\Lambda_j(\cdot)$ and use this information to determine the cut-off parameters $\tau_{m,j}$. Alternatively, we can estimate the cut-off parameters, which avoids the need to specify $\Lambda_j(\cdot)$. This is the approach we follow because by not specifying $\Lambda_j(\cdot)$ the model gains an interesting degree of flexibility. Specifically, for identification purposes, we set $\tau_{0,j} = -\infty$, $\tau_{1,j} = 0$, and $\tau_{6,j} = +\infty$, estimating freely the remaining four cut-off parameters.

In order to be able to estimate the parameters of the model, we need to make distributional assumptions on the unobserved random components. We start by assuming that $\varepsilon_{i,j}|x_i, v_i \sim N(0, 1)$, where the normalization of the variance to 1 implies no loss of generality. Then, based on (A2), the conditional probability of observing $\tilde{y}_{i,j} = m$ is given by

$$\begin{aligned} \Pr(\tilde{y}_{i,j} = m|x_i, v_i) &= \Pr(\tau_{m-1,j} \leq w_{i,j} < \tau_{m,j}|x_i, v_i) \\ &= \Pr(w_{i,j} < \tau_{m,j}|x_i, v_i) - \Pr(w_{i,j} \leq \tau_{m-1,j}|x_i, v_i) \\ &= \Phi\{\tau_{m,j} - (x_i'\beta_j + \sigma_j v_i) | x_i, v_i\} - \\ &\quad \Phi\{\tau_{m-1,j} - (x_i'\beta_j + \sigma_j v_i) | x_i, v_i\} \\ &= h_j(\tilde{y}_{i,j}|x_i, v_i), \end{aligned}$$

where $\Phi(\cdot)$ denotes the normal distribution function. Assuming that the disturbances $\varepsilon_{i,j}$ are conditionally independent (given x_i and v_i) across i and j , we can write the probability that for a certain firm we observe $(\tilde{y}_{i,1} = m_1, \tilde{y}_{i,2} = m_2, \tilde{y}_{i,3} = m_3, \tilde{y}_{i,4} = m_4)$ as

$$\Pr(\tilde{y}_{i,1} = m_1, \tilde{y}_{i,2} = m_2, \tilde{y}_{i,3} = m_3, \tilde{y}_{i,4} = m_4|x_i, v_i) = \prod_{j=1}^4 h_j(\tilde{y}_{i,j}|x_i, v_i).$$

Since we also do not observe v_i , we need to integrate it out of $h_j(\tilde{y}_{i,j}|x_i, v_i)$ in order to obtain an expression of the individual contribution to the likelihood that can be used for estimation. This expression corresponds to

$$L_i(\theta) = \int_{-\infty}^{+\infty} \prod_{j=1}^4 h_j(\tilde{y}_{i,j}|x_i, v_i) g(v_i) dv_i,$$

where θ denotes the vector of parameters of the model and $g(\cdot)$ is the density function of v_i . Following Dhaene and Santos Silva (2010), we assume that $g(v_i)$ is such that $\sinh^{-1}(\gamma v_i)/\gamma$ has a standard normal distribution.¹⁴ That is, the shape-parameter γ introduces additional flexibility in the model by allowing the distribution of the random effect component to have an unspecified degree of excess kurtosis. In the model presented in Section 4, the estimate of γ is -0.5740 (s.e. 0.0944), indicating that the random-effects have a distribution with substantial excess kurtosis.

Finally, in order to make the model operational it is necessary to define how the integration is performed. In our application, this was done using 50-point Gauss-Hermite integration.

APPENDIX B

In this Appendix we describe the covariates used in the ordered probit model whose results are presented in Section 4, and provide the corresponding summary statistics. All the covariates used in the model are dummy variables. The details are as follows:

Explicit contracts – Equal to one if the percentage of sales under written contracts is larger than 50 percent of total sales.

Implicit contracts – Equal to one if the relationship with customers is essentially a long-term one (more than one year).

Price discrimination – Equal to one if the price of the firm's product is decided on a case-by-case basis.

Quantity discount – Equal to one if the price depends on the quantity sold but according to a uniform price list.

Price set by customers – Equal to one if the price of the product is set by the firm's main customer(s).

Price set by competitors – Equal to one if the price of the product is set by the firm's main competitor(s).

Labour costs – Equal to one if the labour cost share is above the median of the sample.

¹⁴The use of this sort of transformation was pioneered by Burbidge, Magee and Robb (1988).

Intermediate input costs – Equal to one if the other input costs share is above the median of the sample.

Competition – Equal to one if the number of firm's competitors is equal to 5 or bigger.

Domestic market – Equal to one if Portugal is the main destination market for the firm's product.

Price competitiveness – Equal to one if the firm considers price as a very important factor for competitiveness.

Quality competitiveness – Equal to one if the firm considers quality as a very important factor for competitiveness.

Delivery competitiveness – Equal to one if the firm considers delivery period as a very important factor for competitiveness.

Services – Equal to one if the firm operates in the Services sector.

Intermediate goods – Equal to one if "other companies" is the main destination of sales (as opposed to wholesalers, retailers, Government, consumers).

Size – Equal to one if the number of employees is larger than 250.

Capital structure – Equal to one if the share of domestic capital (owned by Portuguese entrepreneurs) is larger than 50 percent.

Table A1 summarizes the relative importance in the sample of the above defined covariates. The entries in the Table record the share of firms in each category, with the exception of the labour and intermediate input costs, which represent the corresponding average shares, and the capital structure, which represents the share of firms whose national capital accounts for 50 percent or more of total capital. For instance, from the Table we see that around 83 percent of firms have implicit contracts, i.e., they have an essentially long-term relationship with customers, and that the distribution of implicit contracts is relatively homogeneous across sectors and do not vary much with the size of firms. In contrast, only in about 25 percent of the firms do formal contracts account for 50 percent or more of total sales (explicit contracts), and its distribution varies significantly across sectors and firms' size.

Table A1: Main characteristics of the sample
(Share of firms in each category in percentage)

	Total	Sectors		Firms' size	
		Manufacturing	Services	Small	Large
Explicit contracts	25.5	23.9	40	23.6	36.1
Implicit contracts	82.6	83.3	76.7	82.0	86.5
Price discrimination	37.4	38.3	30.0	37.8	35.3
Quantity discount	41.0	42.2	30.0	40.8	42.1
Price set by customers	11.7	11.8	11.1	10.9	16.5
Price set by competitors	12.3	12.9	6.7	13.6	4.5
Labour costs ^(a)	27.3	26.2	36.8	27.6	25.2
Intermediate input costs ^(a)	39.3	43.1	5.1	39.2	40.3
Competition	76.0	74.8	86.7	79.0	58.6
Domestic market	68.4	66.3	87.8	70.5	56.4
Price competitiveness	59.5	61.4	42.2	59.2	60.9
Quality competitiveness	77.0	76.4	82.2	76.1	82.0
Delivery competitiveness	51.1	51.7	45.6	50.0	57.1
Intermediate goods	30.9	30.6	33.3	31.8	25.6
Size (large firms)	15.0	14.5	18.9	–	–
Capital Structure ^(b)	88.2	87.6	93.2	90.4	75.4

^(a) Average of labour or intermediate input cost share (percent);

^(b) Share of firms whose national capital accounts for 50 percent or more of total capital.

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