

Endogenous frequencies and large shocks: price setting in Greece during the crisis.*

Huw Dixon (Cardiff Business School)
Theodora Kosma (Bank of Greece)
Pavlos Petroulas (Bank of Greece)♦

ABSTRACT

We utilize a unique micro price data set for Greece that underpins the Greek CPI. It spans almost two decades, during which Greece suffered a large economic shock. We find that during this time there were significant changes in the pricing behavior of Greek firms. We also find macro-economic developments such as annual inflation and output growth are important factors in determining the frequency and size of price changes. This leads to an intertemporal inflation dynamic linking current inflation to future price behavior and inflation. Utilizing the empirical estimates from the data, we combine a Taylor rule and Euler equation with the inflation dynamic resulting from the asymmetric impact of inflation on the frequency of price increases and the frequency of price decreases. The results of the simulations capture the Greek inflation developments well. Moreover, they also capture developments in the frequency of price increases and decreases seen in other economies and over different time-periods.

JEL classification: E31, E37, C26, C41

Keywords: inflation dynamics, frequencies, prices, microdata.

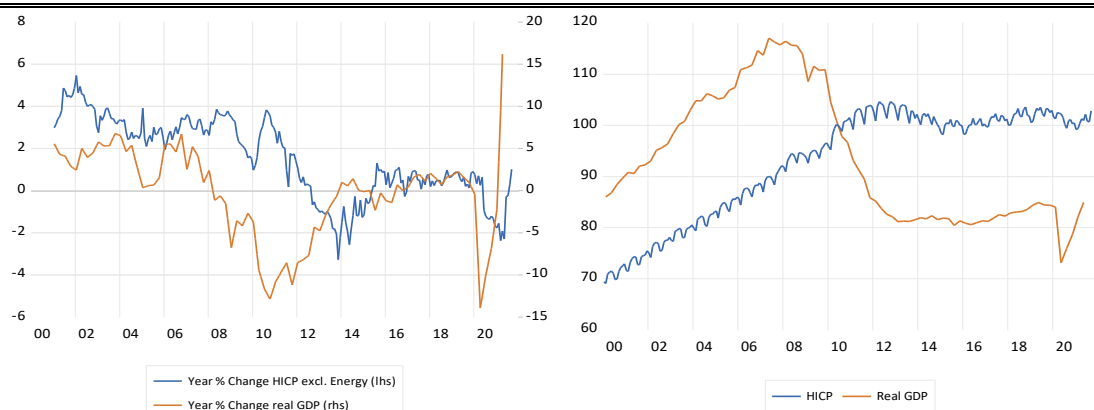
* We are grateful to the Hellenic Statistical Authority for sharing the micro price data and in particular to Argiro Kourtaki and Spiridoula Sideri for sharing their knowledge of the Greek micro data with us. For useful comments and suggestions we would like to thank Dimitris Malliaropoulos, Francesco Lippi, Thomas Zoerner, participants at the ICMAIF conference in Crete on May 2022 and in the PRISMA network workshop in Frankfurt on December 2022. The views expressed in the paper are those of the authors and do not necessarily reflect those of the Bank of Greece.

♦ Corresponding author: Bank of Greece, 21 E Venizelos Ave, Athens, 10250, Greece, Email address: ppetroulas@bankofgreece.gr

1. Introduction

In the period since 2002, Greece has had a unique macroeconomic experience. From the creation of the hard Euro until 2008, Greece enjoyed a period of growth. Like many countries around the world, its output declined, albeit moderately, with the great financial crisis. However, in the wake of the great financial crisis the euro area sovereign debt crisis erupted, which hit Greece strongly. In particular, the economic adjustment programs, or “rescue package”, imposed on Greece in mid-2010, in order to secure a loan large enough to keep the country afloat, exacerbated the economic downturn. At the peak of the crisis in 2013, real GDP had contracted by around 26 percent from its 2010 level. In 2021 it still remains about 25 percent below that level. At the same time wages (both average and minimum) were reduced by more than 20 per cent whilst unemployment increased from a pre-crisis level of around 8 percent to 28 percent. By way of comparison, during the height of the Great Depression in the United States in the early-1930s, real GDP fell by a cumulative 28 percent and the unemployment rate peaked at 25 per cent.¹ Despite the enormous contraction in output, wages and employment, inflation averaged about 0 percent over this period (see Figure 1).

Figure 1: Output and price developments in Greece



Source: Elstat

In this article, we investigate the impact of this large shock on the price setting behavior of firms in Greece. We use, for a first time, a product-level data underlying the Greek consumer price index from January 2002 to March 2020. We will divide our period into two segments: pre-crisis 2002-2010, and post-crisis from 2011 and onwards. The division reflects the imposition of “rescue package” in mid-2010 when the sovereign debt crisis became fully

¹ See G. Tavlás (2019) for a description of the Greek crisis.

evident. It also coincides with the start of the inflation decline. We use the term “post crisis” not to mean after the crisis has ended, but after it started.

We start our analysis of the price setting behavior of firms by considering the whole distribution of price spell durations in the data set. We examine the distribution of durations of price spells (DD) and the corresponding cross-sectional distribution of durations (CSD).² We find that short price spells are produced only by small share of firms and that the duration of the ‘average firm’ to change its price is significantly longer than in other comparable countries. We then proceed by using the Greek price microdata to construct aggregate statistics, such as the share of prices that change in a given month, namely the monthly frequency of price increases and decreases, as well as the average sizes of price increases and decreases. These four statistics determine inflation by a simple identity and enable us to gauge the impact of macroeconomic developments on inflation. We find that: 1) The frequency of price increases is primarily determined by and increasing in the level of annual HICP inflation and growth of output. 2) The frequency of price decreases is primarily determined by and decreasing in the level of annual HICP inflation. 3) The size of price increases and decreases are both influenced by the level of annual inflation and output growth. 4) Inflation in Greece is mainly driven by developments in the relative frequencies of price increases and decreases.

We believe these results are interesting for a variety of reasons. Most importantly, the fact that the current behavior of prices depends on past inflation (reflected in the annual HICP) implies an endogenous dynamic of inflation over time. Higher past inflation will lead to a higher frequency of price increases and lower frequency of price decreases, which will tend to increase current inflation. We find that this endogenous inflation dynamic fits with the data we observe in Greece. In particular, based on the aforementioned findings we set up and simulate a small model where inflation dynamics are endogenous. We find that this endogenous inflation dynamic fits with the data we observe in Greece and is in line with stylized facts in the development of the frequency of price changes observed in other countries, during different time-periods.

The remainder of the paper is structured as follows. Section 2 presents the data set and Section 3 presents the cross-sectional aspect of the data. Section 4 presents time series

² The same information can be summarised as the hazard function or survival function. In this paper, we focus on DD and CSD as being the clearest way to model the data.

evidence on the frequency and size of price changes in Greece and investigates key macroeconomic drivers for frequencies and sizes of price changes. It also presents findings on changes in the distributional aspect on the size of price changes. Section 4 presents a partial model simulation based on results from the empirical analysis, where inflation displays an endogenous dynamic. The simulation is able to replicate key features in the data. Section 5 concludes.

2. The Data

In this study, we utilize a unique data set of micro prices obtained by the Hellenic Statistical Authority (ELSTAT), which is used to compute the national index of consumer prices. It consists of 742 products (or items), across unique outlets at the NUTS 2 level, which translates into 46729 unique product identifiers.³ The data are monthly from January 2002 to March 2020 and unbalanced as the products in the consumer price index change over time. In total, we have more than 8 million price observations, which cover more than 75% of the Greek HICP. Our data does not include most energy prices, prices on fresh fruit and vegetables, seasonal items, centrally collected prices, telecommunication prices and several service related components in particular for transport prices. Furthermore, the price data have been matched to historical VAT rates at the product level. The drawback of the data set is the lack of information concerning product substitution, changes in product metric and information on whether a price observation is a sales-price or not.⁴

A careful examination of the data leads us to the following two 'cleaning' procedures. 1) Very small price changes, of less or equal 0.2%, which are probably due to mistakes or software data approximation differences, are set to 0. This concerns 7,280 observations and changes are mostly at the fourth or fifth decimal of the price. 2) Price changes have been trimmed at the 1st and 99th percentiles given a non-zero price change. This implies that our largest price decrease is 50% while our largest price increase is 100%, which corresponds to a typical

³ The data were originally by 'product names' which have been matched to COICOP 8 level digits using a list on products researched for the HICP index" for the years 2015 and 2010. Products that have not been included in these two lists have been approximated with a relevant COICOP 8 digit by the researchers.

⁴ Product substitution may refer to e.g. the change of the type of outboard motor that is being measured, so we can see a price change from 10000 euros down to 1200 euros between months. Changes in the metric may for example reflect the change in the price collected from a daily full time rate in cleaning services to an hourly rate.

seasonal sale of 50% and its subsequent increase back to its ‘normal’ price.⁵ Finally, In order to identify sales in our data we utilize a filter, which builds on Nakamura and Steinsson (2008a) and has been developed further in Gautier et al. (2022).⁶

We can construct an annual inflation time series using our price-quote dataset, both with and without sales. First, we calculate the price changes for each of the 46729 unique product identifiers and the frequency of price changes is measured as the share of prices that change each month. These frequencies are then weighted using relevant weights ($w_{j,t}$) at some aggregate level. For the relevant aggregation level (COICOP level) j , the frequency in a given month $f_{j,t}$ is simply the (unweighted) proportion of prices that change each month. Thus the aggregate frequency for a specific month is:

$$f_t = \sum_{j=1}^n w_{j,t} \cdot f_{j,t} \quad (1)$$

where n = the relevant number of COICOP levels. Whilst our data is not the full set of price-quotes and excludes some products, in general the aggregate month-on-month inflation is given by:

$$\Pi_t = \sum_{j=1}^n w_{j,t} \cdot \Pi_{j,t} \quad (2)$$

Where $\Pi_{j,t}$ is the geometric average of price relatives (ratios of current price to the previous month) over all price-quotes within the product type. However, if we define $\pi_{j,t}$ as the average price relative excluding 1s, i.e. the average conditional on the price changing, we have

$\Pi_{j,t} = f_{j,t} \cdot \pi_{j,t}$ and hence:

$$\Pi_t = \sum_{j=1}^n w_{j,t} (f_{j,t} \cdot \pi_{j,t}) \quad (3)$$

⁵ The trimming addresses a majority of price changes due to metric changes and due to product substitutions.

⁶ For details on the sales filter see Nakamura and Steinsson (2008b) and appendix A3 in Gautier et al. (2022). The filter performs in a satisfactory manner when compared to NSI flags on sales for other European countries. Filtered data, i.e. excluding sales, contains however usual end-point problems. As such we discard the three last months of our sample.

Both frequencies and price changes can be broken down further into increases (+) and decreases (-) as in Klenow and Kryvtsov (2008):

$$\Pi_t = \sum_{j=1}^n w_{j,t} (f_{j,t}^+ \cdot \pi_{j,t}^+ - f_{j,t}^- \cdot \pi_{j,t}^-) \quad (4)$$

There are potentially four different approaches to the data: unweighted with and without sales, and weighted with and without sales. The unweighted data is constructed with the special case of $n=1$ and $w_{1,t} = 1$

There are thus two questions we need to consider with respect to our micro data: what is the impact of sales on annual inflation and what is the impact of weighting the micro data. In Figures 2A and 2B we depict the annual inflation rates of our series both including and excluding sales as well as the weighted and unweighted data, where the weights are at the COICOP 4 level alongside the official HICP inflation excluding energy. We can see that sales – which are transitory- do not affect aggregate annual inflation.⁷ This is in line with Kehoe and Midrigan (2007) who argue that transitory price changes, such as temporary sales, yield much less aggregate price flexibility than an equal number of permanent price changes.⁸

Figure 2A: Actual and constructed annual inflation, including and excluding sales

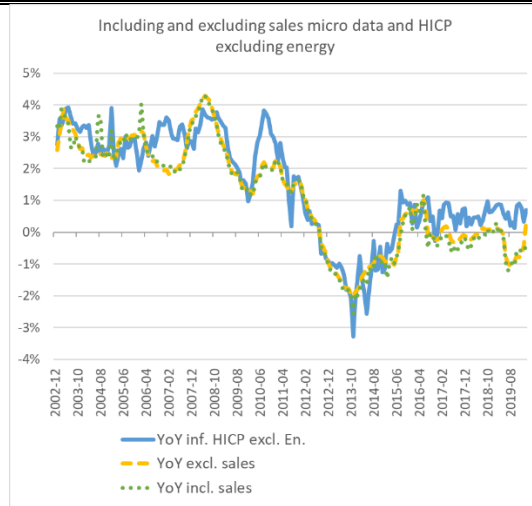
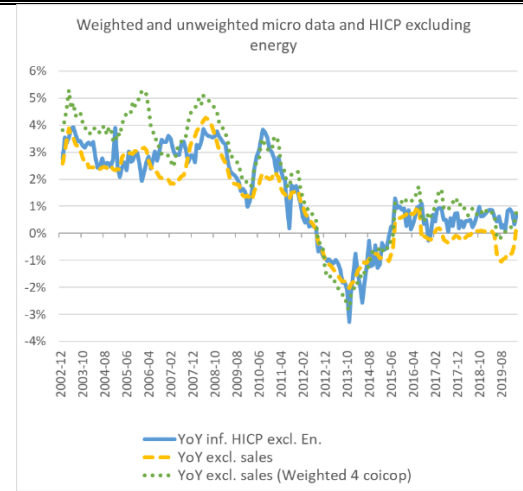


Figure 2B: Actual and constructed annual inflation, weighted and unweighted



Source: Elstat and authors calculations

⁷ As we can see in Figure A2, the constructed month on month inflation including sales is much more volatile after 2013 and over the whole period has a variance over 5 times that of the series excluding sales.

⁸ Even so, Alvarez and Lippi (2020) and Kryvtsov and Vincent (2021) argue, since sales are associated with large volumes of expenditures they can be seen as an integral part of price-flexibility.

We can also see that both the weighted and unweighted series follow HICP inflation excluding energy closely. In fact, the mean absolute error with inflation excluding energy is smaller for the unweighted series than for the weighted. Moreover, there is an imbalance: there are relatively few prices for services, but they have a very big weight. We will thus proceed our analysis using equal weights for our products and with price changes excluding sales.⁹

3. A cross sectional analysis of price changes

When we consider price setting there is often a focus on prices that do change, how many prices change and by how much, as they are the ones ‘producing’ inflation. However, these prices tend to be a minority of the whole spectrum of prices used to measure inflation. One informative way to look at price setting is to focus on the cross sectional aspect of price developments through the properties of price spells and the distribution of duration of price changes. In this way, we can represent better the pricing behaviour in Greece as we take into account both the prices that change as well as the prices that do not change. In particular we can see how long do prices stay fixed on average, how long it takes for the average firm to change its price and how many firms are responsible for a majority of price changes.¹⁰ To do this we need to introduce the concepts of a price-spell and the corresponding distribution of durations (DD) and cross-sectional distribution of durations (CSD).

3.1. Price spells.

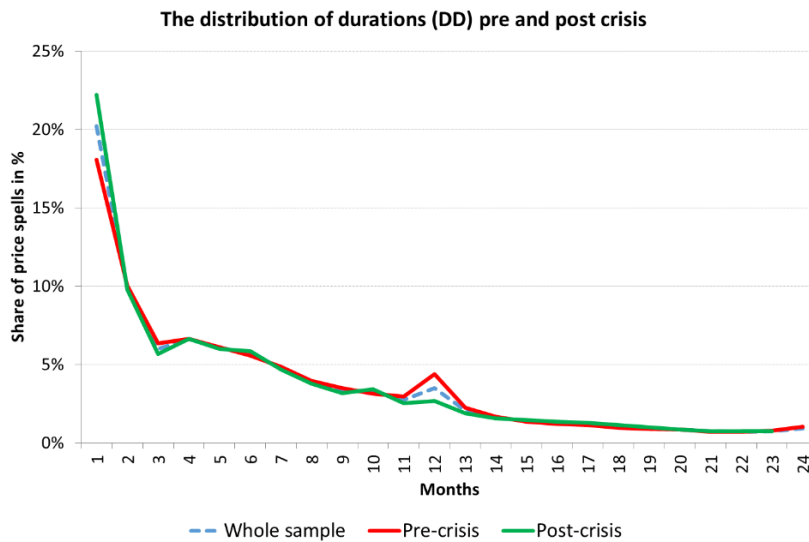
A price spell is a sequence of the same price set by an individual seller for a particular product. In our data there are 746,938 price spells, with an average duration of 10.7 months. This consists of 359,204 spells pre-crisis with an average duration of 11.5 months, whilst post-crisis we have 387,734 spells with an average duration of 10 months. We can see that the average duration decreased after 2011. In Figure 3 we show DD for the whole sample and each sub-period for the first 24 months. The horizontal axis gives the duration of the price spell, and the vertical axis the share of all spells: the distribution DD gives the share for each duration from 1 month to the maximum F months, with shares summing to one and being non-negative.

$$DD = \{\alpha_i^D\}_{i=1}^F : \sum_{i=1}^F \alpha_i^D = 1, \alpha_i^D \geq 0. \quad (5)$$

⁹ In order however to obtain a more balanced view of price developments in Greece results will also be presented for the broad sectors of “food”, “non-energy industrial goods” and “services” in the appendix, as these sectors tend to have significantly different behaviour in their price setting.

¹⁰ Alvarez (2007) provides an informative survey of estimates of price durations for a number of countries and discusses their implications for the assumptions of various theoretical models.

Figure 3: The distribution of durations



Source: Calculations by authors

The shapes of the distributions are similar: there are a lot of short price-spells, with 30% of spells lasting for only one or two months.¹¹ The distributions look very different to the exponential distribution that would be generated by a standard Calvo model. If we compare the pre and post-crisis distributions, they are similar except for two key features: first, there are more one period spells post crisis, and second the 12 month spike has (almost) gone.¹² The second feature implies that element of time dependence has reduced somewhat post-crisis.¹³ Finally, Figure 3 just covers the first 24 months – we can note that there is a very long tail of price spells with durations that run into years. In fact, out of all 742 products, there are 90 products for which some sellers have not changed their prices within 15 years.¹⁴ For 6 products, there are sellers who have not changed their prices at all in the whole sample (see Table A1 in appendix 1).

¹¹ Note that this excludes sales: including sales would increase the proportion of short spells even more.

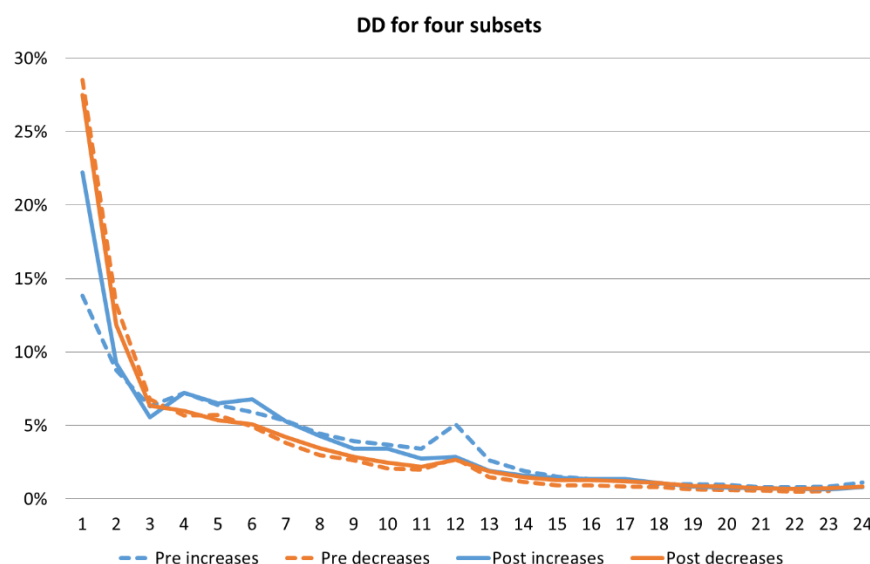
¹² This is consistent with findings from the third wave of the Wage Dynamics Network (WDN). In particular, unpublished evidence for Greece shows that post-crises the share of firms that change prices annually is around 30% (the surveys' reference period is 2010-2013). The relevant share pre-crises was around 41%. The latter evidence comes from the first wave of the WDN which was conducted in 2007-2008 (see, Druant et. al 2010).

¹³ Evidence from the third wave of the WDN shows that most of the firms changing their prices more often compared to the pre-crises period do so due to the increased volatility of demand, stronger competition in the market and more frequent price changes by competitors. This is more akin to a state dependent pricing strategy. Similar evidence is provided for Spain by Izquierdo and Jimeno (2015) and for Italy by D'Amuri et.al. (2015).

¹⁴ For example, while a served soft-drink has changed its price in most outlets, in two outlets it has remained constant for 15 years.

The overall distribution does however hide some broad sector differences. In particular, while the distribution of durations for 'Food' remained fairly unaltered, for non-energy industrial goods (NEIG) we see a clear increase in the share of short price spells (the share of monthly price spells more than doubles post-crisis). By contrast, for Services the share of short price spells is almost halved. Moreover, for both NEIG and Services we see a clear reduction in the share of annual (12-month) price spells (see Figure A3 in Appendix A)

Figure 4: The distribution of durations of increases and decreases



Source: Calculations by authors

It is important to note that price spells differ significantly if we partition the whole sample into subsets. Firstly, we can divide spells into two groups depending on whether the spell ends with an increase or a decrease.¹⁵ The majority (61%) of spells end with an increase and only 39% end with a decrease. However, if we subdivide each of these groups into two by period: pre-crisis and post-crisis, we can see that there is a big difference. Pre-crisis the share of spells ending with an increase was 69%, whilst post-crisis it fell to just 54%. In Figure 4 we show the DD for each of these four subsets, defined by how the spell ends and when it occurred.

The dotted lines are both pre-crisis spells, with blue being spells that end with increases and red the spells that end with decreases. The solid lines are post-crisis with the same color-coding for the spell ending. As we can see, the post-crisis distributions are closer together and

¹⁵ For this exercise, we only use uncensored spells (since we need to know how they ended and how they began).

for much of the distribution lie in between the pre-crisis lines. Interestingly, post-crises, i.e. during the low inflation period, there is a downward shift in the distribution of spells that end with increases.

An alternative is to look at the price spell data is to exploit its panel structure and take into account the fact that the spells are being generated by the behavior of the agents setting the prices (which we call firms). We can follow a row of the panel in terms of the price of a product/outlet pairing, following a particular price over time. The behavior of the firms setting prices is better captured by the cross-sectional distribution of durations (CSD). In particular, firms that reset prices frequently generate a lot of short price spells. The easiest way to understand this is to think of a simple economy consisting of two firms over a year. One resets its price each month generating 12 one-month spells, the other generates one 12 month spell. In DD we observe a distribution of 12/13 one-month and 1/13 twelve-month spells, with a mean of 1.85 months. The cross-sectional distribution looks at the two firms and averages across them, with $\frac{1}{2}$ one-month spells and $\frac{1}{2}$ 12 month spells. That is, in any one month there will be two spells, one of duration 1 month and the other 12 months. The cross sectional average across the two firms is thus 6.5 months and more accurately reflects the structure of the economy. In our data set, the firms which reset prices infrequently are less represented in the DD. On a formal level, the cross-sectional distribution means that spells are “length weighted”: longer spells are more important than shorter spells. The CSD is a set of positive coefficients adding up to one.

$$CSD = \{\alpha_i\}_{i=1}^F : \sum_{i=1}^F \alpha_i = 1, \alpha_i \geq 0. \quad (6)$$

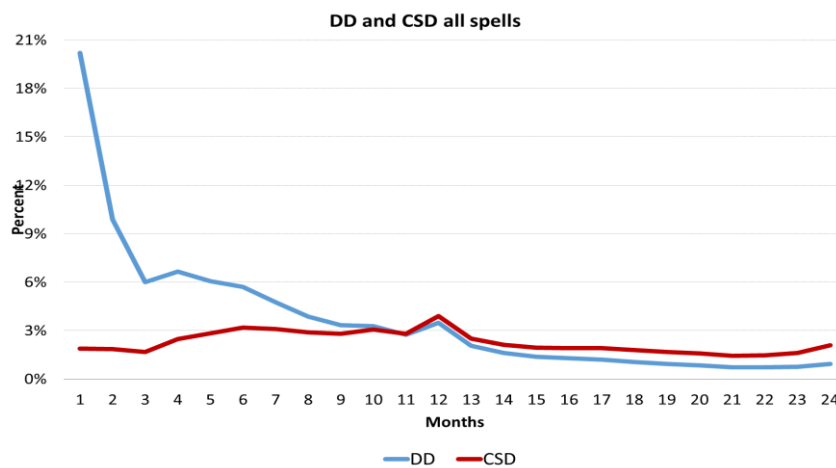
There is a simple equation linking the CSD to the DD, where in effect the shares of DD are length weighted. From Dixon and Le Bihan (2012) we have:

$$\alpha_i = \frac{i\alpha_i^D}{\sum_{j=1}^F j\alpha_j^D} \quad (7)$$

The CSD share α_i is equal to the corresponding α_i^D multiplied by the ratio of the spell length i to the mean of DD. This implies that the two distributions “cross-over” as the spell length passes by the mean price spell from DD. The average cross-sectional duration is 29 months, which is about three times longer than the average length of a spell. This indicates that the

firms in Greece on average set prices for 29 months.¹⁶ This is substantially longer than in other countries. For example, in the UK if we exclude food and energy, we obtain a mean CSD of 4.34 quarters (14 months).¹⁷ The difference between the mean of DD and CSD reflects the heterogeneity of pricing behaviour; if all firms set prices for the same length of time (as in the classic Taylor model), then the two distributions would have exactly the same mean.¹⁸ The fact that the mean CSD is longer than the mean DD reflects the fact that firms in different sectors generate different spell lengths (and indeed, a single firm might generate a range of spell lengths in the sample). In the Greek data the large difference between the means of CSD and DD reflect the great heterogeneity of pricing behaviour.¹⁹

Figure 5: DD and CSD



Source: Calculations by authors

In Figure 5 we show the two distributions DD and CSD for the first 24 months durations across the whole sample. They cross over at 11 months which is the mean spell duration from DD (rounded up from 10.7). For shorter durations the shares for the CSD are much smaller than those of the DD. From the formula, the share of 1 period spells is less than one tenth in CSD as opposed to DD (0.02 vs 0.20). This implies that the large 20% share of one-month spells in our sample is being generated by just 2% of firms. The firms generating most of the short

¹⁶ When excluding right hand censored spells. With right censored spells the average would be even longer.

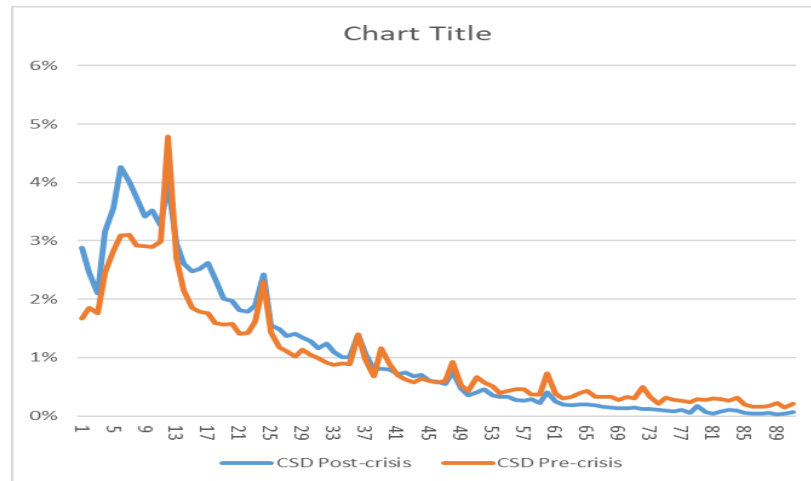
¹⁷ See Dixon et al (2021) page 58 and Appendix Table A4.6.

¹⁸ For example, if the economy consists for two firms setting prices for N months, the average price spell is simply N, and the average across the two firms is also N.

¹⁹ For a formal analysis of the relation between the means of DD and CSD, see Dixon and Tian (2017) Theorem 1.

spells are in Food and to a lesser extent NEIG. The pre-crisis twelve-month spike is generated mostly by the Service sector and to a lesser extent in NEIG and is almost totally absent in Food. Finally we can note that the proportion of firms setting prices for 24 months is larger than the share of those firms setting prices for one month (CSD has a long fat tail in contrast to the long thin tail of DD).

Figure 6: CSD pre and post crisis



Source: Calculations by authors

Plotting the CSD for the pre- and post-crisis period (Figure 6), we see the crisis has had a heterogeneous impact on firms' price setting behaviour, with some firms responding with more frequent price changes, while others with less frequent price changes.²⁰ On balance, the average price in Greece was set for almost 34 months pre-crisis, while the average price was set for only about 21 months post crisis.

4. A time series analysis of price changes in Greece

4.1. Developments in the frequency

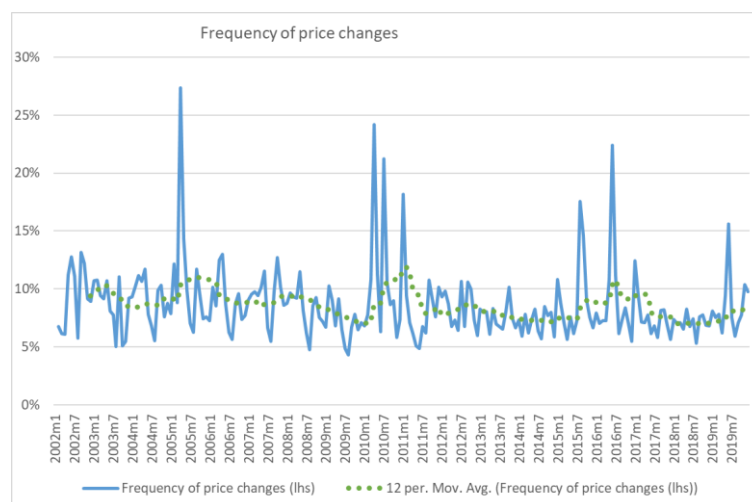
As mentioned early on, the frequency of price changes is measured as the share of prices that change each month. The measure of frequency is closely tied to the average duration of a price spell (from DD), where the average frequency over the sample is equal to the inverse of the average duration.²¹

²⁰ For this exercise, we exclude right hand censored spell in order to avoid sudden jumps caused by the end of the sample in March 2020.

²¹ If we take our earlier example with two firms, one resetting prices every month the other every 12 months. The frequency of price change over a 12 month period is to have 50% of the firms resetting

On average over the entire period, the frequency of price changes - excluding sales - is 8.6%.^{22,23} We observe large occasional spikes in the frequency of price changes (see Figure 7). All these spikes are related to those VAT changes which affected a majority of products (more than 50%) included in our sample (see Appendix Figure A3). Irrespective of whether we include the VAT spikes or not, the total frequency declined by only about 1 percentage point over the entire period. The fairly constant frequency is generally in line with both a time-dependent pricing strategy in the likes of Calvo as well as with menu-cost models with small aggregate shocks. However, the relative stability of the frequency is masking a significant underlying shift in behaviour. In the case of Greece, the aggregate shock hitting the country during the euro area crisis and its subsequent developments was very big and sustained.

Figure 7: Frequency of price changes, excluding sales



Source: Calculations by authors

If we split the total frequency of price changes into price increases and price decreases (Figure 6) we observe that the frequency of price increases has declined more significantly post crisis

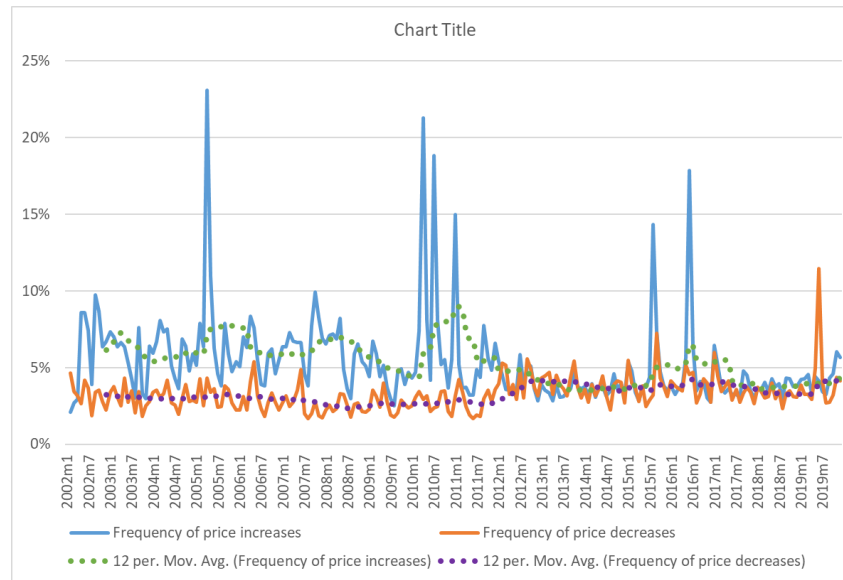
price for 11 months and 100% for one month: this is an average frequency over the year of 54%, the reciprocal of which is the mean spell duration of 1.85 given by DD.

²² See Table A1 for summary statistics

²³ Including sales the average frequency is about 12.6%. Moreover, including sales prices when calculating the frequency of price changes over time gives us two distinct periods for Greece. One, pre crises where the frequency was declining, i.e. prices were becoming more rigid and the other post crisis where the frequency was increasing – see figure A3 in the Appendix. The increasing frequency of price changes post-crisis coincides with a significant increase in the share of sales prices – see figure A4 in the Appendix. This is in line with recent models where customers' reactions lead firms to adopt a pricing strategy with rigid 'reference' prices and temporary sales (see Nakamura and Steinsson, 2011). Indeed, in Greece, when excluding sale prices the extent of price flexibility remains fairly stable over time. On the other hand, firms have tried to increase flexibility and accommodate the large decline in their customers' disposable income by a more extensive use of sales.

by about 2 percentage points while the frequency of price decreases has increased by about 1 percentage point. Hence the modest fall of 1 percentage point in the aggregate frequency reflected a more dramatic fall in price increases and a non-negligible increase in price decreases.

Figure 8: Frequency of price increases and decreases, excluding sales



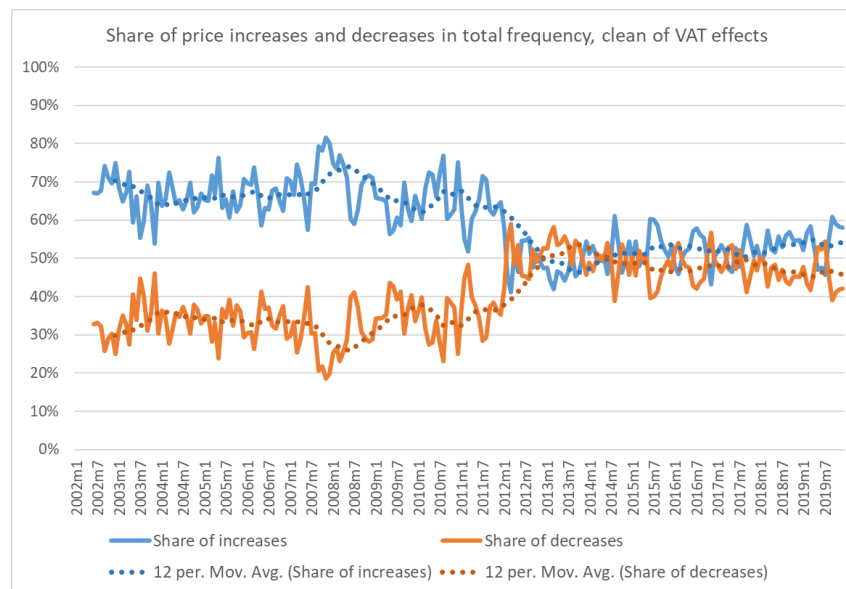
Source: Calculations by authors

On balance, this implies that price increases have gone from being about 2/3 of all price changes to being about 1/2 of all price changes (Figure 9).²⁴ This sharp change in share of relative price increases is not evident in any other euro area country (see Gautier et al. 2022). Even so, developments in the relative share of price increases and decreases were gradual. It took almost two years (2011-2013) until a new ‘balance’ was struck where half of all price changes were price increases.

The long period of adjustment in the share of relative frequencies may reflect the fact that that average spell duration is about 11 months and that it takes the average firm about 29 months to change its price in Greece. As such, it seems that firms responded gradually to the economic shock in Greece and when the time came for firms to change their price they decided to reduce it, rather than to increase it.

²⁴ This is also consistent with the evidence on the decline in the share of spells ending with an increase post-crises, from a pre-crisis level of 69% to 54% described in the four subset of DD in Section 3 (Figure 4).

Figure 9: Share of price increases and decreases in total frequency, net of VAT changes



Source: Calculation by authors

4.1.1. Drivers of the frequency price changes

Given the significant changes observed over time in the composition of the frequency of price changes one important question is what are the economic drivers of the frequency of increases and decreases?

Early studies such as Bils and Klenow (2004), Dhyne et al. (2004), Golosov and Lucas (2007), Mackowiak and Smets (2008) and Klenow and Malin (2011) focus attention on cross-section evidence on the determinants of frequency. Other authors such as Gagnon (2009) and Dhyne et al. (2004) found the effects of inflation on the frequency of price changes to be insignificant as inflation affects price increases positively and price decreases negatively with no overall effect. More recent papers like Vavra (2014) and Nakamura et al. (2018) have found that for the US data, inflation co-varies strongly with frequency over time. Similarly, for the UK, Dixon et al. (2020) find that the annual inflation rate significantly affects the frequency of price changes, but only through the frequency of price increases.

In this paper we adopt a time series approach with a single equation estimation methodology similar to Dixon et al. (2020).²⁵ Our explanatory variables are HICP inflation, retail sales growth

²⁵ Porqueddu and Fabiani (2017) also use time series analysis to examine whether the recession that followed the global financial crises affected the price setting mechanism in Italy.

and consumer sentiment about future developments.²⁶ All variables are in a monthly frequency. In addition we include monthly dummies in order to capture seasonality and dummies for VAT changes that may affect the frequency of price changes temporarily. In order to determine what kind of inflation and output growth, i.e. month-on-month, quarter-on-quarter or annual rates of change, are the most relevant for explaining the frequency of price changes, we follow a general to specific approach. We find that the annual rates of change of inflation and output growth are the most relevant, while for the sentiment indicator the level seems to be the most relevant.²⁷

The general to specific results confirm what is *ex ante* a logical supposition, namely that year on year changes of real and nominal variables – as opposed to month on month or quarter on quarter changes – are an important determinant of price changes. First, as Dixon et al. (2020) put it, “Annual inflation is how inflation is perceived: it is the annual inflation rate that is announced and talked about in the media and what people usually mean by ‘inflation’”. Second, for many firms output has a clear seasonal pattern. For example, tourist season in the Mediterranean peaks during the summer months, and so do prices. In this respect, the most relevant comparison of prices is the same month of the previous year, i.e. annual inflation.

How would we expect the explanatory variables to affect frequency? In a purely time dependent model, none of these variables would matter as the timing of price changes would be driven by the duration since the previous price change²⁸. However, in a state-dependent framework, the decision to change the price this month is driven by the distance of the current price from the optimal flexible price p^* , which is itself a function of the general price and output level, usually written (in log-linearized form) as:

$$p_t^* = P_t + \gamma y_t \quad (9)$$

²⁶ We have tested a variety of other variables such as the growth of industrial production, the general economic sentiment indicator, current consumer sentiment as well as current and forward-looking sentiment indicators for industry and services.

²⁷ As Dixon et al. (2020) note: “annual inflation is a linear restriction on a general 12-month lag structure on inflation, which imposes equal weights... In effect, the annual inflation rate is a parsimonious way to capture the effects of lagged inflation.”

²⁸ Note however that in a time-dependent model, the size of the price change will be affected by the current and future values of p_{t+i}^* (the reset price is an average of p_{t+i}^* over the lifetime of the price spell).

Where P_t is the general price level, y_t the level of output and γ is the sensitivity of the optimal flexible price to output. Importantly, if $\gamma=0$ then there might be no relationship of output to the optimal price (this has been called *real price rigidity* by Ball and Romer 1990). However, we would usually expect γ to be strictly positive (even if small) reflecting either an upward sloping marginal cost curve at the firm level or an upward sloping labour supply curve. Higher inflation or output growth would both lead to a higher p^* and hence an increase in the proportion of firms increasing price (more firms become too far below the optimal level) and a decrease in the proportion of firms decreasing price (less firms are too far above the optimal price). Similarly for the sentiment indicator capturing beliefs of future developments an increase would imply a higher p^* going into the future.

Whilst the current value of p^* relative to the current price might determine whether the price changes or not, the optimal reset price will depend on future p^* . If a firm does decide to reset its price this month, the price it will want to set will be some sort of weighted average over future optimal flexible prices p_{t+i}^* for $i \geq 0$, with the weights depending on the probability of the price to be set lasting for i periods. We should note that our macro variables, according to eq. 9, also imply opposite signs for the frequency of increases and decreases. Thus, it may be the case that for the total frequency of price changes the ‘net’ effect may be overly small or even non-existent.

In Table 2 we present the results for our estimates. Our regressions include a lagged dependent variable and our explanatory variables are instrumented by own lags in order to avoid simultaneity. There are two dependent variables: frequency of price increases and frequency of decreases. For each dependent variable, we estimate 5 regressions, all with monthly and VAT dummies. The first three equations are regressions with one of the three explanatory variables on their own (inflation, output growth and sentiment of future developments), the fourth equation is the regression with two ‘traditional’ variables (inflation and output growth) and the fifth all three explanatory variables.

Turning first to the frequency of increases regressions (1-5) we see that the lagged dependent variable has a non-negligible effect, implying some limited inertia in the frequency of increases. At the same time annual inflation has a significant and large effect. Specifically a 1 percentage point increase in inflation leads to an increase in the frequency of price increases by 0.397 percentage points (regression 1). Similarly, a 1 percentage point increase in retail

sales volume growth increases the frequency of price increases by almost 0.074 percentage points (regression 2). At first glance this implies that inflation is more important for price increases than output growth. However, we should note that output growth (or retail sales volume growth in our case) is inherently more volatile than inflation. Indeed for the whole sample the standard deviation of retail sales growth is 4 times larger than that of inflation while for the pre-crisis period it's 7 times larger. As such, for Greece both inflation and output have affected the frequency of price increases to an almost equal degree. Continuing to the effects of sentiment on the frequency of price increases (regression 3) we obtain, rather small effect both statistically as well as economically. . This implies that a 2 standard deviations increase raises the frequency of price increases by only 0.01 percentage points. In regressions 4 and 5 we see that both inflation and retail sales growth retain their significance and are still economically important.

Continuing with the estimations explaining the frequency of price decreases we find that both inflation and retail sales growth are significant, albeit the latter is not robust. The sentiment indicator, while statistically significant by itself has again a negligible economic significance and is also not robust. As expected the variables enter with the opposite sign compared to regressions for the frequency of price increases. Inflation has less than half the impact for the frequency of price decreases compared to the frequency of price increases (0.397 vs -0.166). On balance, our estimations seem to explain the frequency of price increases to a larger degree than the frequency of price decreases, by a significant margin, judging from the adjusted R-squared. The frequency of decreases is to a larger extent idiosyncratic.²⁹

The Greek experience stands in somewhat contrast to the UK estimates of Dixon et al (2020), where output was not found significant in explaining the frequency of price increases and decreases. This could be for two main reasons. First, the Greek retail sales measure we use is a better measure of output than the industrial output measure used in the UK study.³⁰ Second, the changes in Greek output were much more dramatic than in the UK. They were both larger as well as longer lasting, bringing thus out the effect of output on pricing behavior better.

²⁹ The results are broadly similar if you use only IV or even simple OLS estimations.

³⁰ Industrial output is significant for the frequency of decreases for Greece but with the 'wrong' sign. We believe that retail sales is a more pervasive measure of economic activity as it covers more than half of private consumption, which in turn represents about 60 percent of Greek GDP. By contrast, industry in Greece is around 10 percent of GDP over our sample period.

Table 2: Determinants of the frequency of increases and decreases, LDV IV estimations

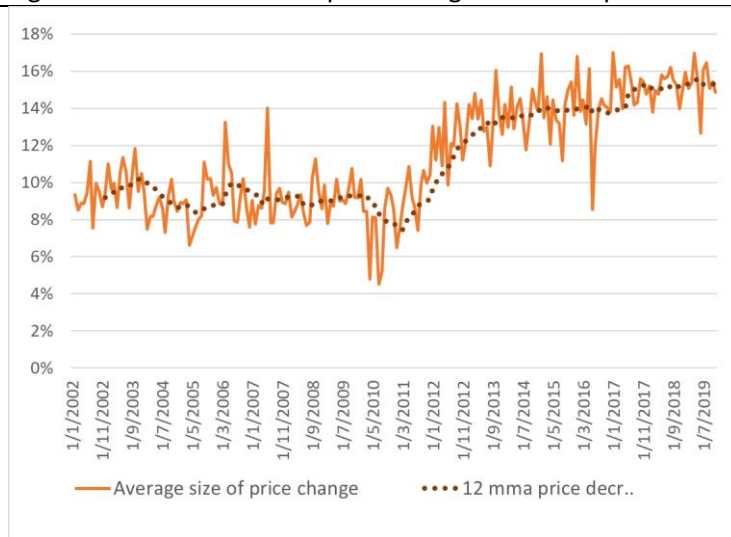
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
VARIABLES	Frequency of price increase					Frequency of price decrease				
LDV	0.216*** (0.0340)	0.314*** (0.0317)	0.325*** (0.0303)	0.204*** (0.0326)	0.211*** (0.0317)	0.231*** (0.0495)	0.338*** (0.0478)	0.337*** (0.0466)	0.231*** (0.0495)	0.235*** (0.0488)
Annual HICP inflation	0.397*** (0.0516)			0.341*** (0.0501)	0.316*** (0.0484)	-0.166*** (0.0294)			-0.161*** (0.0303)	-0.152*** (0.0297)
Retail sales growth		0.0742*** (0.0144)		0.0602*** (0.0132)	0.0367** (0.0176)		-0.0143* (0.00843)		-0.00529 (0.00823)	0.00317 (0.0112)
Consumers Future Economic Situation			0.000212*** (3.48e-05)		0.000105** (4.46e-05)			-5.56e-05*** (2.08e-05)		-3.83e-05 (2.84e-05)
Constant	0.0331*** (0.00301)	0.0366*** (0.00324)	0.0442*** (0.00354)	0.0355*** (0.00291)	0.0399*** (0.00332)	0.0309*** (0.00227)	0.0249*** (0.00210)	0.0227*** (0.00220)	0.0307*** (0.00228)	0.0289*** (0.00255)
Observations	209	209	209	209	209	209	209	209	209	209
R ² -adj	0.848	0.829	0.839	0.861	0.869	0.628	0.586	0.602	0.626	0.635

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Estimations include a constant, monthly dummies and VAT change dummies

4.2. Developments in the size of price changes

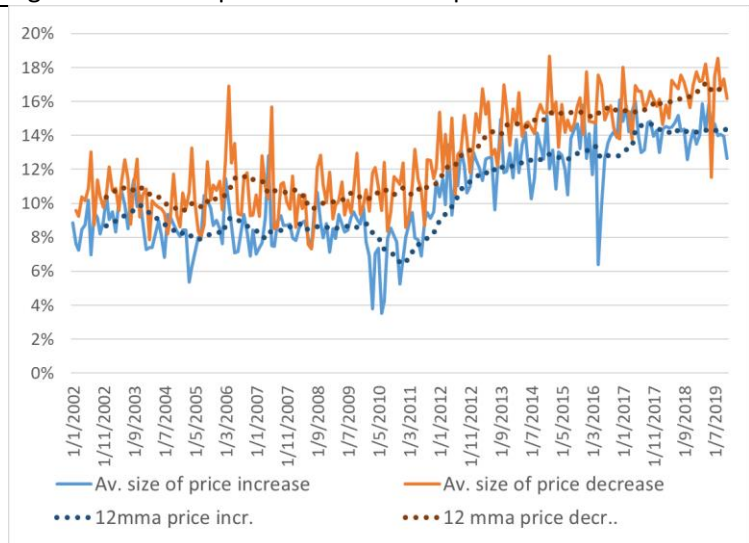
Turning our attention to developments in the absolute size of price changes for Greece, we notice an unusual pattern. Namely, that the average price change post crisis has increased significantly, from around 10 per cent to about 15 per cent (Figure 10). Moreover, the increase in the size of price changes over time is evident for both price increases, from slightly below 10% pre crisis to around 14% post crisis, as well as price decreases, from slightly above 10% pre crisis to around 17% post crisis (Figure 11).

Figure 10: Size of absolute price changes over the period.



Source: Calculation by authors

Figure 11: Size of price increases and price decreases.



Source: Calculation by authors

Intuitively one would expect rising price changes to be associated with higher inflation. If we consider equation 5, high inflation would lead the current price to drift away from the optimal price, resulting thus in larger price adjustments when the decision to change prices is taken. However, in our case higher price changes are observed during a period with *lower* inflation. This phenomenon is also observed in Norwegian CPI data.³¹ This relation is confirmed by estimations similar to those in Table 1 but where the dependent variables are the size of price changes (as measured by the proportionate growth rates), the size of price increases and the size of price decreases (see Table 3).

We obtain the result whereby higher inflation and improving sentiment lead to smaller price increases (models 1 and 3). Retail sales growth leads to larger price increases only when inflation is included (model 5). By contrast, the size of price decreases seem to be explained only by inflation. What is evident in Table 3 is that the magnitude of the lagged dependent variable is about 2-3 larger than in the regressions for frequency, implying that there is significant persistence in the size of price changes.

In order to investigate more closely the underlying reasons of the increase in the average price change after the Greek crisis in 2011, we plot the price change distributions pre and post crisis for all non-zero price changes (Figure 12). As our price changes are expressed in *dlogs* we create bins, where each bin has a range of 2, which is approximately 2%. For ease of presentation we truncate our distribution at $|\log 54|$ which corresponds to a decrease of around 42% ($-\log 54$) and an increase ($+\log 54$) of around 71%. So the first bin contains the share of all price changes from $-\log 54 \leq$. The second bin contains all price changes $-\log 54 >$ and $-\log 52 \leq$ etc up to the last bin which contains all price changes that are larger than the log change of 54. The y-axis shows the share of non-zero price changes to all non-zero price changes that are contained in each bin.

³¹ See Wulfsberg (2016).

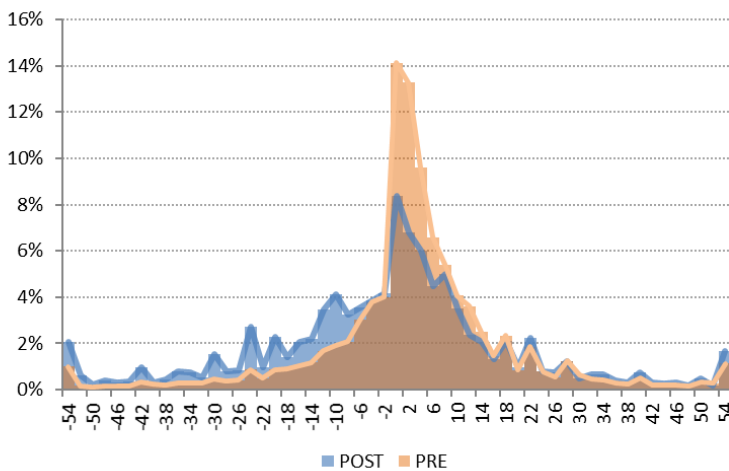
Table 3: Determinants of the size of price increases and decreases, LDV IV estimations

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
VARIABLES	Size of price increase					Size of price decrease				
LDV	0.691*** (0.0473)	0.850*** (0.0301)	0.838*** (0.0299)	0.678*** (0.0514)	0.671*** (0.0508)	0.607*** (0.0616)	0.842*** (0.0393)	0.834*** (0.0398)	0.590*** (0.0658)	0.583*** (0.0671)
Annual HICP inflation	-0.327*** (0.0768)			-0.353*** (0.0867)	-0.330*** (0.0832)	-0.497*** (0.103)			-0.535*** (0.114)	-0.526*** (0.113)
Retail sales growth		-0.0154 (0.0147)		0.0106 (0.0160)	0.0464** (0.0220)		-0.0187 (0.0198)		0.0158 (0.0208)	0.0360 (0.0295)
Consumers Future Economic Situation			-0.000103*** (3.68e-05)					-6.92e-05 (5.06e-05)		
Constant	0.0475*** (0.00671)	0.0248*** (0.00431)	0.0218*** (0.00439)	0.0494*** (0.00737)	0.0434*** (0.00706)	0.0736*** (0.00969)	0.0363*** (0.00614)	0.0346*** (0.00630)	0.0766*** (0.0105)	0.0737*** (0.0103)
Observations	209	209	209	209	209	209	209	209	209	209
R ² -adj	0.825	0.813	0.819	0.823	0.830	0.710	0.682	0.682	0.707	0.705

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Estimations include a constant, monthly dummies and VAT change dummies

Starting with the price increase (the bins >0) we can see that the main difference lies mainly in below average price increases (below 10% for the crisis period). A large mass of smaller price increases has disappeared post crisis.³² By contrast larger price increases are still evident to the same extent. This may imply that ‘smaller’ shocks post crisis, which could potentially be absorbed by margins, were not passed on to consumers.³³ By contrast, larger shocks were passed on to a similar extent. Thus as ‘smaller’ price increases disappear, the average price increase becomes larger post crisis.

Figure 12: Distribution of Prices changes before and after 2011



Note: X axis is measured in log change terms. Thus -54 implies $e^{(-54/100)} \approx 1 \approx 42\%$, a price decrease of 42%. Similarly +54 implies a price increase of 71%. The distribution in the graph is truncated at the absolute log change value of 54.

For the price decreases (the bins <0 in Figure 10) we can see that post crisis, there is a significant mass, both below, but mainly above the pre-crisis average price decrease. Thus, while smaller price decreases were almost equally common in both periods, larger price decreases gained traction in the post-crisis period.³⁴

³² This is a pervasive feature and can be seen in all broad sectors, see Figure A6 in Appendix A.

³³ In a low inflation environment, where cost shocks are rare and price increases less frequent, firms may be reluctant to increase prices if they are able to absorb it in profit margins, as they are aware that consumers react negatively to price increases that they consider unfair. In general, customers have limited information about shocks affecting firms and observe economy wide variables. The ‘lost small price increases’ can therefore broadly be seen in the light of customer market and fair prices theories (see Fabiani et. al. 2006 and Alvarez 2007).

³⁴ While some of the spikes observed for price decreases in the post crisis distribution may reflect some substitution or sales effect that we have not been able to capture the mass difference compared to the pre-crisis period is significantly different for it to be attributed to such data issues.

4.3. What drives inflation

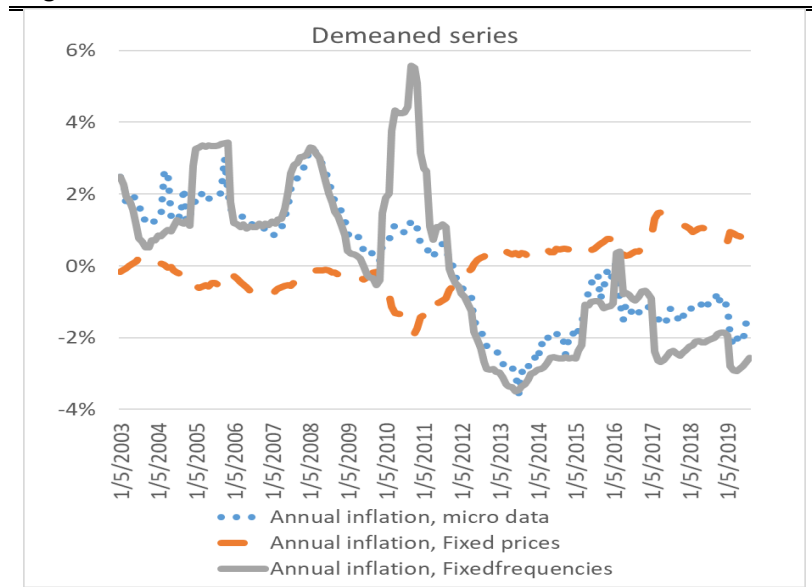
As inflation is product of the frequency of price changes and the size, we want to investigate which of these two components is the main driver of inflation developments in Greece over the past two decades. In a simple exercise, similar to that of Gautier et al. (2022) we posit the following two counterfactual inflation rates:

$$\Pi_{\bar{f},t} = \sum_{j=1}^n w_{j,t} (\bar{f}_{j,t}^{(+)} \cdot \pi_{j,t}^{(+)} - \bar{f}_{j,t}^{(-)} \cdot \pi_{j,t}^{(-)}) \quad (10)$$

$$\Pi_{\bar{\pi},t} = \sum_{j=1}^n w_{j,t} (f_{j,t}^{+} \cdot \bar{\pi}_{j,t}^{(+)} - f_{j,t}^{-} \cdot \bar{\pi}_{j,t}^{(-)}) \quad (11)$$

One where we hold the frequencies constant at their average and let the size price changes vary like in data (eq. 10) and one where the size of price changes is held constant and the frequencies vary as in the data (eq. 11). We can then use the month on month inflation rates to construct corresponding counterfactual annual inflation rates and compare them to the actual inflation rate generated by the micro data. Thus in equation (10) all inflation dynamics come from developments in the size of price changes while in equation (11) all inflation dynamics come from developments in the frequencies. Finally, in Figure 13, we compare these two counterfactuals with the actual inflation calculated from eq. (4), where both the frequencies and sizes vary.

Figure 13: Counterfactual and micro data based inflation.



Source: Calculation by authors

Figure 13 shows that the inflation rate obtained by the micro data co-varies strongly with the inflation rate where prices are fixed and all the inflation dynamics come from changes in the frequency of increases and decreases. By contrast, the counterfactual, where frequencies are fixed and inflation dynamics come from changes in the size of price increases and decreases shows little connection with actual developments. In fact both in month-on-month and year-on-year terms the correlation of the inflation obtained from the data and the ‘fixed price’ counterfactual is around 0.80, while the correlation with the ‘fixed frequency’ counterfactual is about -0.20. Lastly, this finding holds also if we divide the full sample into the two sub-periods of pre- and post-crisis. Namely, within each subperiod inflation developments are driven – almost fully – by developments in the frequency of increases and decreases. These results are in line with the findings of Gautier et al (2022) for the euro area.³⁵

5. Endogenous inflation dynamics.

In this section we will look more detail as to how past inflation can affect current inflation and hence lead to inflation persistence. We focus on the fact that annual inflation seems to be an important determinant of the current frequencies of increases and decreases. Thus, when we are looking at price changes this month, they are going to be affected by the previous behavior of prices. For simplicity, we will assume that current inflation does not affect the size of price changes.³⁶ We do this by incorporating our regression results by adapting the simple 3 equation New-Keynesian model. Our adaptation involves replacing the new Keynesian Phillips curve with an empirical Phillips curve based on our estimated equations.

We start with the most basic Euler equation where the output gap at time t is defined as:

$$x_t = E_t x_{t+1} - \frac{1}{\sigma} (i_t - E_t \pi_{t+1} - i^*) + \epsilon_{dt} \quad (12)$$

³⁵ The main role of frequencies as a driver of inflation is also found in Alvarez et al. (2019) for Argentina.

³⁶ As we have seen, inflation developments have been driven, almost fully, by developments in the frequency of increases and decreases.

Where x_t is the output gap at time t , E_t are expectations at time t , and π_{t+1} is inflation at time $t+1$. In this simple model, there is no investment so that output is equal to consumption.

We include a simple Taylor rule where the nominal interest rate (i) at time t is:

$$i_t = i_\pi \pi_t + i_x x_t + \varepsilon_{it} \quad (13)$$

The interest rate responds to current inflation and output, with $i_\pi > 1, i_x \geq 0$.

Finally, we include a ‘modified’ Phillips curve, which is based on our regressions. Specifically, for each month we have the identity:

$$\Delta \Pi_t = f_0^+ \Delta \pi^+ + f_0^- \Delta \pi^- + \pi_0^+ \Delta f^+ + \pi_0^- \Delta f^- + \epsilon_{\pi t} \quad (14)$$

Where the difference is from the initial “steady state” values (given by the subscript 0). We further simplify the model in the light of section 4.3 by taking the counterfactual form where the size of price increases and decreases are fixed. From our regression models (4) and (9) of Table 2, we have in difference form the following equations driving changes in frequencies:

$$\Delta f^+ = 0.341 \Delta \Pi^A + 0.204 \Delta f_{-1}^+ + 0.06 x_t \quad (15)$$

$$\Delta f^- = -0.161 \Delta \Pi^A + 0.231 \Delta f_{-1}^- \quad (16)$$

We are giving the output gap the coefficient for retail sales growth. Given the behavior of Greek output in this period, we do not believe the output gap to be well defined in the data.

We also have the annual rate of inflation being given by the sum of the current and previous 11 months month on month inflation:³⁷

$$\Pi_t^A = \sum_{i=0}^{11} \Pi_{t-i} \quad (17)$$

Finally we define our shock variable:

$$\epsilon_{\pi t} = \rho \epsilon_{\pi, t-1} \quad (18)$$

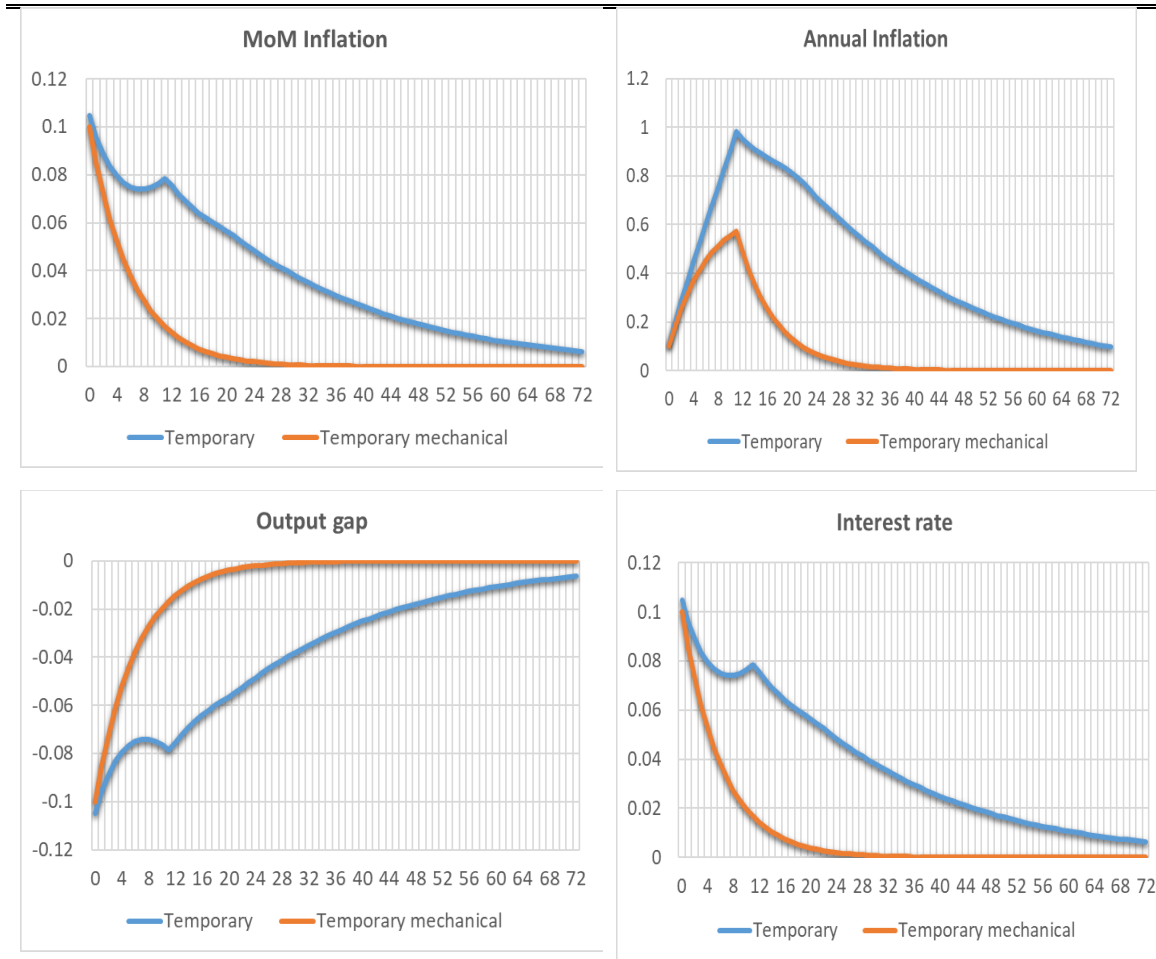
³⁷ This is an approximation that ignores the compounding of inflation, but works well for inflation rates of 5% or less.

We will first investigate a temporary shock where ρ is 0.85, which implies that the initial shock has a half-life of 4 months and dies out after approximately 2 years. Second, we look at a highly persistent shock where ρ is 0.99, with a half-life of almost 6 years, resulting in period of higher inflation for many years. In all instances, we scale our shock appropriately to 0.1, which implies an increase of month-on-month inflation by 0.1 percentage points on impact. We will compare the outcome of our variables of interest, inflation, output and interest rates with a ‘mechanical’ approach, where we switch off equations (15) and (16) and simply introduce the shock into equation (14). That is, we will not have a feedback loop between annual inflation and the frequency of increase and decrease, which create further inflation pressures.

The path of the economy in our simple adapted new Keynesian model is the outcome of the interaction above equations. The initial inflation shock will have a positive feedback generated by the endogenous inflation dynamic as the frequencies respond to the gradual rise in annual inflation. However, there is also negative feedback, as the Taylor rule leads to an increase in the nominal and real interest rate from (13), which leads to a fall in output via (14), which leads to a fall in the frequency of price increases via (15). Eventually, the economy will return to its initial steady-state. The Euler equation (14) assumes a unit intertemporal elasticity of substitution which is very standard (albeit stylized), as is the Taylor rule coefficient on inflation and output of 1.5 and 0.5 respectively (which satisfies the Taylor principle). In the appendix we provide some alternative calibrations and scenarios.

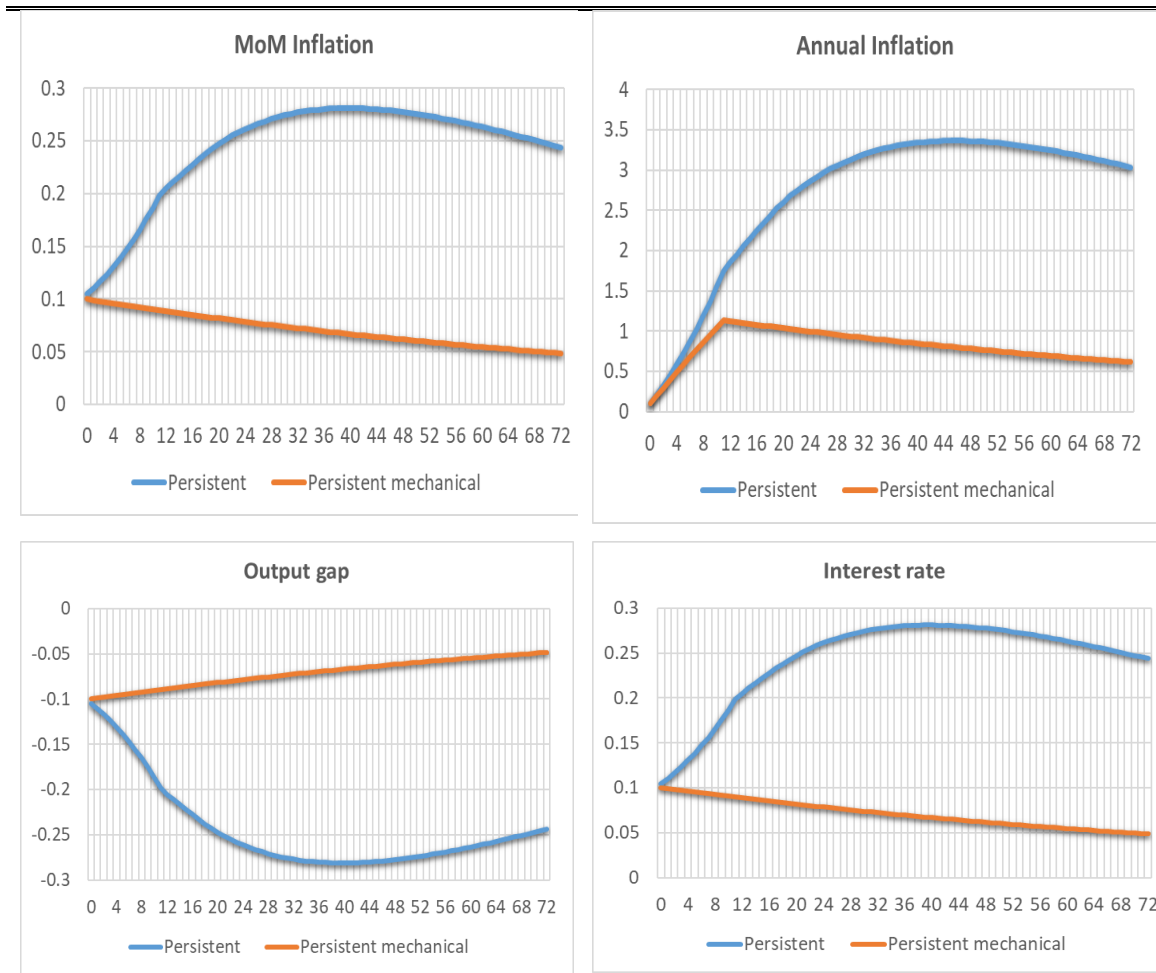
The monthly impulse responses of our variables are presented in Figure 14, for a temporary shock of 0.1 p.p. on month-on-month inflation, and in Figure 15, for a persistent shock. The responses are at a monthly frequency for up to 6 years (72 months) after the shock.

Figure 14: Impulse responses of a temporary shock to month on month inflation



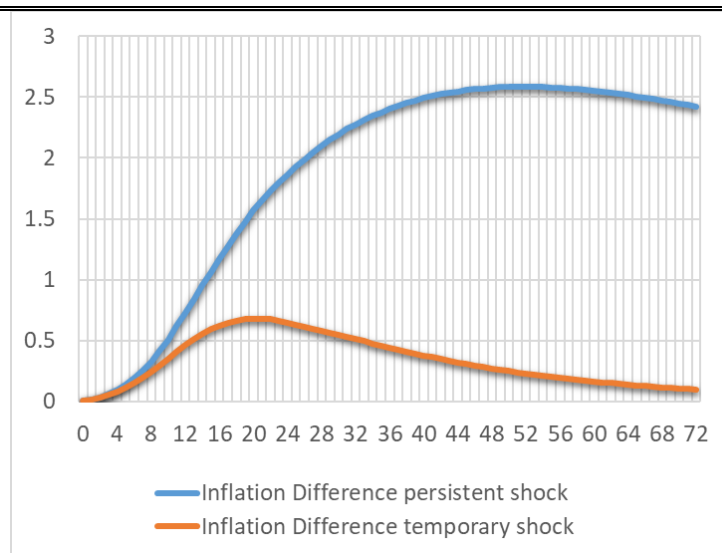
We can see that, in the mechanical approach the shock dies off within two years approximately, as there are no frictions, while annual inflation peaks after one year at almost 0.6 percent. By contrast, our model which includes the endogenous response of the frequency of price increases and decreases to the macro economic outlook creates significant persistence in the reaction of inflation. In particular, annual inflation peaks after one year at about 1 percent and remains at elevated levels for the entire period thereafter. Naturally, the effect on the output gap and the interest rate reaction are also significantly larger and significantly more persistent. Note that the spike at 12 months for mom inflation reflects the peak of the cumulative effect of annual inflation, which also feeds through to output and the interest rate.

Figure 15: Impulse responses of a persistent shock to month on month inflation



In the case of a persistent shock, we see that the effect on annual inflation peaks at slightly above 1 percent and declines thereafter linearly. By contrast again, when the frequency of price increases and decreases react endogenously to the macro-economic environment, inflation is both significantly higher, peaking at almost 3.5 percent after 48 months, and remains at levels above 3 percent for the entire period. Consequently, the reactions of output and interest rates are also significantly higher and longer lasting. In the persistent shock case, the mechanical response of mom inflation simply follows the initial shock slowly dying away, with just under half of it left after 72 months. Output and the interest rate are also at half of their impact values, with annual inflation being just above half (since its peak was at 12 months and not on impact).

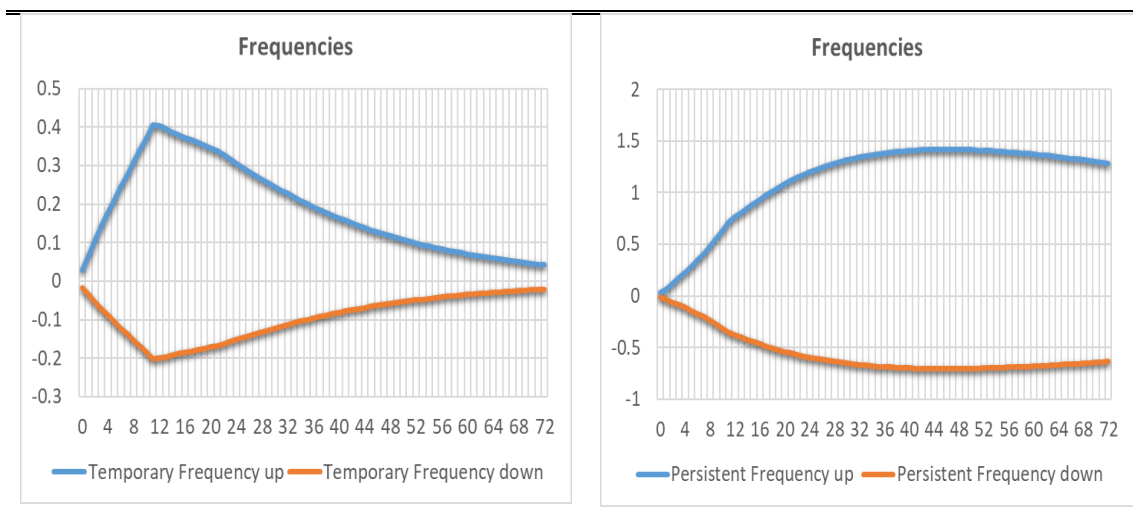
Figure 16: Deviation from mechanical response of annual inflation for a temporary and persistent shock.



One implication of above exercises is that the reaction of inflation depends on the duration of the shock. In particular the deviation of the endogenous response to the mechanical is larger the more persistent the shock. In Figure 16 we can see that the deviation from the mechanical response is about 4 times larger for a persistent shock compared to a temporary shock.

Moreover the difference of the endogenous response versus the mechanical response peaks much later. The reason behind these developments is because a more persistent a shock affects the frequency of price increases and decreases for a longer time period and hence to a greater extent. In Figure 17 we can see the endogenous reactions of the frequency of price increases and the frequency of price decreases to the temporary and persistent shocks. In the case of the temporary shock the frequency of price increases goes up, peaking after one year at 0.4 percentage points, while the frequency of decreases declines to -0.2 percentage points. Thereafter as annual inflation starts to decline the 'gap' in the frequencies starts to close slowly. By contrast, in the case of a persistent shock, the frequency of price increases (price decreases) continue to go up (decline) until annual inflation peaks at 48 months and slowly converge to steady state, still remaining far from steady state at 72 months.

Figure 17: Impulse responses of frequencies to a shock to month on month inflation



The simulation results are very much in line with the developments in the relative frequencies observed in Greece (see Figures 8 and 9).³⁸ In particular, Greece was hit by a large negative shock whereby the frequency of price increases declined by approximately 2 percentage points, while the frequency of price decreases went up by approximately 1 percentage point. The full impact of the changes in frequencies took about 2 years (24 months) to materialize.

We can also see that in Figure 17, in the right-hand panel, the effect of a positive inflation shock has a larger impact on the frequency of price increases than on the frequency of price decreases. I.e. it affects the frequencies asymmetrically. All else equal, this implies that in periods of high inflation the total frequency of price changes (the frequency of price increases plus the frequency of decreases) is higher than for low inflation periods. This result is in line with observations in several other countries over different periods of time, including Mexico, in Gagnon (2009), for Norway (see Wolfsburg 2016) as well as for the US and the UK (see Nakamura et al. 2018 and Dixon et al 2020 respectively).³⁹

³⁸ Figures B1 and B2 in the Appendix simulates the responses of 1) a shock to energy prices in the order of magnitude similar as the observed in 2021, that is, an out of sample simulation of our model and 2) the impact of a large negative shock to output similar to that observed in Greece during the crisis.

³⁹ We should note however that our data and the estimated results refer to a different basket of products. Most notably our data set does not include prices on energy and fresh fruits and vegetables.

We have illustrated the implications of our empirical results for generating significant inflation persistence due to the endogenous inflation dynamic in the estimated model. Whilst we have used the simple new Keynesian model, we could also introduce the empirical Phillips curve into a more complex model allowing for investment, habit formation and other more realistic features. However, these would introduce more complex dynamics alongside the endogenous inflation dynamic we are seeking to highlight.

How should we interpret the empirical Phillips curve captured in equations (14-18)? We do not claim to have estimated anything more reduced form relationships in Tables 2 and 3, and there are thus alternative interpretations that can be made. The simplest is that price setters for consumer goods and services are influenced by the annual rate of inflation, which is what is most prominent in the news. This is a backward-looking measure from one perspective. However, it is also forward looking in the sense that there is a high persistence in the annual rate of inflation and so a higher current rate of inflation would imply a higher rate in the coming months (for example in the 6-9 month horizon), which would also influence a forward looking price-setter. Furthermore, one can think of the annual rate as an AR(12) with equal weights on monthly inflation, hence as a simple ARIMA forecasting model for the new monthly inflation that will emerge in the coming months. It is a topic for further research to interpret the reduced form equations structurally, and this would require more detailed firm-level data rather than the HICP price-data used in this paper.

6. Conclusions

We analyze price developments in Greece over the period 2002-2019 during which Greece went through a shock of similar magnitude of the Great depression. We find that during the crisis there were significant changes in the pricing behavior of firms. Both price increases and decreases became larger. While the former increased over most of the distribution of price decreases, the latter simply saw small price increases disappear, increasing thus the average. The frequencies of price increases and price decreases also showed significant movements. The share of price increases declined from about $\frac{2}{3}$ of the total frequency of price changes to about $\frac{1}{2}$ of the total. Correspondingly, the share of the frequency of price decreases went up.

In this paper we have explored the relationship between the macroeconomic variables of inflation and output growth with pricing behavior. We then regress these macro-economic variables on the frequency of price increases and decreases and find that annual inflation is an important determinant for both, increasing the frequency of increases and decreasing the frequency of decreases. Output growth has the effect of increasing the frequency of increases, but does not affect the frequency of decreases. The effect of inflation is stronger on the frequency of price increases than with decreases. These results imply that the inflation response reacts endogenously via an (asymmetric) impact on the frequency of price increases and the frequency of price decreases and current inflation affects future pricing behavior and hence future inflation.

Utilizing the results of the estimations, we set the endogenous inflation dynamic as a replacement for the new Keynesian Phillips curve and add a Taylor rule and Euler condition which provides a feedback mechanism via interest rates and output to moderate the inflation response. The simulations are able to replicate key developments of the Greek economy well and are also in line with stylized facts on the frequency of price changes of other economies and different periods of investigation. There are two key points to these results. First, inflation dynamics across time are endogenous, as monthly inflation -through changes in frequencies- feed into annual HCIP inflation which then affects pricing going on into the future. Second, there is an asymmetric effect of macro-economic conditions on the frequency of increases and the frequency of decreases.

The simulation, based on the estimated equations, captures the developments of the Greek inflation well. Lastly, the results of the simulation also captures stylized facts of developments in the frequency of price increases and decreases seen in other economies and over different time-periods. In particular, it shows that an increase (decrease) in inflation increases the total frequency of price changes to be larger (smaller). This is because the impact of inflation on the frequency of price increases is larger than its impact on decreases.

References

- Alvarez, F., Beraja, M., Gonzalez-Rozada, M., and Neumeyer, P. A. (2019). From Hyperinflation to Stable Prices: Argentina's Evidence on Menu Cost Models. *The Quarterly Journal of Economics*, 143(1):451-505.
- Alvarez F., Lippi F. (2020). Temporary Price Changes, Inflation Regimes, and the Propagation of Monetary Shocks. *American Economic Journal: Macroeconomics* 12(1): 104-152.
- Alvarez, L. J. (2007). What do micro price data tell us on the validity of the New Keynesian Philips Curve? Bank of Spain Working Paper No. 0729.
- Ball L., Romer D. (1990). 'Real rigidities and the non-neutrality of money', *Review of Economic Studies*, Vol. 57, pp. 183–203.
- Bils, M., Klenow, P. (2004). 'Some evidence on the importance of sticky prices', *Journal of Political Economy*, Vol. 112, pp. 947–985.
- D' Amuri, F., Fabiani, S., Sabbatini, R. Tartaglia Polcini, R., Venditti, F. Viviano, E. and Zizza, R. (2015). Wages and prices in Italy during the crisis: the firms' perspective. Bank of Italy Occasional Paper No. 289.
- Dhyne, E., Alvarez, L. J., Le Bihan, H., Veronese, G., Dias, D., Hoffmann, J., Jonker, N., Lunnemann, P., Rumler, F., and Vilmunen, J. (2006). 'Price setting in the Euro area: some stylized facts from individual consumer price data', *Journal of the European Economic Association*; 4, pp. 575–584.
- Dixon H., Le Bihan H. (2012). Generalised Taylor and Generalised Calvo Price and Wage Setting: Micro-evidence with Macro Implications. *The Economic Journal* 122(560): 532-554.
- Dixon H., Tian.K (2017), What We can Learn About the Behaviour of Firms from the Average Monthly Frequency of Price-Changes: An Application to the UK CPI Data, *Oxford Bulletin of Economics and Statistics*, 79: 907-932.
- Dixon H., Luintel K., Tian K. (2020). The Impact of the 2008 Crisis on UK Prices: What We Can Learn from the CPI Microdata. *Oxford Bulletin of Economics and Statistics*, 86(2): 1322-1341.
- Dixon H, Franklin J and Millard S (2021). Sectoral shocks and monetary policy in the United Kingdom, Cardiff Economics Working Paper No. E2021/10.
- Druant M. , Fabiani S., Kezdi G., Lamo A. Martins, F. Sabbatini, R. (2009). How are firms' wages and prices linked: survey evidence in Europe. ECB Working Paper No. 1084.
- Fabiani, S., Druant, M., Hernando, I., Kwapil, C., Landau, B., Loupias, C., Martins, F., Mathä, T., Sabbatini, R. Stahl. H. and Stockman, A. (2006). What firms' surveys tell us about price-setting behavior in the Euro Area. *International Journal of Central Banking* Vol 2 (3): 3-47.
- Gagnon, E. (2009). 'Price setting during low and high inflation: evidence from Mexico', *The Quarterly Journal of Economics*, Vol. 124, pp. 1221–1263.

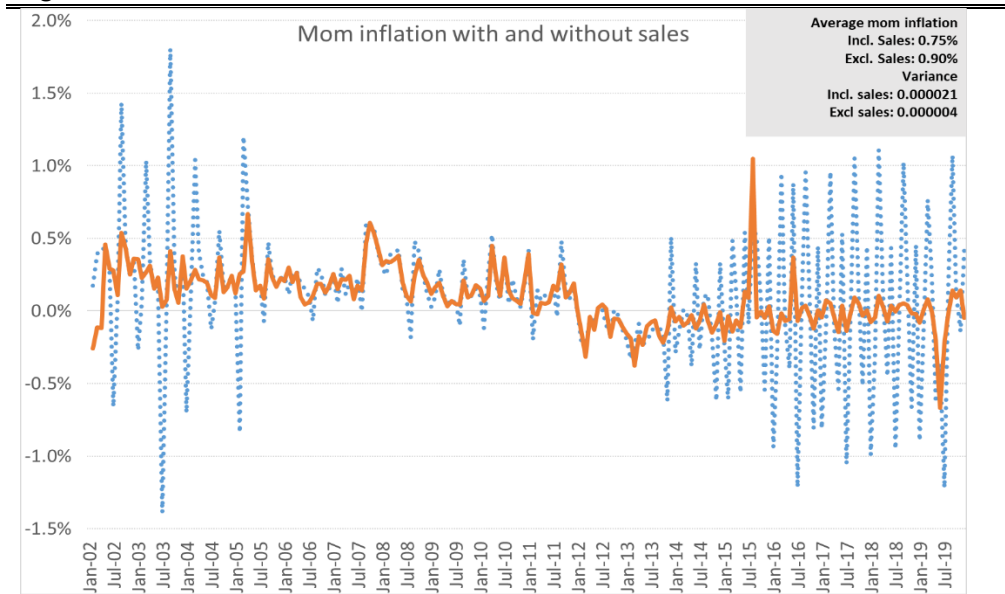
- Gautier E., Conflitti C., Faber P.R., Fabo B., Fadejeva L., Jouvanceau V., Menz J-O., Messner T., Petroulas P., Roldan-Blanco P., Rumler F., Santoro S., Wieland E., Zimmer H. (2022). New facts on consumer price rigidity in the euro area, ECB working paper No 2670.
- Golosov, M., Lucas R. (2007). 'Menu costs and Phillips curves', *Journal of Political Economy*, Vol. 115, pp. 171–199.
- Izquierdo M. and Jimeno, J.F. (2015). Employment, wage and price reactions to the crisis in Spain: firm-level evidence from the WDN survey. Bank of Spain Occasional Paper No. 1503.
- Kehoe P., Midrigan V. (2007). Sales, Clustering of Price Changes, and the Real Effects of Monetary Policy, Federal Reserve Bank of Minneapolis, Working Paper No. 652.
- Klenow, P. J., Kryvtsov, O. (2008). State-Dependent or Time-Dependent Pricing: Does It Matter for Recent U.S. Inflation? *The Quarterly Journal of Economics*, 123(3):863-904.
- Klenow, P.J., Malin, B. (2011). 'Microeconomic evidence on price-setting, handbook of monetary economics', in: Friedman, B. and Woodford, M. (eds), *Handbook of Monetary Economics*, edition 1, Vol. 3, chapter 6, Amsterdam: Elsevier, pp. 231–284.
- Kryvtsov O., Vincent N. (2021). The Cyclicalities of Sales and Aggregate Price Flexibility. *The Review of Economic Studies* 88(1): 334-377.
- Mackowiak, B., Smets, F. (2008). On Implications of Micro Price Data for Macro Models. CEPR discussion paper 6961 and ECB Working Paper 960.
- Midrigan V. (2011). Menu Costs, Multiproduct Firms, and Aggregate Fluctuations. *Econometrica* 79 (4): 1139–80.
- Nakamura, E. and Steinsson, J. (2008a). Five Facts about Prices: A Reevaluation of Menu Cost Models. *The Quarterly Journal of Economics*, 123(4):1415-1464.
- Nakamura, E. and Steinsson, J. (2008b). Supplement to Five Facts about Prices: A Reevaluation of Menu Cost Models". *The Quarterly Journal of Economics*, 23(4):1415-1464.
- Nakamura, E. and Steinsson, J. (2010). Monetary Non-Neutrality in a Multi-Sector Menu Cost Model. *The Quarterly Journal of Economics*, 125(3):961-1013.
- Nakamura, E., Steinsson, J., Sun, P., and Villar, D. (2018). The Elusive Costs of Inflation: Price Dispersion during the U.S. Great Inflation. *The Quarterly Journal of Economics*, 133(4):1933-1980.
- Porqueddu M. and Fabiabi, S. (2017). Changing prices...changing times: evidence for Italy. ECB Working Paper No. 2002.
- Tavlas G. (2019) *The Theory of Monetary Integration in the Aftermath of the Greek Financial Crisis*
- Vavra, J. (2014). 'Inflation dynamics and time-varying volatility: new evidence and an Ss interpretation', *Quarterly Journal of Economics*, Vol. 129, pp. 215–258.

Wulfsberg F. (2016). “Inflation and Price Adjustments: Micro Evidence from Norwegian Consumer Prices 1975–2004” *American Economic Journal: Macroeconomics*; 8(3): 175–194.

Appendix A:

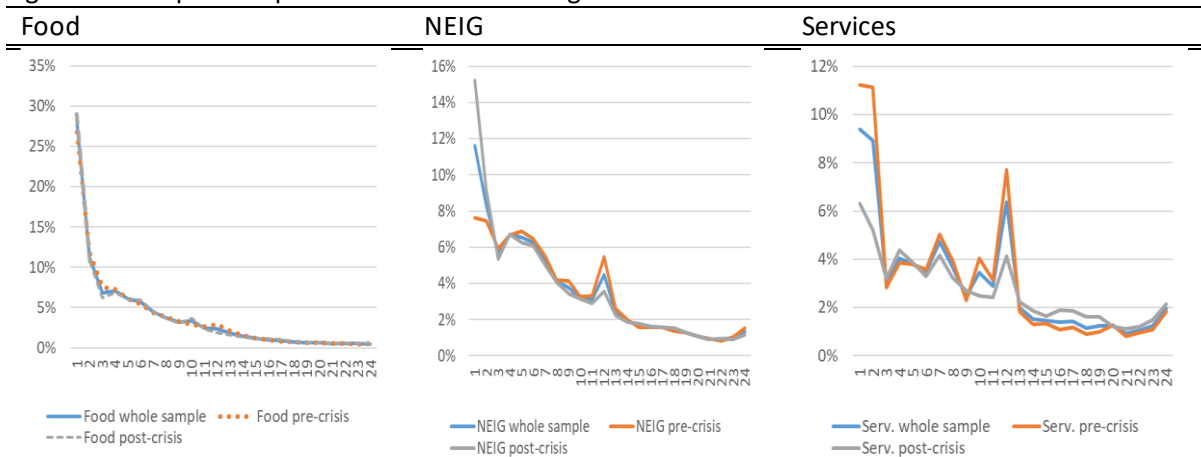
A1: Figures and Tables referred to in the text.

Figure A1: Constructed MoM inflation



Source: Elstat and authors calculations

Figure A2: DD pre and post crisis for broad categories



Source: Elstat and authors calculations

Table A1: Items/Products with no price change for 15 years in at least 1 outlet.

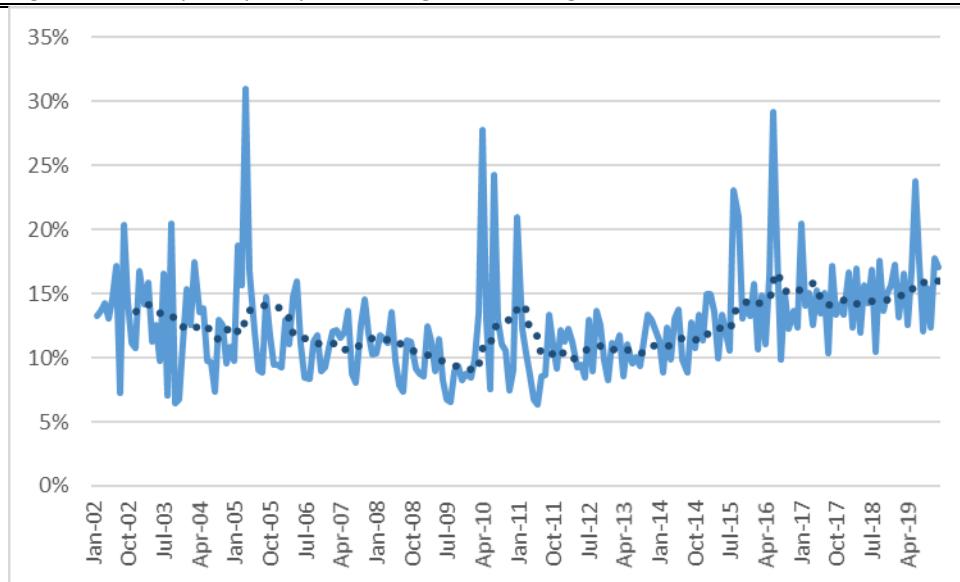
1	X - COLA SERVED	36	KEY CONSTRUCTION	71	PENCILCASE
2	CHEST X-RAY	37	SCREWDRIVER	72	SCHOOL NOTEBOOK
3	SHOCK ABSORBER	38	FIREWOOD	73	TOAST / SANDWICH TOAST / SANDWICH IN A
4	LIGHTER	39	COFFEE GREEK SERVED	74	CANTEEN
5	MEN'S HAIRCUT	40	INSTANT COFFEE IN A CANTEEN	75	KITCHEN TABLE
6	CAR ANTI-REFRIGERATOR	41	READY MADE CAKE	76	ROSES
7	SUITCASE	42	GARDEN PRUNER	77	FRONT LIGHT OF A CAR
8	SWEET SERVED	43	COMMON / SATELLITE TV ANTENNA	78	ZIPPER
9	MYOPIA GLASSES (LENSES)	44	DOLLS	79	OIL FILTER
10	GYMNASTICS	45	TEASPOON	80	PORTABLE ICE FRIDGE
11	WOMEN'S HAIRSTYLE	46	LIPSTICK	81	PHYSIOTHERAPY
12	CORRECTIVE	47	FOREIGN LANGUAGE DICTIONARY	82	PLANT IN A POT
13	IMPORTED FLOWERS	48	SWIMMING LESSONS	83	PHOTOCOPIES
14	FOOTBALL / BASKETBALL TICKETS	49	FOOD KNIFE	84	X - COLA IN CANTEEN
15	EDUCATIONAL CD-ROM	50	CLOTHES PROCESSING	85	BRIEFCASE
16	CAR TIRE	51	MICROBIOLOGICAL EXAMINATION (BLOOD)	86	CHRYSANTHEMA
17	DOG VACCINATION	52	FOOTBALL BALL / BASKETBALL	87	GOLDEN WEDDING RINGS
18	DVD RENTAL	53	BABY'S FEEDING BOTTLE	88	GOLDEN CROSS
19	TOOTH EXTRACTION RELIGIOUS CEREMONY (FUNERAL)	54	ICE CREAM SERVED	89	SOIL FOR PLANTS
20	EXPENSES	55	PUZZLE	90	CONSERVATORIES
21	OUTBOARD MOTOR	56	PLAYMOBIL TYPES TOYS		
22	SHOE REPAIRS	57	CRUTCHES		
23	WASHING MACHINE REPAIR	58	DRAWING / PAINTING BRUSH		
24	VISIT TO A CARDIOLOGIST	59	CAR WASH		
25	VISIT TO AN ORTHOPEDIC	60	ORANGE SOFT DRINK, SERVED		
26	VISIT TO AN OPHTHALMOLOGIST	61	BUMPER		
27	VISIT TO A PATHOLOGIST	62	SEA RACKETS & TYPE TENIS BALLS		
28	HOUSE PAINTER WORKS	63	CLOCK/ALARM-CLOCK		
29	ELECTRICIAN WORKS	64	SOUVLAKI		
30	PLUMBER WORKS	65	SEA MATRESS		
31	GREETING CARD / POSTER	66	BALL PEN		
32	CARPET CLEANING & STORAGE	67	ELEVATOR MAINTENANCE MAINTENANCE CENTRAL HEATING		
33	DENTAL CLEANING	68	BURNER		
34	BUILDING CLEANING	69	DENTAL FILLINGS		
35	FISHING ROD	70	DRIVING SCHOOL		

Note: Blue colour denotes items/products where no price change has occurred for the entire sample in at least 1 outlet.

Table A2: Summary of Frequencies and sizes of price changes 2002-2019

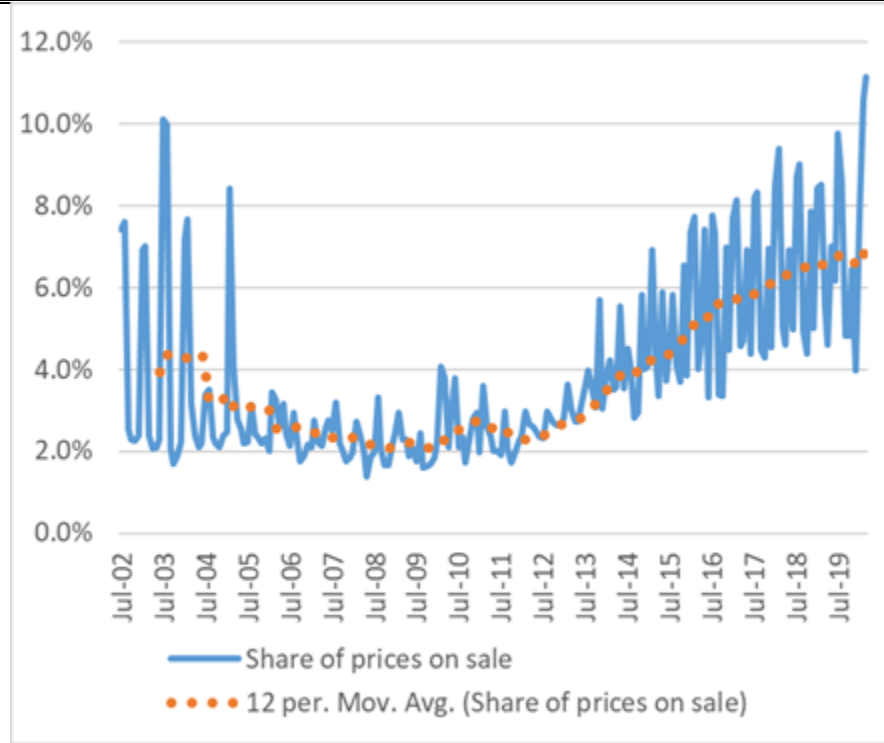
Period	Freq up	Freq down	Size up	Size down
2002-2019 Full sample	5.30%	3.30%	10.50%	12.70%
2002-2010 Pre-crisis	6.30%	2.90%	8.50%	10.50%
2011-20 Post-crisis	4.40%	3.70%	12.60%	14.90%

Figure A3: Frequency of price changes, including sales



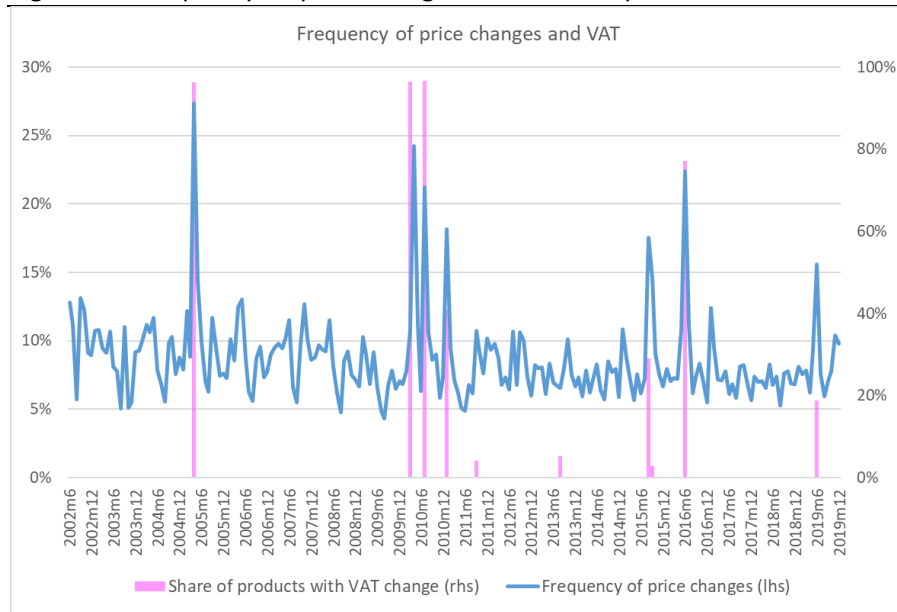
Source: ELSTAT, calculation by authors

Figure A4: Share of prices on sale in Greece



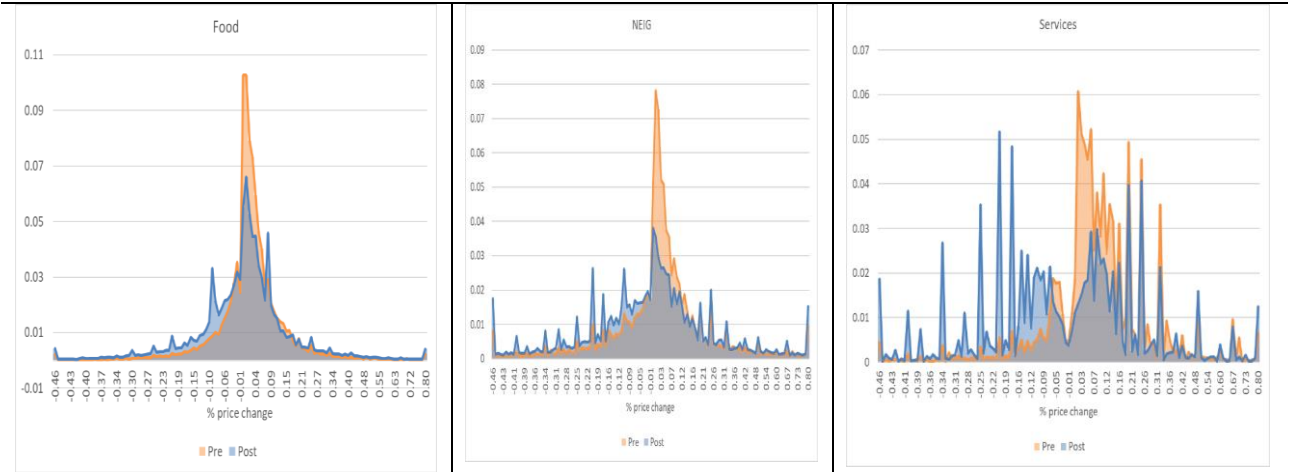
Source: Calculation by authors

Figure A5: Frequency of price changes and share of products with VAT changes



Source: ELSTAT, calculation by authors

Figure A7: Pre and post distribution of price changes, broad categories



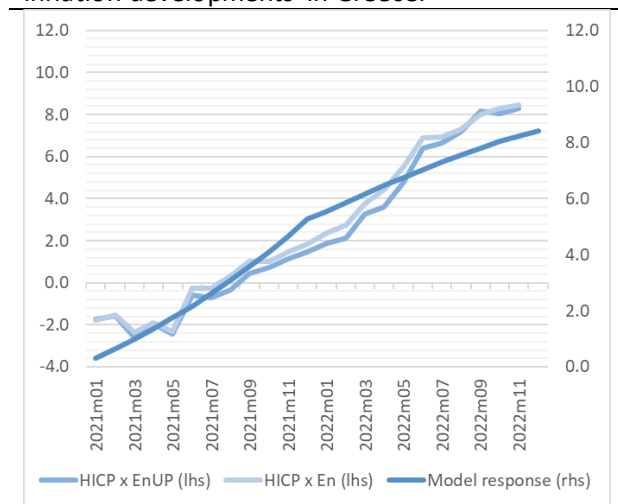
Source: ELSTAT, calculation by authors

Appendix B:

Additional simulations

In the first simulation (Figure B1), we are interested to see whether our results produce accurate out-of-sample simulations for core inflation in Greece. In particular, calibrate a shock equivalent

Figure B1: Out of sample simulation of core inflation developments in Greece.



Source: calculation by authors

to the energy price developments seen in Greece during 2021. We need to remember that our regression analysis is conducted for the period up to December 2019.

During 2021, the energy component of HICP increased from -9% year on year to +40%. On month-on-month terms, this implies an increase of 2.58% on average, which, using the energy weight of HICP implies an average shock of 0.3% month-on-month to headline HCIP. Thus, we shock our model with a 'persistent' shock of 0.3% to the month on month inflation and

observe what it implies for core-inflation developments.

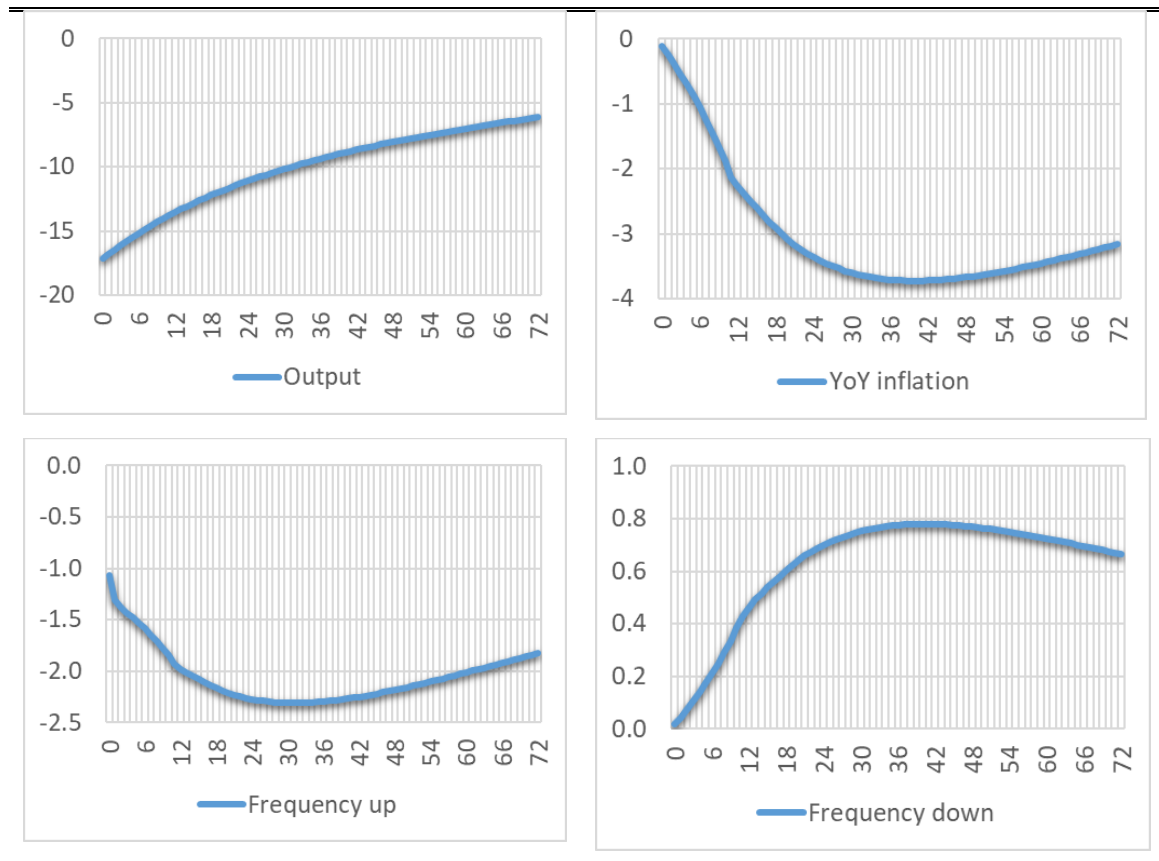
We compare the model based implications with developments in the actual annual core inflation (excluding energy and excluding energy and unprocessed food) in Greece for the period January 2021 to November 2022. The magnitude of the model-based response is in line with actual developments observed in Greece. Lastly, we can note that during 2022 with the war in Ukraine the energy contribution to headline inflation increases temporarily to 0.47% month-on-month.

In the second simulation we shock output growth so that output growth reaches about -20% year on year, which is approximately the largest decline observed in the retail volume sales growth during the crisis. The shock is persistent (The volume index on retail sales itself, i.e. the level of output, declined from about 180 to around 100 over the crisis period, cumulatively that is about 44%).

The main difference here is that we switch off the interest rate channel with respect to output. This is in line actual developments for Greece as the country: 1) does not have an independent

monetary policy, being part of the euro area 2) was excluded from most monetary policy operations as it entered the rescue program.

Figure B2: Impulse responses of a persistent shock to output



A large and persistent negative shock to output produces results for inflation and frequencies similar to those observed in Greece during the post crisis period. Annual inflation rates in the HICP excluding energy as well the frequencies of increases and decreases moved by similar magnitudes.

In sum, the model is able to reproduce both in sample as well as out-of-sample developments with respect to core inflation developments in Greece.