EUROPEAN CENTRAL BANK

EUROSYSTEM

Occasional Paper Series

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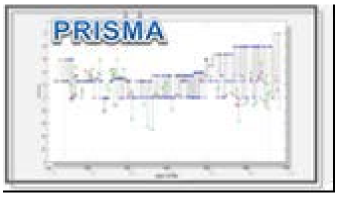
Some implications of micro price-setting evidence for inflation dynamics and monetary transmission



No 321

Price-setting Microdata Analysis Network (PRISMA)

This Occasional Paper contains research conducted within the Price-setting Microdata Analysis Network (PRISMA). PRISMA (2018-22) consisted of economists from the European Central Bank (ECB) and the national central banks (NCBs) of the European System of Centra Banks (ESCB). PRISMA was coordinated by a team chaired by Luca Dedola (ECB) and consisting of Chiara Osbat (ECB), Peter Karadi (ECB) and Georg Strasser (ECB). Fernando Alvarez (University of Chicago), Yuriy Gorodnichenko (University of California Berkeley), Raphael Schoenle (Federal Reserve Bank of Cleveland and Brandeis University) and Michael Weber (University of Chicago) acted as external consultants (for further information, see Price-setting Microdata Analysis Network (PRISMA).

This work is part of a set of papers within the ECB's Occasional Paper Series, resulting from the report of the ECB's PRISMA network, which is summarised here.

Set of Occasional Papers related to the ECB's PRISMA network

No 319, "Price adjustment in the euro area in the low-inflation period: evidence from consumer and producer micro price data"

No 320, "E-commerce and price setting: evidence from Europe"

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Contents

Abstract

This paper analyses the implications of the evidence on micro price setting gathered by Price-setting Microdata Analysis Network (PRISMA) for inflation dynamics and monetary policy, relying on calibrated models and direct empirical evidence. According to models calibrated to the euro area micro evidence in Gautier et al. (2022, 2023), infrequent price changes and moderate state dependence in price setting should result in a meaningful Phillips curve in the euro area. Empirical estimates of the Phillips curve during the low-inflation period confirm previous findings of a relatively flat but stable slope. This estimated flat slope reflects both infrequent and subdued price adjustment in response to aggregate shocks, i.e. the presence of nominal and real rigidities. Model-based simulations show that, due to non-linearities in price setting, changes in trend inflation above 5-6% would have significant effects on the euro area Phillips curve. Similarly, shocks to nominal costs larger than 15% would result in non-linear effects on inflation dynamics in calibrated models. In line with these simulations, recent micro evidence suggests that the return of higher and more volatile inflation seems to be associated with higher frequencies of price changes, mainly because the frequency of price increases rises with the level and volatility of inflation.

Keywords: state-dependent price setting and non-linearities, heterogeneity, real and nominal rigidities, price Phillips curve.

JEL codes: E3, E5.

1 Introduction

Inflation is the sum of heterogeneous individual price-setting decisions, whose analysis requires microdata. Price adjustment is “lumpy”: prices change infrequently, and both price increases and decreases may be substantial. Infrequent price adjustment is critical for monetary transmission, as it shapes the speed at which aggregate shocks affect inflation. However, as well as this nominal rigidity, the size of the adjustment, i.e. how much various “reset” prices adjust, also affects inflation dynamics. An initial aspect is whether price setting is state-dependent, i.e. whether the prices that change are those most in need of adjustment, as otherwise they would be very misaligned with respect to their target values. As a result, price changes may be very large in response to small aggregate shocks, amplifying the reaction of aggregate inflation, even with a relatively low repricing rate. Non-linearities in the size of aggregate shocks are also possible. A second aspect concerns “real rigidities”, i.e. the responsiveness of target prices to costs. If firms only partially pass through underlying changes in costs to price changes, “real rigidities” will slow inflation dynamics and amplify the effects of infrequent repricing. Obviously, both how often and how much prices change can only be gauged using microdata. Likewise, microdata are necessary to investigate how individual firms pass through their costs to prices. The ESCB Inflation Persistence Network (IPN) pioneered studies of micro prices as far back as the early 2000s.[1] The Price-setting Microdata Analysis Network (PRISMA) updated and extended the IPN work in several areas (see Gautier et al., 2022). The microdata collected by PRISMA comprise 135 million price quotes underlying the Harmonised Index of Consumer Prices (HICP) in 11 countries from 2010 to 2019, encompassing 166 categories of the euro area HICP (60% of products), a much larger share than the 50 IPN categories.

PRISMA has analysed the macroeconomic implications of the micro evidence on price setting by estimating the effects of structural demand and supply shocks, and by using simulations from models calibrated to match microdata. First, the micro price evidence can be used to derive implications for the monetary policy transmission mechanism through the lens of state-of-the-art price-setting models, which underscore state dependence in decisions to revise prices. Second, estimating the responses of micro prices to structural shocks may help to identify which margins of price adjustment matter for the inflationary consequences of aggregate shocks in the data.

This paper reviews the implications of the evidence on micro price setting for inflation dynamics and monetary policy in the euro area. The next section uses cross-sectional evidence from micro price changes in the euro area to derive implications for the monetary policy transmission mechanism through the lens of state-of-the-art price-setting models, emphasising state dependence in firms’ price-changing decisions. It shows that price setting in the euro area is consistent with a

[1] See the IPN webpage.

limited degree of state dependence and a meaningful Phillips curve relationship. The latter, according to the calibrated models, was also broadly stable for the range of low inflation rates observed in the euro area until 2019. Nevertheless, model-based simulations show that, due to non-linearities in price setting, changes in trend inflation above 5-6% would have significant effects on the euro area Phillips curve. Similarly, shocks to nominal costs larger than 15% would result in non-linear effects on inflation dynamics in calibrated models. In addition to model-based analysis, estimates of the actual response of micro prices to demand and supply-side structural shocks can also help to shed light directly on key aspects of inflation dynamics and monetary transmission. Specifically, such analysis can document which price adjustment margins matter for the inflationary consequences of aggregate shocks in the data. Several PRISMA papers have studied these aspects. Section 3 focuses on the findings in the paper by Gautier et al. (2022), based on the large retail price dataset discussed in Gautier et al. (2023). Section 4 surveys findings from other PRISMA papers that use datasets limited to specific countries or sectors but that enable better identification of drivers of firms' responses to cost shocks and their implications for inflation dynamics.

2 Model-based analysis of euro area evidence on price setting

2.1 Approach and models

One way to infer the slope and possible non-linearities of the Phillips curve relationship of the euro area is to calibrate two structural price-setting models using micro price data. Specifically, this section relies on the following two price-setting models (see Box 1 for more details):

(a) The “information-constrained state-dependent pricing” model of Woodford (2009).

(b) The “logit price dynamics” model of Costain and Nakov (2019).

These two models provide different micro foundations for deviations from full state dependence in price setting with fixed costs for reviewing prices (see the seminal paper by Golosov and Lucas, 2007). Model (a) is a generalisation of the standard full-information model of state-dependent pricing (see, for example, Caballero and Engel, 2007). Specifically, decisions about when to review a firm’s existing prices are made based on imprecise awareness of current market conditions. Imperfect information is endogenised, using a variant of the “rational inattention” theory proposed by Sims (2003, 2006). Model (b) is also a generalised model of state-dependent pricing. Like Woodford’s model, Golosov-Lucas (2007) is nested in this model, as is the benchmark time-dependent Calvo model, as two polar extremes. Within this framework, firms sometimes make mistakes in responding to aggregate and idiosyncratic shocks due to imperfect information processing. It, too, has rational inattention micro foundations, as shown by Matejka, Steiner and Stuart (2019). The main difference compared with Woodford’s model is that firms sometimes also err in their pricing decisions, conditional on adjustment, in addition to the “errors in timing” found in Woodford’s framework.

Box 1
A brief description of the theoretical models calibrated to euro area microdata

Information-constrained state-dependent pricing

The Woodford (2009) model of information-constrained pricing is a general state-dependent pricing model, similar to the “generalised Ss model” of Caballero and Engel (2007). The main difference compared with this model is that the adjustment hazard function is derived from optimising first principles, rather than exogenously imposed. Imperfect information is endogenised using a variant of the theory of “rational inattention” proposed by Sims (2003, 2006). In the model, the timing of price *reviews* is determined by optimisation, subject to an information constraint. It thus allows for the costs of obtaining and/or processing more precise information about the current state (both firm-level and aggregate), between the intermittent occasions on which full reviews of pricing policy are undertaken. When a firm decides to pay the fixed cost required for a full review of its pricing policy, it obtains *full information* about the economy's state at that moment. Hence, when price changes occur, they are based on full information, as in the standard fixed menu cost model. However, *between* such reviews, the firm's information about current economic conditions is less accurate. In particular, the decision *whether to conduct a full review* must be made on the basis of much more imprecise information than will be available after the review is conducted. Therefore, prices do not necessarily adjust at precisely the moment at which they first become far enough out of line for the profit increase from a price review to justify the fixed cost. In other words, firms sometimes err in the "timing" of their price adjustments.

Logit price dynamics

In the Costain-Nakov (2019) model, firms set prices to maximise profits, subject to two types of "control" costs. The first cost is proportional to the level of precision in price setting. The more effort decision-makers devote to the pricing decision, the more accurately the newly set prices reflect fundamentals. The second cost penalises deviations from purely random timing of price adjustment. Since firms economise on this cost, sometimes they forgo profitable adjustment opportunities (generating stickiness), and sometimes adjust prices even though the realised gain from adjustment is relatively small.

In equilibrium, the new prices firms set are distributed *around* their optimal levels, with a dispersion that is inversely related to the effort expended on decision-making. At the same time, prices are sometimes out of line with fundamentals, also because the resulting probability of adjustment is a *smoothly* increasing function of the price gap, rather than a zero-one step function, as in the benchmark "fixed menu cost" model.

The parameters controlling the two price-setting frictions are the two costs in the pricing and in the timing decisions, which are assumed to take different values in principle. Both are expressed in terms of labour time and are multiplied by the wage and subtracted from the flow of profits. The model is otherwise akin to Golosov-Lucas (2007), with firms facing both idiosyncratic productivity and aggregate inflation risk. In fact, the Golosov-Lucas (2007) framework is nested in this model as a limit variant with perfectly accurate pricing and perfectly accurate timing decisions. The Calvo (1983) model is also nested in this model, as the limit with precise pricing but purely random timing.

The Costain-Nakov model is quite similar in spirit to Woodford's. The main difference is that, in the latter model, conditional on a review, prices are set optimally, while on adjustment they are distributed *around* the optimal price in the former model. Hence, Woodford's model features "errors in timing" only, while the Costain-Nakov model has both errors in timing and "errors in pricing".

2.1.1 Calibration to euro area micro price data

To calibrate the two price-setting models, we use data on frequencies and the size distribution of price changes in the euro area. Specifically, to capture the heterogeneity in price setting in the euro area documented in Gautier et al. (2022), the two models are calibrated with data from the following three sectors: (1) food (combining processed and unprocessed), (2) non-energy industrial goods (NEIG), and (3) services. Energy prices are not included in the micro price dataset; this limits sectoral heterogeneity, for example in comparison with Gautier and Le Bihan (2022).[2] To derive implications for aggregate inflation (excluding energy), the three sectors are aggregated using the following weights based on the euro area HICP: 0.2405 (food), 0.2973 (NEIG) and 0.4622 (services). The monthly adjustment frequencies in the data are shown in Table 1, while Chart 1 shows the distribution of price changes for the three sectors (excluding sales prices). It is apparent that the sectors are quite heterogeneous in terms of price-setting features, even when excluding sales: for example, the repricing rate in the food sector is more than double that of NEIG and services (see also the discussion in Gautier et al., 2022).

Table 1
Sectoral monthly frequencies of price changes (excluding sales)

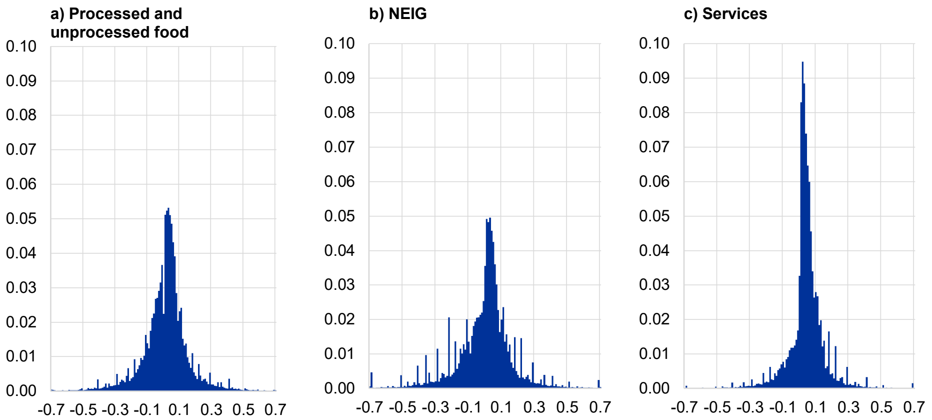
(share of prices changing each month)

Sector	Frequency
Processed and unprocessed food	13.6%
NEIG	6.4%
Services	5.7%
Overall	7.8%

Source: Gautier et al., 2022.

Chart 1
Empirical distribution of non-zero price changes by sector

(percentage points)



Source: Gautier et al., 2022.

We calibrate the two models by minimising a distance criterion comprising the frequencies of price adjustment in each sector, as well as each sector's histogram of price changes excluding sales.[3] The sectoral repricing rates are matched perfectly, which is important, since they have a first-order effect on the simulation results. The food and NEIG sectors' histograms are matched better than the services histogram,

2 This paper calibrates a rich multi-sector model to French microdata, finding that accounting for sectoral heterogeneity is crucial to capture the monetary transmission mechanism.

3 The histograms comprise 140 equally spaced bins between -0.70 and +0.70 log points of price changes.

which shows the highest kurtosis (i.e. its probability mass is more concentrated around the mean, but with "fat" tails with much larger price changes).

2.2 Macroeconomic implications for small and large aggregate shocks: the Phillips curve and non-linearities

Given the models and the calibration, it is possible to trace the implications of each framework for the Phillips curve and to identify potential non-linearities in its slope due to changes in trend inflation and large shocks. One way to characterise the Phillips curve is to compute the theoretical equivalent of the Phillips multiplier in Barnichon and Mesters (2021), defined as the ratio between the areas under the inflation and unemployment impulse responses to a monetary policy shock. The higher the ratio in absolute terms, the greater the effect on sectoral inflation of a 1% fall in sectoral unemployment over the horizon considered. At 2% trend inflation for a 24-month horizon, the ratios shown in Table 2 are obtained (Chart 2 shows that the absolute value of the multiplier does not vary much across horizons between six and 24 months, see also Box 3).

Table 2

Phillips multipliers by sector

(ratios of the areas under the impulse responses of inflation and unemployment over a 24-month horizon)

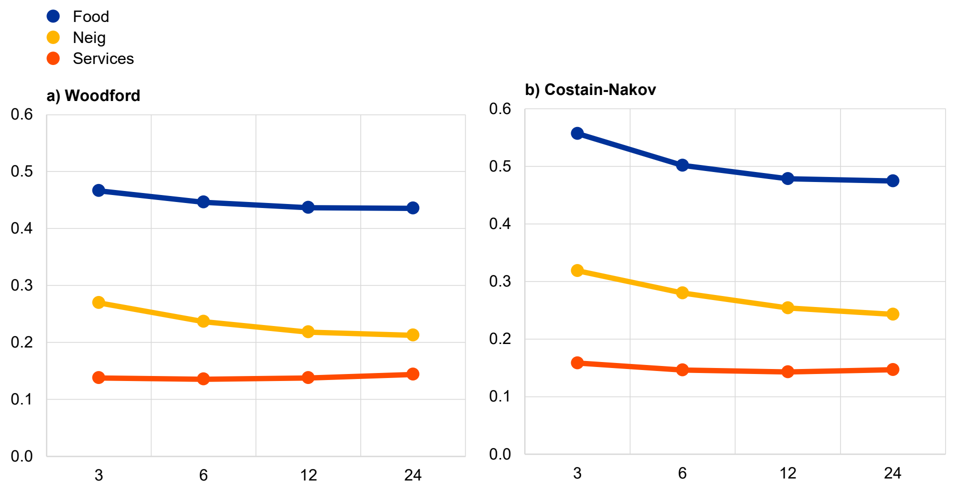
Model/Sector	Food	NEIG	Services	Overall
Woodford	-0.4353	-0.2126	-0.1437	-0.2343
Costain-Nakov	-0.4748	-0.2430	-0.1469	-0.2543

Source: ECB calculations.

Chart 2

Phillips multipliers by sector and horizon at 2% annual trend inflation

(percentage points)



Source: ECB calculations.

The Phillips multipliers differ substantially across sectors, with inflation reacting less to unemployment in services than in food and NEIG, while the aggregate multiplier is close to the NEIG multiplier. The sectoral heterogeneity in price setting translates into heterogeneity in the Phillips multipliers. The lower multiplier in services reflects both the lower repricing rate and the lower degree of state dependence implied by the price-change distribution. Nevertheless, the aggregate Phillips multiplier for the overall economy is close to the multiplier for the NEIG sector, even though the 6.4% repricing rate in this sector is lower than the 7.8% aggregate rate. At a value of -0.23 to -0.25 across models, the theoretical Phillips multiplier implies that, in order to increase aggregate inflation (excluding energy) by 1% on average over two years, it is necessary to decrease average unemployment by around 4 percentage points in the same period. The results in Box 3 can also be used to derive the implied slope (κ) of the structural Phillips curve. Given a scale factor of around ten in both calibrated economies, the implied structural slopes are between -0.023 and -0.025. These values are larger than the implied slope, based purely on the calibrated 7.8% monthly frequency of price changes (abstracting from real rigidities). This stems from the implicit degree of state dependence, in line with the results of Auclert et al. (2021) on the Phillips curve in state-dependent models.[4] The Costain-Nakov model has a slightly steeper Phillips curve slope than Woodford's model, as on adjustment, prices are set around, rather than exactly at, their optimum level. This means that, in response to an inflationary shock, a larger mass of firms is pushed towards the steeper part of the adjustment hazard function, increasing the selection effect and the effective degree of price flexibility.

The calibrated state-dependent models allow the degree of non-linearities in the inflation dynamics implicit in the micro price data of the euro area to be inferred. We distinguish two types of non-linearities in the Phillips curve: (1) for increasing trend inflation rates; and (2) in response to nominal shocks of increasing size.

2.2.1 Model-based non-linearities under increasing trend inflation rates

The repricing rate is predicted to increase with higher trend inflation, resulting in a steeper Phillips curve and a more rapid inflation response to demand and supply-side shocks. One feature of state-dependent pricing models is that price setting depends on the level of expected and actual trend inflation (see the recent paper by Alexandrov, 2021). The higher the trend inflation, the higher the repricing rate, as unchanged prices are eroded over time, deviating from their desired level even absent other cost shocks. Moreover, effective price flexibility also increases, since firms respond more to shocks that raise their costs, as they factor in the higher rate of trend inflation expected to prevail in the future. Table 3 reports the 24-months Phillips multiplier for annual trend inflation rates of between 0% and 10%, together with the associated repricing rates. As trend inflation rises, the Phillips curve

[4] The value of κ in the standard Calvo model based on a 7.8% monthly repricing rate would be around -0.007.

becomes steeper, as shown by the Phillips multiplier, which almost doubles in absolute terms, from -0.23 to -0.25, to -0.37 to -0.40. Demand shocks, such as monetary policy impulses, are transmitted more rapidly to inflation, and their real effects diminish. Note that the relatively rapid increase in the Phillips multipliers is accompanied by only a limited rise in the overall adjustment frequency, shown in the last two rows of Table 3. Not only is this due to the repricing rate entering the Phillips multiplier non-linearly (see Box 3), but it also suggests higher effective price flexibility, since selection effects are also intensified as trend inflation rises, as discussed above. Support for the mechanism underlying this non-linearity is found in US data by De Veirman (2022), who finds an empirical link between changes in the repricing rate and the slope of the Phillips curve (see Box 2 below).[5]

Table 3

Phillips multipliers and frequencies at increasing trend inflation rates

(ratios of the areas under the impulse responses of inflation and unemployment over a 24-month horizon)

Model/Trend inflation	0%	2%	4%	6%	8%	10%
Phillips multiplier						
Woodford	-0.2240	-0.2343	-0.2665	-0.2989	-0.3344	-0.3666
Costain-Nakov	-0.2445	-0.2543	-0.2864	-0.3201	-0.3569	-0.3964
Predicted frequencies						
Woodford	7.8	7.9	8.1	8.3	8.5	8.7
Costain-Nakov	7.6	7.7	7.9	8.1	8.3	8.5

Source: ECB calculations.

Box 2
Evidence on time variation in estimates of the slope of the US Phillips curve

In sticky price models, inflation is more sensitive to aggregate demand fluctuations when firms change their prices more frequently. These models imply that the slope of the short-run Phillips curve depends positively on the frequency of price adjustment.

De Veirman (2022) empirically examines how the Phillips curve slope depends on the frequency of price adjustment in the United States between the first quarter of 1979 and the fourth quarter of 2016. The paper detects a statistically significant positive relationship between the slope and the frequency when using trimmed mean consumer price inflation, while the relationship is insignificant for other standard inflation measures. This is reminiscent of the finding of Ball and Mazumder (2019, 2021) that, in the United States and in the euro area, the Phillips curve slope is more precisely estimated when they measure core inflation by median inflation, rather than by inflation excluding food and energy. They argue that median and trimmed mean inflation are better at filtering out transitory fluctuations in relative prices than measures of inflation excluding food and energy. This may explain why, in De Veirman (2022), the Phillips curve with trimmed mean inflation has an excellent fit and relatively tight confidence bands around the coefficient estimates, which

[5] This is different from the non-linearities in recessions versus expansions at low inflation rates found by Forbes et al. (2021) for reduced-form Phillips curves in the United States and other advanced economies. Hazell et al. (2021) also find that post-1990s point estimates of the slope of the Phillips curve are lower than in previous periods.

makes it easier to detect a relationship between the Phillips curve slope and the price adjustment frequency.

An extensive body of literature finds that, in several countries, the Phillips curve has flattened relative to the 1970s and 1980s. See, for example, De Veirman (2009), Ball and Mazumder (2011) and Blanchard, Cerutti and Summers (2015). The results from De Veirman (2022) are consistent with the interpretation that the US Phillips curve has flattened endogenously, as a result of declining repricing rates.[6] His findings suggest that the US Phillips curve slope has mostly been close to zero since the late 1990s, due to relatively infrequent price adjustment at that time. For the period from the Great Recession onwards, this is consistent with the fact that inflation has remained stable, notwithstanding a long sequence of negative output gaps.

When allowing for a non-linear relationship between the Phillips curve slope and the frequency of price adjustment, De Veirman (2022) finds that, empirically, this relationship is convex. In other words, the slope is more sensitive to price adjustment frequency when many firms adjust their prices. In this respect, the data are in line with the New Keynesian Phillips Curve (NKPC), which is derived from a standard New Keynesian model with nominal rigidities, as in Calvo (1983).

However, the slope of the empirical Phillips curve is much flatter than that of the theory-based NKPC, which assumes the same empirical price adjustment frequencies, while other structural parameters are set to standard values. This finding suggests that relying only on empirical repricing rates to gauge the short-run response of inflation to aggregate demand fluctuations would result in overestimation (see also Section 3).

2.2.2 Non-linearities under large nominal shocks

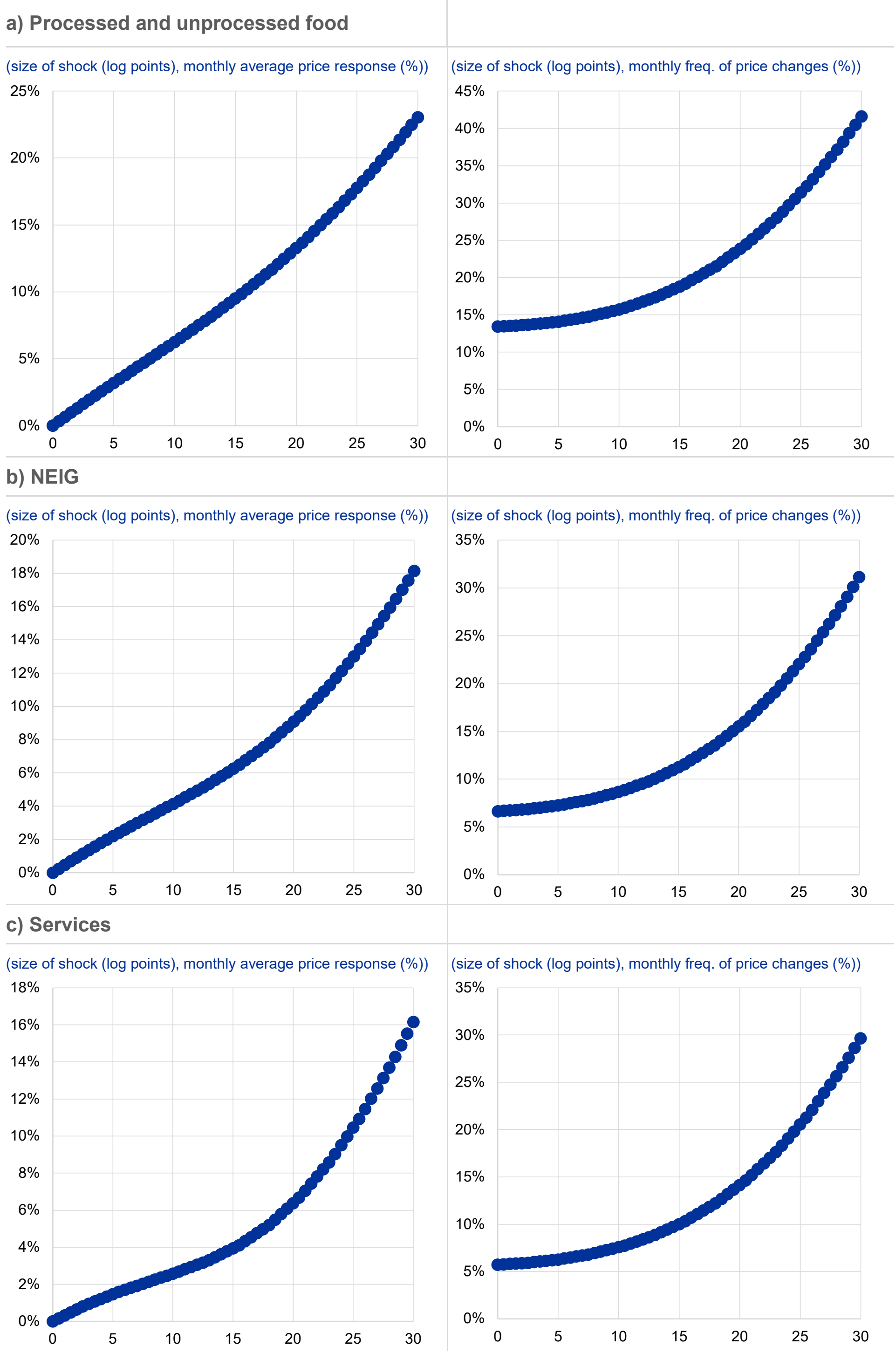
According to the models calibrated to the euro area, nominal shocks need to be relatively large to have non-linear effects on inflation dynamics. One feature of state-dependent pricing models is that the greater the shocks to nominal costs, the more misaligned the unchanged prices, resulting in more frequent price adjustment and larger price changes. Therefore, in a more volatile macroeconomic environment, effective price flexibility should increase under state-dependent price setting. Chart 3 below shows how inflationary effects and adjustment frequencies change in response to once-and-for-all nominal shocks ranging in size from 0 to 30 log points (0 to 35%) (as a reminder, see the finding of Gautier et al., 2023, that the median price increase in the euro area, excluding sales, is around 7%). For all three sectors, the first-year inflationary effects (calculated as the average increase in the price level over this period) increase approximately linearly with the size of the shock for sizes of 0 to 15 log points (around 15%). Just over this threshold, the price response starts rising at a somewhat faster rate, as larger shocks to nominal costs have increasing inflationary consequences. The frequency of repricing is initially rather flat, but then rises steadily. Nevertheless, the limited effects on repricing rates

[6] Other papers documenting a flattening Phillips curve include Blanchard (2016), Del Negro, Lenza, Primiceri and Tambalotti (2020) and Okuda, Tsuruga and Zanetti (2021). See Costain, Nakov and Petit (2021) for an explanation of this flattening based on a state-dependent pricing model.

for shocks below 5% are consistent with the evidence in Gautier et al. (2022) of small cyclical fluctuations in this statistic in the euro area in the period 2005-19.

Chart 3

Effects of nominal shocks of increasing size across sectors



Source: ECB staff calculations.

2.2.3 The return of inflation and non-linearities in price adjustment: some preliminary evidence for 2022

Since 2022, due to the supply chain disruptions caused by the coronavirus (COVID-19) pandemic and the major shocks caused by the Ukraine war, inflation has risen sharply in all euro area countries. This period of more volatile and higher inflation allows us to investigate further the presence of non-linearities in repricing rates and to understand better the transmission of such large shocks to inflation.

However, the micro price data underlying HICPs and producer price indices (PPI) in the euro area countries are not yet available for 2022. To investigate how features of price adjustments change with higher inflation, we rely on various data sources and previous findings from the academic literature documenting pricing patterns in a period of high and more volatile inflation.[7]

A few papers have documented the features of price adjustment in the mid-1970s and 1980s, when inflation was high and more volatile. Wulfsberg (2016) and Nakamura et al. (2018) have provided several results on price adjustment patterns using CPI micro price data in Norway and in the United States, contrasting the mid-1970s and 1980s with more recent periods, when inflation was lower and less volatile. They both show that the frequency of price adjustment correlates much more strongly with inflation when the inflation rate is high and more volatile than when inflation is low and relatively stable. In contrast, the absolute size of price increases did not rise with inflation in the United States, while Wulfsberg (2016) even found that the absolute size of price changes decreases with inflation. Results from other countries during periods of hyperinflation, such as Argentina (Alvarez et al., 2018) and Mexico (Gagnon, 2009), corroborate these findings. Overall, when trend inflation is higher than 5%, the correlation between frequency and inflation becomes stronger.

Firm-level business surveys could provide timely information on the frequency of price adjustment in 2022. For example, every month, Banque de France collects qualitative information from business leaders about their price decisions. This survey is conducted among several thousands of firms of all sizes, in the manufacturing sector and also in business-to-business services.[8] **Chart 4** below shows the evolution of the frequency of firms reporting price increases and decreases in the period 2012-22. In the low-inflation period, the overall frequency of firms reporting price changes was broadly constant, while the frequencies of price increases and price decreases moved in opposite directions, consistent with the findings of Gautier et al. (2022, 2023) for both CPI and PPI microdata. Since inflation was higher and more volatile in late 2021 and early 2022, the share of firms reporting price changes has been steadily rising across all sectors, including services. The peak frequency of firms changing prices in April 2022 was close to 50% in the manufacturing sector

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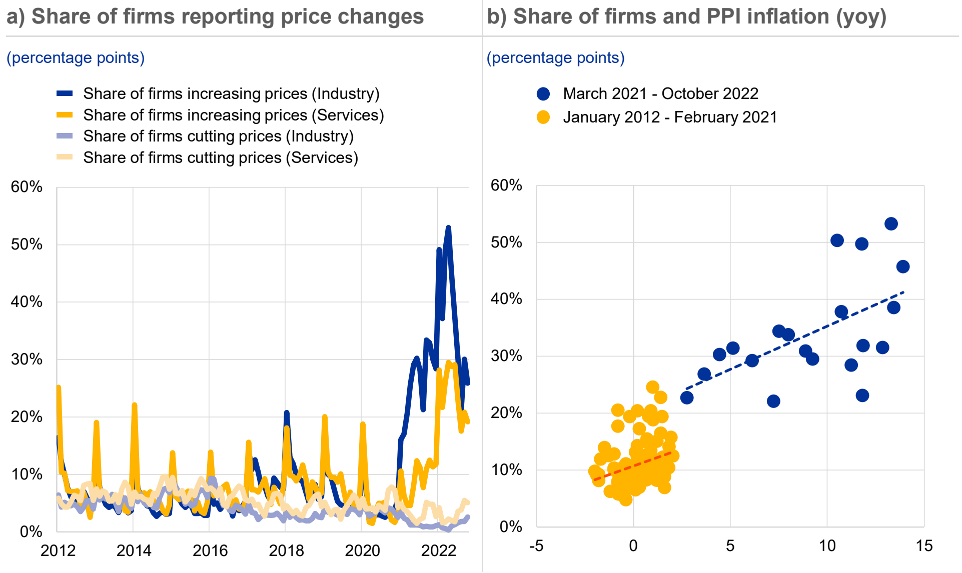
7 For the period 2020-21, Henkel et al. (2023) also provide detailed evidence on how large economic shocks induced by the COVID-19 period have affected pricing patterns in several euro area countries.

8 Loupias and Sevestre (2013) and Harris et al. (2020) have documented several facts on price stickiness using these survey data.

and 30% in business services, ranging between 10% and 15% in the period 2012-21 (compared with an average monthly frequency of price changes in the French PPI of around 27%). This increase in the frequency of price changes by firms is mainly driven by a sharp rise in price increase frequency. Overall, in the manufacturing sector, the frequency of price changes moves more closely in line with inflation when PPI inflation is higher than 4% to 5%.

Chart 4

Share of firms changing their prices in French business survey and PPI inflation



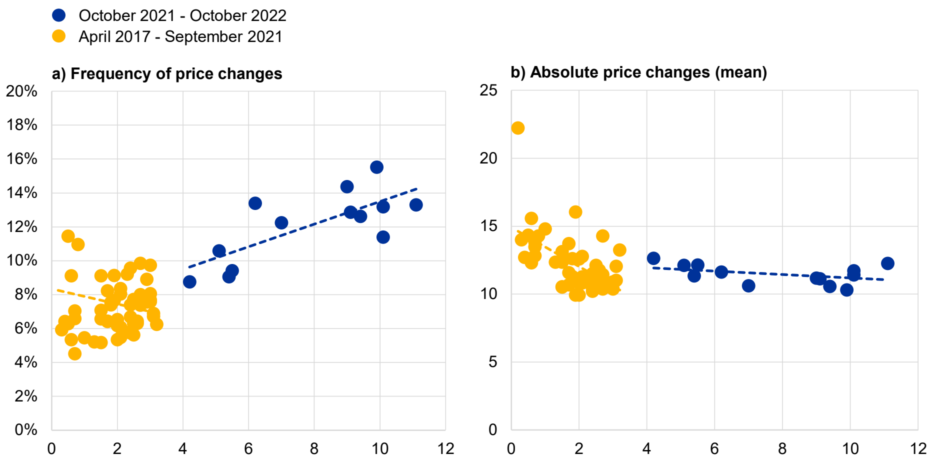
Source: Banque de France monthly economic survey (Enquête Mensuelle de Conjoncture – EMC), manufacturing sector and business services, all firm sizes. Answers to the qualitative question about past evolution of firms' own prices over the last month.
Note: Share of firms changing prices on vertical axis; months and 12-month French PPI inflation on left-hand and right-hand horizontal axes, respectively.

In the United Kingdom, CPI microdata document the frequency and size of price changes in the recent period. The UK microdata underlying the CPI are released monthly with the publication of price indices, allowing for the timely computation of standard price-setting statistics. **Chart 5** plots the frequency of price changes in the United Kingdom before and after 2022 against CPI inflation. In line with evidence for the euro area, when inflation is low, the frequency of price changes is only weakly correlated with inflation. When inflation exceeds 4% in 2022, the frequency of price adjustments is much more strongly correlated with inflation. As regards the absolute size of the price changes, we do not find a strong correlation in 2022 or in prior periods. This evidence suggests that retailers update their prices more frequently when inflation is higher, which should accelerate the response of inflation to macro shocks, other things equal.

Chart 5

Frequency and size of price adjustment in the United Kingdom versus CPI inflation (2017-22)

(percentage points)



Source: ECB staff calculations based on Office for National Statistics (ONS) data.

Overall, the return of higher and more volatile inflation seems to be associated with higher price-change frequencies, mainly because the frequency of price increases rises with inflation. Conversely, there is no consistent evidence that the absolute size or dispersion of absolute price changes moves with inflation. In higher inflation periods, either due to larger shocks or higher trend inflation, aggregate factors become an important motive for price changes, as predicted by state-dependent price-setting models. This provides some empirical support that large shocks or higher trend inflation would help to accelerate inflation dynamics and the transmission of nominal shocks to inflation in line with the above simulation results.

3 Implications for monetary transmission of the responses of retail micro prices to macroeconomic shocks

Evidence on the actual response of micro prices to aggregate shocks can also help to shed light directly on key aspects of inflation dynamics and monetary transmission. The previous section used cross-sectional evidence from micro price setting to derive key implications for the monetary policy transmission mechanism, through the lens of state-of-the-art price-setting models, focusing on the Phillips multiplier. Nevertheless, studying the actual response of micro prices to structural shocks can help to document which price adjustment mechanisms are key for inflation dynamics. Several PRISMA papers have studied these issues. This section focuses on findings based on the large retail price dataset in Gautier et al. (2023). The next section will survey results from other PRISMA papers, using datasets that are limited to specific countries but enable better identification of how firm-level costs affect prices.

Building on the evidence on conditional price adjustment to structural shocks, including monetary policy shocks, provides empirical estimates of the Phillips multiplier. The Phillips multiplier introduced in the previous section operationalises empirically the link between economic slack and the aggregate price level and inflation underpinning the theoretical Phillips curve, and the monetary transmission mechanism in sticky price models (see Box 3). Moreover, using estimates of the impulse responses of average reset prices conditional on structural shocks, it is possible to disentangle the role of nominal and real rigidities in shaping inflation dynamics. It is well known that, in the workhorse Calvo model, the dynamics of the aggregate price level h periods after a shock occurring is given by the following equation:

$$p_{t+h} = (1-\theta)p_{t+h-1} + \theta p^*_{t+h},$$

where p* is the average "reset" price conditional on the shock (defined as the cross-sectional average of all non-zero price changes in response to the shock in each period t+h), and θ is the repricing rate in each period. Clearly, the lower the repricing rate θ, and thus the more pervasive the nominal rigidities due to price stickiness, the smaller and slower the response of the aggregate price level to shocks buffeting reset prices. For the typical aggregate shock, substantially smaller than idiosyncratic shocks affecting micro prices, this equation provides a good approximation of the effects of aggregate shocks independently of the degree of state dependence, since movements in the repricing rate do not respond significantly (see, for example, Costain and Nakov 2012). Nevertheless, the response of the reset price p* can still provide important clues on the relevance of state dependence since it reflects the strength of the selection effect. In other words, when state dependence results in a strong selection effect, firms that revise their prices should react very sharply in the short run, as the main drivers of price changes are relatively large idiosyncratic shocks of the same sign as the aggregate shock. For example, in the first few periods after an expansionary monetary policy shock, price changes will mostly reflect large and positive idiosyncratic shocks to firms' costs, which are the key determinant of repricing decisions. These "selected" price changes will show sharp increases on average, much greater than the marginal effect on firms' costs of the monetary easing itself.

Analysing reset prices is useful in understanding the transmission mechanism since they provide information on real rigidities. This is particularly true when selection effects are small, as in this case idiosyncratic shocks do not have much effect on the average response of reset prices to macroeconomic shocks.[9] Since reset prices depend on firms' current and expected marginal costs and mark-ups, their conditional responses may provide crucial evidence on the role of real rigidities in shaping the propagation of monetary policy and other structural factors, beyond nominal rigidities and price stickiness. Real rigidities broadly indicate all the channels through which measures of slack, such as unemployment or the output gap, affect marginal costs, mark-ups and thus reset prices. As argued by Bils et al. (2012), real rigidities play a crucial role in making the Phillips curve very flat in most estimated dynamic stochastic general equilibrium (DSGE) models used for policy analysis. Specifically, in the case of an expansionary monetary policy shock, a reset prices response that builds up gradually over time could be due to the slow propagation of the monetary stance into nominal cost pressures, owing to the sluggish reaction of wages to the monetary stimulus or of other input costs, working through the supply chain and via second-round effects (a channel dubbed "pipeline pressures": see, for example, Rubbo, 2020, and Smets et al., 2019). Alternatively, it could be due to reluctance on the part of repricing firms to set their new prices above those of competitors that have not yet decided to change their prices, temporarily accepting lower mark-ups (a channel dubbed "firms' strategic complementarities": see, for example, Nakamura and Steinsson, 2010). Finally, a slow reset price response could also be due to information frictions that cause firms to act "myopically", for example, by preventing repricing firms from accurately forecasting the effects of the monetary policy (or aggregate demand) shock on their own future costs and demand conditions (see, for example, Sims, 2008).[10] By slowing down the response of reset prices to cost changes, real rigidities are crucial in accounting for a relatively flat Phillips curve, in addition to nominal rigidities, even under state-dependent pricing (see, for example, Gertler and Leahy, 2010). However, nominal rigidities are often necessary for real rigidities to matter. This is particularly true in the cases of pipeline pressures and mark-up adjustment above (due to firms' strategic complementarities). Under both mechanisms, repricing firms delay full adjustment of their new prices as they "wait" for adjustment by suppliers or competitors that have not yet changed their prices. Moreover, the role of real rigidities may differ across shocks and thus account for different prices and inflation dynamics (see, for example, Mackowiak and Smets, 2008). For example, strategic complementarities at the firm level may imply a

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9 In general, state dependence implies that it is necessary to correct for selection bias in reset prices: for example, following the approach of Dedola, Kristoffersen and Zuellig (2023).

10 Real rigidities may thus affect the link between measures of slack, such as unemployment and marginal costs (e.g. sticky wages), and how marginal costs translate into price changes (e.g. mark-up adjustment).

different response to idiosyncratic and macro shocks, whereas the latter affect all competitors. Otherwise, very large shocks to which most firms adjust can attenuate the desire to "wait" for adjustments by others, thus reducing the degree of strategic complementarity and increasing the size and speed of price responses.

Nominal and real rigidities in the euro area can be assessed empirically on the basis of estimates of the responses of both aggregate inflation and reset prices inflation, conditional on the structural demand shocks used in Gautier et al. (2022). Specifically, Gautier et al. (2022) estimate the response of cumulative inflation and of some decompositions of cumulative inflation[11] to the following structural shocks affecting changes in aggregate demand: a) monetary policy shocks obtained from Jarocinski and Karadi (2020); and b) global demand shocks obtained from Baumeister and Hamilton (2019). Following Barnichon and Mesters (2021), these two shocks can also be used to estimate Phillips multipliers for aggregate inflation and, extending the methodology of these authors, for reset price inflation as well. As discussed in Box 3, the Phillips multiplier for reset price inflation can provide evidence on the contribution of real rigidities to a relatively flat Phillips curve in the euro area. Nevertheless, the Phillips multiplier for reset price inflation would not allow us to disentangle the role of the specific channels underlying real rigidities, such as firms' strategic complementarities or information frictions. As discussed in the next section, the identification of these channels separately requires detailed information about firm-level costs or expectations, which is not readily available in matched datasets of firm-level prices.

Box 3
Phillips multipliers and the structural slope of the Phillips curve

The Phillips multiplier was introduced in Barnichon and Mesters (2021). As already observed by these authors, there is a close link between the slope of the Phillips curve in sticky price models and the Phillips multiplier of aggregate inflation. Specifically, the Phillips multiplier is proportional to the structural slope of the Phillips curve (κ) relating inflation to unemployment. This proportionality factor (φ) depends on other structural parameters determining how monetary (or other demand) shocks affect unemployment, under the further identifying assumptions that these structural shocks do not affect natural unemployment or have permanent effects on (expected) inflation. For example, positing that, in response to a monetary shock, unemployment follows a simple autoregressive process (AR(1)) with parameter ρ^u, it is possible to show that the Phillips multiplier over any horizon h is equal to the following expression in a standard Calvo model:

$$PM_h = \kappa\varphi = \kappa\frac{1}{1-\beta\rho^u}$$

where β is the relevant firm-level discount factor. Since Auclert et al. (2021) show that a very broad class of sticky price models, under both time-dependent and state-dependent price setting, yields a Phillips curve with such a structural slope κ for small aggregate shocks, the above result implies

11 Cumulative inflation is constructed at COICOP-5 country level, using the statistics on frequency and size of price adjustment computed from microdata: in particular, inflation from time t-1 to time t for a given COICOP-5 sector in a given country is obtained by multiplying the corresponding frequency of price adjustment by the corresponding average size of (non-zero) price changes. A similar approach is also taken for the other price variables. For more details, see Gautier at al. (2022).

that this crucial parameter can be recovered from estimates of the Phillips multiplier and the proportionality factor, and related to its theoretical counterparts in state-dependent models. An important caveat is that, since the empirical identification of κ relies on using demand shocks, its estimates cannot be used to gauge the effects of supply-side shocks.

Moreover, building on the results of Hazell et al. (2021), either the proportionality factor φ or the slope κ can be estimated directly, without assuming that unemployment conditional on the monetary policy (or other demand) shock necessarily follows an AR (1) or other specific processes. Specifically, the slope κ can be estimated by regressing average inflation on average unemployment over a relatively long time interval t, t+T (and appropriately discounted with an assumed discount factor β), instrumented with monetary policy or any other structural demand shocks (see eq. 15 in Hazell et al., 2021). While micro price data are not strictly necessary to obtain these estimates, their use to compute aggregate inflation ensures a degree of consistency with models calibrated to match their features. Moreover, microdata can be useful to further disentangle the determinants of the slope of the Phillips curve, as we discuss below.

It is well known that the slope κ is, in turn, a function of parameters reflecting both nominal and real rigidities, where the latter are broadly defined as the elasticity of marginal costs (and possibly also mark-ups) to changes in unemployment due to a demand shock (which does not affect natural unemployment). For instance, in the benchmark Calvo model, the following expression holds for κ in terms of deep structural parameters:

$$\kappa = \frac{\big(1-\beta(1-\theta)\big)\theta}{1-\theta}\omega,$$

where ω (<0) indicates the elasticity of marginal cost to unemployment, while θ is the Calvo repricing rate. A lower ω in absolute value implies a lower value of κ and a flatter Phillips curve. Importantly, the parameter ω could be a function of frictions affecting the mapping from unemployment into marginal costs, such as sticky wages, and of frictions affecting the mapping from marginal costs into reset prices, such as strategic complementarities. One way to infer the strength of real rigidities through the value of ω would be to use the above expression for κ, setting θ as equal to the observed repricing rate. However, in the presence of state dependence, the observed repricing rate would underestimate the impact of nominal rigidities, resulting in an overestimation of the elasticity ω for a given estimate of the slope parameter κ. An alternative way to infer the elasticity ω relies on estimating the Phillips multiplier of reset price inflation. It is possible to show that this multiplier can help to identify ω separately and thus provide independent evidence on real rigidities relative to estimates of the Phillips multiplier of aggregate inflation. Intuitively, reset prices depend on current and expected marginal costs (and possibly mark-ups), so the empirical link between the latter and unemployment conditional on a demand shock can be inferred from the data.

Aggregate inflation is very persistent in response to monetary policy and demand shocks, reflecting both the infrequent repricing rate and the slow reaction of reset prices. The rows in **Chart 6** present, for the monetary policy shock and the global demand shock in Gautier et al. (2022), the estimated responses over 36 months of the following variables: i) the aggregate price level (including unchanged prices); and ii) reset prices (including only non-zero price changes). Both variables are based on the micro prices of “core” sectors in the dataset of Gautier et al. (2022) for 11 euro area countries. The above two shocks are normalised so that the monetary policy shock is contractionary, while the demand shock brings about inflationary pressures (shocks in the opposite direction will have symmetric effects by construction). Starting with the first column, depicting the response of the aggregate price level, consistent with the pervasive price stickiness documented in Gautier et al. (2023), the effects of all shocks appear very gradual, building up over time. The effect of the monetary policy shock is less precisely estimated, while the response to the global demand shock is statistically significant at all conventional confidence levels after 12 months.[12] The price-level response is very persistent, peaking after around 20-24 months, and staying broadly constant, with little sign of further acceleration. This is consistent with these shocks having transitory effects on inflation, suggesting no sustained dynamics in wages and other nominal costs in their aftermath. The responses of reset prices in the second column of **Chart 6** help to shed light on the transmission mechanism underlying the inflation dynamics in the first column. Consistent with the micro price evidence discussed in Section 1, when idiosyncratic factors are the main driver of the decision to change individual prices, the typically smaller macro shocks have no material impact on the repricing rate, and affect aggregate inflation mainly by shifting the average of those prices that are reset according to the "normal" repricing rate (indeed, Gautier et al., 2022, show that repricing frequency is not affected by the above monetary and global demand shocks). However, since the latter is low, but positive, in each period, the very limited short-run effects of both shocks on the aggregate price level must then be mainly due to a very subdued average response of reset prices. This implication is borne out by the response of reset prices whose dynamics in both rows are, indeed, very similar to those of aggregate inflation (which, however, also includes zero price changes). On average, reset prices that change after each shock react very little in the short run, and converge rather slowly to their long-run level, only responding in a statistically significant way after 10-12 months. Moreover, the fact that aggregate and reset price inflation stabilise around similar values after roughly two years implies that the medium-term (dis)inflationary consequences of these aggregate shocks are mostly driven by the dynamics in reset prices, and thus by how much firms decide to adjust their prices in the medium term.

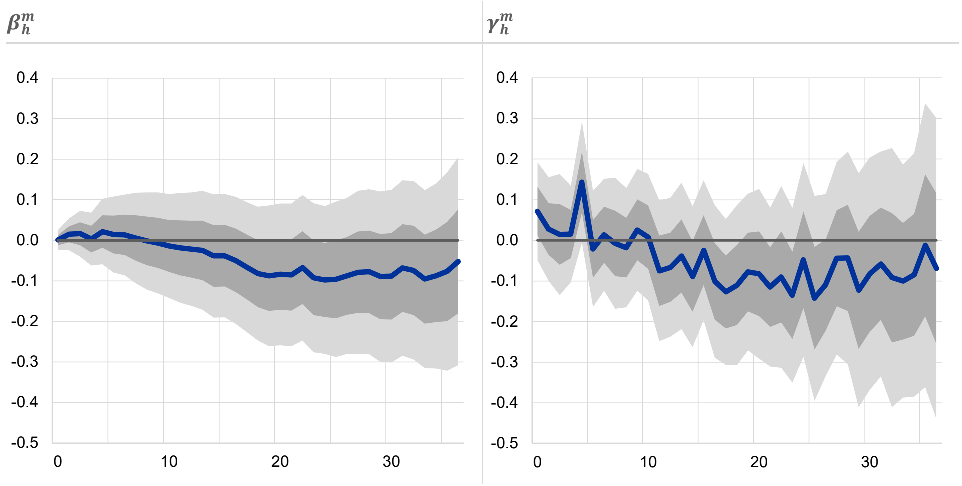
12 Nevertheless, the likelihood that inflation will fall in the 18-24 months after a monetary contraction is around 80%.

Chart 6

Impulse responses of aggregate ($\beta_h^{m,d}$) and reset prices ($\gamma_h^{m,d}$) to a monetary policy and a global demand shock

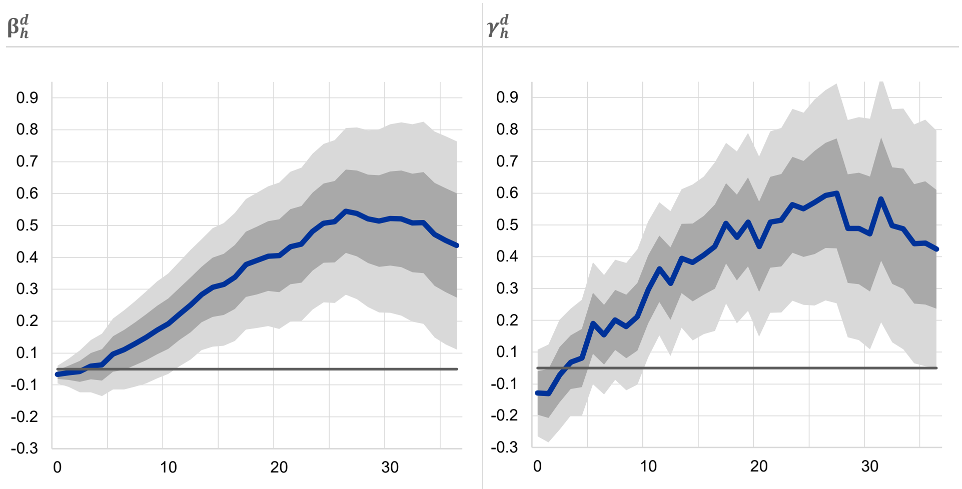
a) Monetary policy shock

(percentage points)



b) Global demand shock

(percentage points)



Source: ECB calculations based on the data and methodology presented in Gautier et al. (2022).
Note: The light and dark grey areas correspond to one and two standard error bands, assuming calendar-based clusters.

The following counterfactual exercise is useful to gauge the effect of the sluggish short-run response of reset prices on aggregate inflation dynamics. We can assume that reset prices jump on impact to p^*, the estimated value at which they converge and stabilise around after the shock, and compute the impulse response of aggregate prices according to a Calvo model for each period h after the shock:

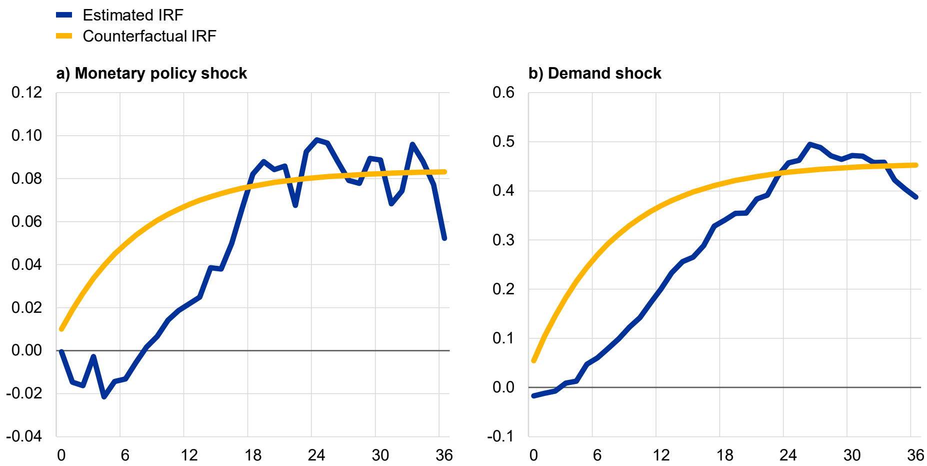
$$p_{t+h}=\left(1-(1-\theta)^{h+1}\right)p^*$$

We calibrate the repricing rate θ to 0.12, the average frequency of price changes in the euro area as estimated in Gautier et al. (2022, 2023), including the sales prices that are used in the impulse responses in the chart, and set p^* to the average of the reset prices impulse response after it stabilises (after roughly 18 months). **Chart 7** shows the results of this counterfactual, together with the point estimates of the impulse response of the aggregate price level already presented in **Chart 6**, where, for ease of comparison, the monetary policy shock (in the left-hand graph) is now normalised to increase prices like the demand shock (in the right-hand graph). The counterfactual tracks the estimated aggregate price dynamics closely after around 18 months, when it amounts to almost 90% of the long-run level of reset prices p^*. However, it entails a much faster dynamic in the short run: after 12 months, counterfactual inflation is larger than actual inflation. This exercise suggests that the estimated subdued response of reset prices contributes to the sluggish reaction of inflation in the short run, in addition to the low repricing rate.

Chart 7

Impulse response functions of aggregate prices, and counterfactual assuming that reset prices jump on impact to their new long-run value

(percentage points)



Source: ECB calculations based on the results in Gautier et al. (2022).

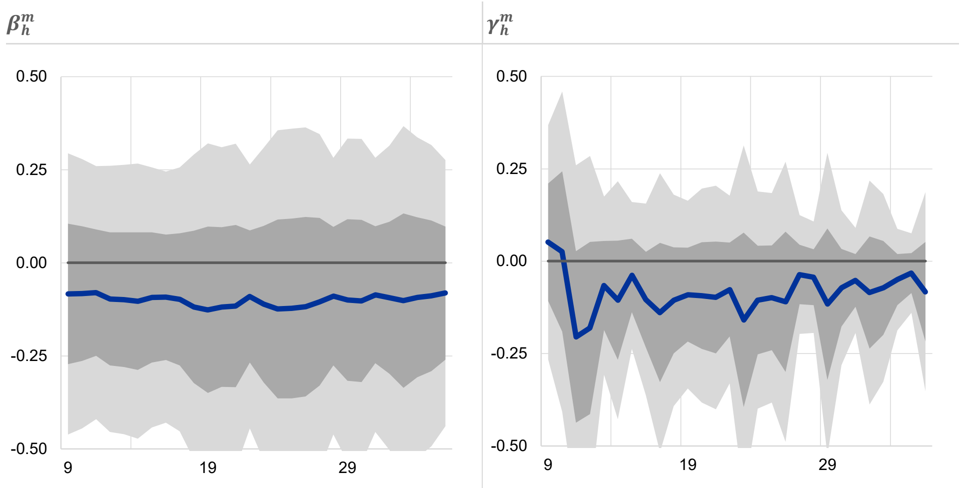
The evidence of a subdued average response of reset prices in the short run is consistent with the model-based results in Section 1 on the limited degree of state dependence and selection in monetary transmission, but also suggests a significant role for real rigidities. A strong selection effect would imply counterfactually large price changes on average in the short run, which would offset, rather than strengthen, the impact of infrequent price changes on aggregate inflation. Moreover, the subdued response of reset prices also suggests that real rigidities, in addition to nominal rigidities, play a significant role in slowing down the propagation of demand shocks into inflation. This sluggish response by reset prices to aggregate shocks stands in stark contrast with the evidence of typically large individual price changes shown in Gautier et al. (2023), as well as the volatile unconditional behaviour of reset prices, documented, for example, by Bils et al. (2012) for the US economy. This finding thus provides new direct evidence in support of a key role for real rigidities in the monetary policy transmission mechanism, in line with standard DSGE models used for policy analysis, including at the ECB.

Chart 8

Phillips multipliers computed for aggregate and reset prices, with cumulated unemployment instrumented with a monetary policy (β_h^m and γ_h^m) and a global demand shock (β_h^d and γ_h^d)

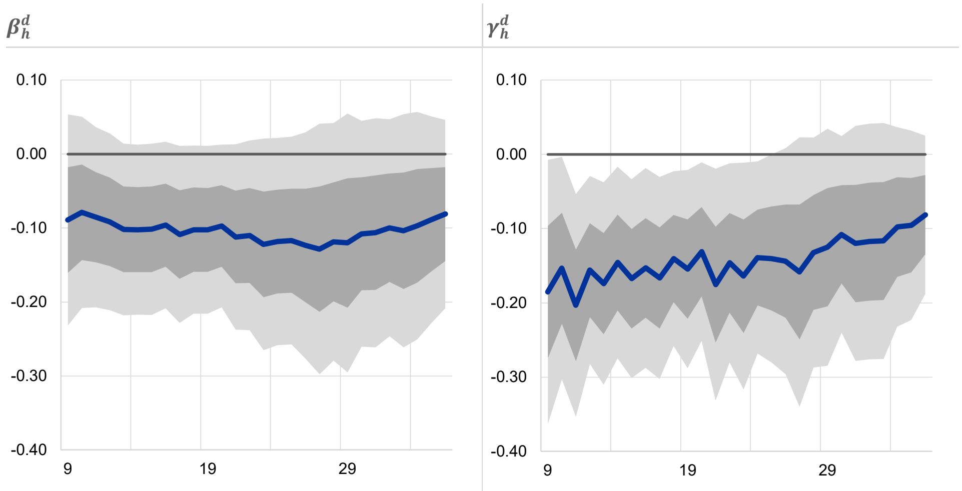
a) Monetary policy shock

(percentage points)



b) Global demand shock

(percentage points)



Source: ECB calculations, based on the data and methodology presented in Gautier et al. (2023).
Note: The light and dark grey areas correspond to one and two standard error bands, assuming calendar-based clusters.

Estimates of the Phillips multipliers enable assessment of the role of nominal and real rigidities in the propagation of monetary policy and global demand shocks in the euro area. Chart 8 shows estimates of the Phillips multiplier for aggregate inflation and reset price inflation[13] from the nine-month horizon onwards, instrumenting the cumulated unemployment with the monetary policy (first row) and the global demand shock (second row). Starting first with monetary policy shocks, the aggregate inflation Phillips multiplier in panel a) of **Chart 8** is estimated to be around -0.1 from the nine-month horizon onwards, similar to estimates in Eser et al.

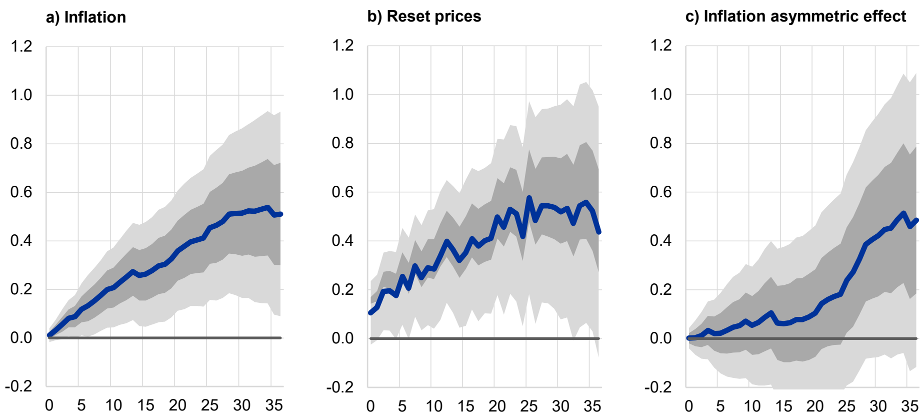
[13] We do not consider the impact period when we cumulate reset price inflation and unemployment.

(2020) based on euro area aggregate data.[14] This implies that, to bring about an average inflation increase of 1% over 12 (or 24) months, average unemployment over the same period needs to be around 10% lower. Clearly, the Phillips multiplier estimated in the data is less than half the model-based multiplier in Section 1, calibrated to the micro evidence on price setting. This suggests that real rigidities, which are not accounted for in the calibrated model in the previous section but are instead a key driver of the actual effects of monetary policy, as discussed above, act to dampen by more than half the effects of slack on inflation. The relevance of real rigidities is also evident in the second column: the Phillips multiplier estimated for reset prices is negative and relatively small, suggesting that the size of price changes also reacts quite sluggishly to the monetary policy shock. In the second row, we report on the same exercise for the global demand shock. These estimates are more precise (they are significantly negative at the 64% confidence level for aggregate inflation and as much as 95% for reset price inflation) and in the same ballpark as the first row.

Chart 9

Impulse responses of inflation and reset prices to inflationary oil supply shocks

(percentage points)



Source: ECB calculations based on the data and methodology presented in Gautier et al. (2023).
Note: The light and dark grey areas correspond to one and two standard error bands, assuming calendar-based clusters.

Reset prices accounted for a more persistent dynamic in response to inflationary oil supply shocks than disinflationary ones, suggesting that their underlying drivers may be a source of asymmetries and non-linearities, in addition to state dependence. Chart 9 shows the estimated responses over 36 months to the oil supply shock in Gautier et al. (2022) of the following variables: i) the aggregate price level (including unchanged prices) in the first column; ii) reset prices (including only non-zero price changes) in the second column; and iii) the asymmetric effects between the response of inflation to inflationary and disinflationary shocks. Specifically, the estimates in the first two columns are obtained for negative oil supply shocks which are inflationary, while the third column shows the difference of the (absolute value of the) inflation response between

[14] As in the case of the impulse response function to a monetary policy shock, the estimates are not significant at conventional confidence levels. Estimates are significant at the 64% level for the global demand shock.

negative (inflationary) and positive (disinflationary) oil supply shocks. In line with the demand shocks discussed above, the first two columns show that inflationary pressures in response to oil supply shocks also build up slowly, reflecting both nominal rigidities and the sluggish response in reset prices. The response of reset prices converges rather slowly to its higher long-run level, even though it is already statistically significant after the first few months. Moreover, the third column shows that the difference in the (absolute value of) price responses to an inflationary and disinflationary oil supply shock is positive and increasing, becoming statistically significant after 24 months.[15] This implies that inflationary oil supply shocks have much more persistent effects than disinflationary ones, and that this asymmetric response is entirely due to the more persistent responses of reset prices (as they drive inflation beyond 24 months). This suggests that the underlying drivers of the latter, reflecting how much firms decide to adjust their prices, may be a source of asymmetries and even non-linearities, in addition to state dependence, in firms' decisions on whether to change prices.

[15] Using daily gasoline price data collected in all gas stations in France, Gautier, Marx and Vertier (2022) show that the reaction of gasoline retail prices to a wholesale price shock does not show any asymmetry.

4 Other micro-based evidence on the determinants of price adjustment

This section reviews other micro-based evidence on the determinants of price adjustment obtained in PRISMA for specific countries and sectors in Europe. These contributions are grouped into the following two strands: a) papers studying the role of state dependence and selection; and b) papers investigating the determinants of adjustment in reset prices and cost pass-through, focusing on specific channels of real rigidities such as firm-level strategic complementarities.

4.1 Further micro-based evidence on state dependence and selection

The evidence of an overall limited degree of state dependence and small selection effects in euro area price setting is directly confirmed by a number of PRISMA studies. Karadi et al. (2022) use supermarket scanner data in the euro area and the United States to estimate the distribution of price misalignments and their relationship with the probability of price adjustments. It uses these objects to assess the contribution of state dependence to the flexibility of the aggregate price level, according to the flexible accounting framework of Caballero and Engel (2007). The estimates imply that price setting is state-dependent in both the euro area and in the United States, but the extent of state dependence is small. The level of monetary non-neutrality predicted by the framework is only 33% higher than in a time-dependent model, which is calibrated to match the frequencies of reference price changes in each region. In another contribution to PRISMA, Dedola, Kristofferson and Zuellig (2023) model state dependence and pass-through jointly using microdata on Danish manufacturers' prices and costs to test for and estimate the strength of selection effects. In support of state dependence, these authors find that energy and import cost shocks affect the probability of price changes. However, they also find that selection contributes little to the aggregate inflation response to these cost shocks.

One set of papers found support for the proposition that not only the repricing rate, but also the kurtosis of price changes, directly related to selection, is important to understand the heterogeneity of monetary policy effects across sectors. A standard prediction of sticky price models is that the repricing rate is a key predictor of the real effects of monetary policy. For instance, Henkel (2020) shows that the output reaction of US manufacturing industries to monetary policy shocks is systematically related to an industry degree of price stickiness. For the euro area, Gautier et al. (2022) show that inflation in sectors with a higher repricing rate reacts more strongly to a monetary policy shock. Recent theoretical literature has shown that, in a broad class of sticky price models under low inflation, the cumulative response of output to a once-and-for-all small monetary shock –

essentially the area under the output impulse response – is proportional to the ratio of the frequency of price changes and the kurtosis of the distribution of (non-zero) price changes (a measure of “fat tails” in this distribution).[16] This ratio is called a sufficient statistic for the real effects of monetary policy. One suggestion as to why these two moments of the price-change distribution do capture the effects of monetary shocks is as follows. If price changes are infrequent, prices will respond slowly to a shock, inducing larger real effects. Thus, the inverse of the frequency of price changes captures the overall degree of price rigidity, a feature which is standard in most sticky price models. For a given frequency of price changes, the patterns of the size of price adjustments also matter. Specifically, if the firms that adjust their prices are those whose prices are very far from their desired value, the price response will be larger and quicker, and the output effect smaller. The kurtosis of price changes turns out to capture this “price selection” effect. Weaker price selection is associated with a higher kurtosis, since the mass of price changes is more concentrated around the mean, with occasional values far from it. For a given repricing rate, this results in a slower response of the aggregate price to a shock and larger real effects of monetary shocks. This price selection effect is maximal in a standard menu cost model, such as Golosov and Lucas (2007), and minimal in a standard Calvo model. In two distinct empirical contributions, Alvarez et al. (2021) and Gautier, Marx and Vertier (2022) test this theoretical proposition using micro price data and find strong supporting evidence for it. Using both consumer and producer price data for France, Alvarez et al. (2021) find that the sectoral price response to a monetary policy shock is proportional to the ratio of kurtosis over frequency of price changes and that both kurtosis and frequency contribute to this result. They also show that the relationship is more robust for producer prices than consumer prices. In the latter case, seasonal sales may explain why the theoretical prediction is less strong than for producer prices.

Frequency and kurtosis of price changes are also closely correlated with the price reaction to cost shocks across gas stations. In Gautier, Marx and Vertier (2022), the empirical test focuses on gasoline retail prices, for which we can observe high-frequency price data and can precisely measure a marginal cost shock. In this case study, where more precise information is available on the kurtosis of price changes and on the reaction of prices to an observed shock, the authors find very robust correlations, not only between the cumulated price response of gas stations and the ratio of kurtosis over the frequency of price changes, but also with both the kurtosis and the frequency of price changes taken separately (**Chart 10**). These correlations are very much in line with the theoretical predictions, and also show that none of the other moments of the price-change distribution correlate as strongly as the frequency and the kurtosis with the cumulated price response. Overall, these two papers show the importance, not only of the repricing rate in understanding the response of prices to a shock to marginal costs across sectors, but also of the kurtosis of price changes, which captures the potential selection effects. This

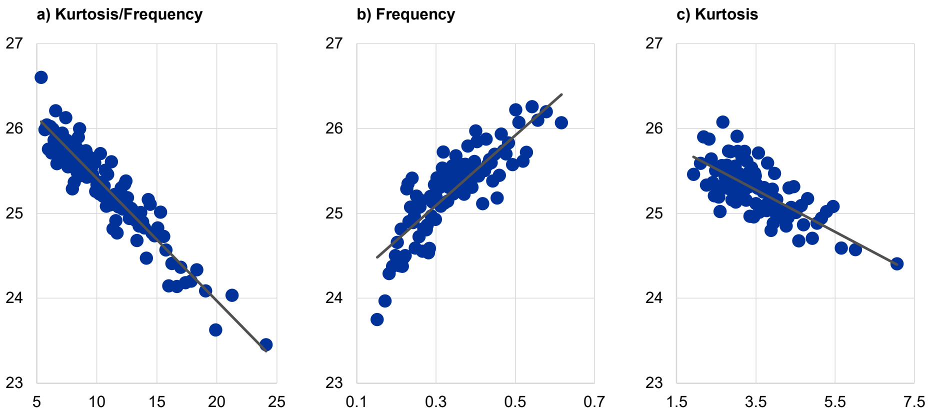
[16] Specifically, kurtosis is the average of the standardised data raised to the fourth power. High values of kurtosis thus arise in two circumstances: a) where the probability mass is concentrated around the mean and the data-generating process produces occasional values far from the mean; or b) where the probability mass is concentrated in the tails of the distribution.

evidence is consistent with the result in Section 2 that state dependence, though limited in the aggregate, is quite heterogenous across sectors in the euro area.

Chart 10

Scatter plots of the cumulative impulse response of prices of gasoline to a cost shock and frequency and kurtosis

(percentage points)



Source: Gautier, Marx and Vertier (2022).
Note: Correlations are calculated across gas stations; statistics are measured for every gas station in France, based on a dataset of daily gasoline prices between 2007 and 2018, collected by the French Ministry of the Economy.

4.2 Micro-based evidence on determinants of pass-through and specific channels of real rigidities

Several PRISMA papers have used microdata to investigate the determinants of cost pass-through and real rigidities. Microdata are key to estimate how firms pass through changes in their costs to prices. Therefore, a few PRISMA papers have merged firm-level price and cost data available for some countries and sectors to obtain precise estimates of pass-through.

A first set of papers has looked at the determinants of pass-through of energy costs, finding evidence in support of pipeline effects. Dedola, Kristofferson and Zuellig (2023) estimate energy costs pass-through due to oil supply shocks by Danish manufacturing firms. As in Gautier et al. (2022), the estimated response of micro prices is slow and builds up over time; this reflects the propagation of the shock through the supply chain from firms more exposed to oil to other firms ("pipeline" effects).

A second set of papers has investigated strategic complementarities at the firm level, finding mixed evidence. Santoro and Viviano (2022) estimate the pass-through of labour costs to prices in Italian microdata. This empirical exercise uses a dataset obtained by merging administrative employer-employee data, firms' balance sheets and a survey on industrial and non-financial service firms conducted every year by Banca d'Italia, which reports information on firms' changes to their prices. To identify the causal relationship, this paper relies on a quasi-natural experiment based on a policy change that occurred in Italy in late 2014, when a substantial, three-year social security contribution cut was announced by the Government for recruitments in the following year. This policy change is interpreted as an exogenous variation in labour costs and related to firms' price changes. The results show that the prices of small firms and firms paying lower wages react to a change in labour costs to a much greater degree than the prices of large firms, supporting the hypothesis that strategic complementarities at the firm level might be at play. Meanwhile, two other papers find opposing evidence of a differential cost pass-through for large versus small firms. The above-mentioned paper by Dedola, Kristofferson and Zuellig (2023) finds that the pass-through of firm-level import costs is very similar across small and large firms (proxied with employment or sales). Dedola, Osbat and Reinelt (2022) find that changes in the corporate tax rates of German manufacturers of supermarket products result in substantial pass-through to retail prices, consistent with producers' market power. Moreover, there is evidence that corporate tax pass-through is significantly larger for producers and retailers with larger market shares

5 Conclusions and policy implications

This paper has analysed the implications for inflation dynamics and monetary policy of the evidence on micro price setting gathered by PRISMA, focusing on model-based and empirical estimates of the structural Phillips curve. In this paper, we have used the cross-sectional evidence on price setting presented in Gautier et al. (2022, 2023) to derive implications for the monetary policy transmission mechanism through the lens of state-of-the-art price-setting models, emphasising state dependence in firms' decisions to change prices. Estimates of the actual response of micro prices to structural shocks, including shocks to the supply side, also help to shed light directly on key aspects of inflation dynamics and monetary transmission, in particular by documenting which margins of price adjustment are key for the inflationary consequences of aggregate shocks in the data.

According to models calibrated to the euro area micro evidence in Gautier et al. (2022, 2023), infrequent price changes and moderate state dependence in price setting should result in a meaningful Phillips curve in the euro area. The model-based analysis shows that price setting in the euro area is consistent with a limited degree of state dependence and a meaningful Phillips curve relationship. The latter has been broadly stable for the range of inflation rates observed in the euro area in the last 15 years.

Sectoral heterogeneity in price setting results in heterogeneous monetary transmission across sectors both in calibrated models and in the data. Consistent with the evidence in Gautier et al. (2022), state dependence in euro area price setting is heterogeneous across sectors, but overall played a limited role in aggregate inflation determination during the low-inflation period. Nevertheless, heterogeneity in state dependence is crucial to account for the heterogeneity in the effects of monetary policy across sectors.

Model-based simulations show that due to non-linearities in price setting trend inflation above 5-6% may have significant effects on the euro area Phillips curve. Non-linearities in price setting associated with state dependence imply that increases in trend inflation above 5-6% would affect the repricing rate and generally price setting across sectors differently, with significant aggregate effects, as summarised by a steeper theoretical Phillips curve.

Similarly, shocks to nominal costs larger than 15% have non-linear effects on inflation dynamics in calibrated models. Non-linearities in price setting due to state dependence can explain the effects of larger business cycle shocks on the repricing rate in the data documented in Gautier et al. (2022), although these shocks have to clear a relatively high threshold for non-linearities to materially affect the transmission mechanism in the calibrated models. Given the relatively stable environment in the period for which microdata were available, however, we have little evidence on the value of this threshold in the euro area data.

Overall, the return of higher and more volatile inflation seems to be associated with higher frequencies of price changes, mainly because the frequency of price increases rises with inflation. In higher inflation periods, either due to larger shocks or higher trend inflation, aggregate factors become an important motive for price changes, as predicted by state-dependent models of price setting. This provides empirical support that large shocks or a higher trend inflation would help to accelerate inflation dynamics and the effects of nominal shocks on inflation, in line with model simulation results.

Empirical estimates of the Phillips curve during the low-inflation period confirm previous findings of a relatively flat but stable slope. We have used demand shocks to estimate the structural slope of the Phillips curve in the euro area, linking core inflation to unemployment as a measure of economic slack. The inflation measure was based on micro price data, thus reducing the incidence of administrative prices or imputations. The structural slope is estimated at -0.013, similar to other estimates for the euro area. Despite being low, such values are still larger than those recently estimated for the United States with similar methodologies.

Such an estimated flat slope reflects both infrequent and subdued price adjustment in response to aggregate shocks, i.e. the presence of nominal and real rigidities. Empirical estimates of the slope of the Phillips curve reflect not only infrequent price adjustment, but also the estimated slow response of reset prices to the small aggregate shocks prevailing in the low inflation period. It is also important to stress that, given the methodology used, linking inflation to unemployment, these low estimates mainly apply to demand shocks and monetary transmission. Supply shocks directly affecting firms' costs may be transmitted at a different speed.

A few PRISMA studies have investigated specific channels through which real rigidities may affect price adjustment, finding mixed evidence. Specifically, the evidence is mixed as to whether firm-level strategic complementarities matter empirically and are stronger for larger firms. This is an important question for future work, since strategic complementarities feature prominently as a driver of real rigidities in the structural models used for policy analysis at the ECB and ESCB. A further important question concerns whether the strength of real rigidities may depend on types of shocks, both at the firm level and in the aggregate.

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Acknowledgements
The authors would like to thank Peter Karadi and Chiara Osbat for valuable comments and suggestions, and Marta Oliva Riera and Stavros Konstantios for outstanding editorial support.

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PDF ISBN 978-92-899-6150-9, ISSN 1725-6534, doi:10.2866/03847, QB-AQ-23-012-EN-N