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Klaus Adam [1]
Erwan Gautier [2]
Sergio Santoro [3]
Henning Weber [4]

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[1] University of Mannheim, CEPR, and CESIfo
[2] Banque de France
[3] Banca d'Italia
[4] ECB and Deutsche Bundesbank)

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Klaus Adam (University of Mannheim, CEPR, and CESIfo)
Erwan Gautier (Banque de France)
Sergio Santoro (Banca d'Italia)
Henning Weber (ECB and Deutsche Bundesbank)

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Abstract

Using micro price data underlying the Harmonized Index of Consumer Prices in France, Germany and Italy, we estimate relative price trends over the product life cycle and show that minimizing price and mark-up distortions in the presence of these trends requires targeting a significantly positive inflation target. Relative price trends shift the optimal inflation target up from a level of zero percent, as suggested by the standard sticky price literature, to a range of 1.1%- 2.1% in France, 1.2%-2.0% in Germany, 0.8%-1.0% in Italy, and 1.1-1.7% in the Euro Area (three country average). Differences across countries emerge due to systematic differences in the strength of relative price trends. Other considerations not taken into account in the present paper may push up the optimal inflation targets further. The welfare costs associated with targeting zero inflation turn out to be substantial and range between 2.1% and 4.5% of consumption in present-value terms.

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Non-Technical Summary

This paper estimates the optimal inflation rate that minimizes the welfare consequences of distorted relative prices in France, Germany and Italy. Prices of goods and services can get distorted by inflation whenever nominal prices are 'sticky', e.g., when they adjust only infrequently over time. In such a situation, inflation can cause the relative price of goods to drift: positive rates of inflation, for instance, cause the relative price of goods to fall over time in the absence price adjustments; likewise, deflation causes the relative price of goods to increase over time.

In light of this, the present paper answers a simple question: what drift in relative prices should monetary policy implement in order to maximally align prices with their efficient values? It shows that price stickiness makes it optimal to target positive rates of inflation in all three countries considered. This is optimal because it is efficient - on average across products - that relative product prices fall over time, albeit at different speeds across countries.

This finding represents a significant departure from standard arguments made in the sticky price literature, which - for its vast majority - rely on models that do not allow for efficient trends in relative prices (on average across products). As a result, standard models conclude that the optimal inflation rate is zero or very close to zero. The present paper shows that this is far from true: price stickiness alone causes an inflation rate between 1.1% and 1.7% to be optimal in the Euro Area.

Clearly, a complete consideration of the question of the optimal inflation target must also take other aspects into account that are not accounted for within the present paper. These considerations comprise the desire to avoid hitting the lower bound constraint on nominal interest rates, the desire to avoid deflation in individual countries forming a heterogeneous currency union, and a range of other factors from which the present paper abstracts. This said, the optimal inflation rates estimated in the present paper shift an important cornerstone determining the optimal inflation target within such a more complete analysis.

Considering the micro price data underlying the construction of the Harmonized Index of Consumer Prices (HICP) in France, Germany and Italy the paper estimates the efficient rates of relative price increase/decrease over the product life cycle for a large set of products. While the efficient relative price trends differ widely across different product categories, they show considerable persistence over time and display common patterns across countries. In particular, the relative price of goods falls rather strongly over

the product lifetime in all countries, even if this effect is somewhat less pronounced in Italy. The relative price of services, however, is largely stable over the product lifetime (France and Italy) or even slightly increases over time (Germany). Taken together these facts imply that the efficient relative price falls, on average across goods and services, so that a significantly positive rate of inflation is optimal in all three countries.

If the central bank targets an inflation rate of zero in such a setting, as would be prescribed by standard sticky price models that do not allow for trends in relative prices, then this generates considerable distortions in relative prices and an increase in average mark-ups. As a result, economic welfare declines by several percentage points in consumption-equivalent terms. Targeting an inflation rate of zero would thus be severely suboptimal.

1 Introduction

The fact that nominal prices fail to flexibly adjust over time is one of the key reasons why inflation can give rise to significant welfare costs. The idea that inflation can generate price misalignments and through these misalignments welfare losses goes back all the way to Lucas (1972) and Phelps (1970). It is enshrined in its modern form, following Woodford (2003), in virtually all structural economic models entertained by central banks.

Minimizing price and quantity misalignments is central in monetary economics because it has proven to be a quantitatively important force determining the optimal inflation target in monetary policy models, see Schmitt-Grohé and Uribe (2010) for an overview. While optimal targets are also affected by a range of additional considerations, e.g., by the presence of a lower-bound constraint on nominal rates (Adam and Billi (2006, 2007), Coibion, Gorodnichenko and Wieland (2012), L'Huillier and Schoenle (2020)), by the desire to overcome downward rigidities in nominal wages (Kim and Ruge-Murcia (2009)), or by the desire to minimize cash distortions (Khan, King and Wolman (2003)), these additional considerations tend to move the inflation target only by quantitatively small amounts under (Ramsey) optimal monetary policy.[1]

Standard monetary models thus conclude that the central bank should target an inflation rate of zero or very close to zero to minimize the effects of price misalignment. Interestingly, policymakers have - at least implicitly - taken this message on board. The European Central Bank (ECB), for example, when providing its justification for an inflation objective of "close to but below two percent", lists three reasons why its objective is *higher than zero*, thereby acknowledging that zero inflation is an important reference point.[2] The goal of the present paper is to show that the reference point of zero inflation is misguided when it comes to determining the optimal inflation target for the Euro Area and that the reference point should be significantly higher than zero.

In recent work, Adam and Weber (2019) spell out a general theory of price and quantity distortions that takes into account that modern economies

[1]This is true with some exceptions. Adam, Pfaeuti and Reinelt (2020) show, for instance, how the effective lower bound on nominal rates can - in combination with low natural rates of interest - justify targeting significantly positive rates of inflation under optimal monetary policy. This, however, requires deviations from the standard model in the form of subjective housing price expectations.

[2]The ECB states the following three reasons for picking a positive inflation objective: (1) the lower-bound constraint and associated deflation risks, (2) the heterogeneity in country-level inflation rates and the desire to prevent deflation in individual countries, and (3) the potential overstatement of the true inflation rate due to unaccounted quality progress. Our estimates fully take into account reason (3), because unaccounted quality progress of new products causes the relative price of existing products to fall, which in turn causes positive rate of inflation to be optimal. The three reasons listed above are stated at: https://www.ecb.europa.eu/mopo/strategy/pricestab/html/index.en.html

are characterized by a high degree of product (or firm) turnover. They show that the optimal inflation target minimizing price and quantity distortions then ceases to be zero. Instead, the optimal target is determined by the efficient trends in relative prices over the lifetime of products. Specifically, if the relative price of products optimally declines over the product lifetime, then positive inflation becomes optimal, as we explain further in section 2.[3]

The previous insight has the potential to shift an important goal post relevant for monetary policy design and the aim of the present paper is to determine its quantitative importance in the Euro Area. Importantly, the paper shows that taking into account the presence of trends in relative prices shifts the reference inflation rate in the Euro Area up to a level between 1.1% and 1.7%. This represents a quantitatively sizable shift.[4]

Our analysis focuses on the three largest Euro Area economies (France, Germany and Italy), which jointly account for 64% of Euro Area GDP in 2019. Specifically, we estimate the efficient relative price trends in these economies for a large number of product categories and use these estimates to provide a theory-consistent estimate of the aggregate inflation rate that minimizes the welfare effects of relative price distortions. The micro price data used in our analysis has recently become available under the Eurosystem's PRISMA (Price-setting Microdata Analysis) research network. It is used for the construction of the Euro Area's Harmonized Index of Consumer Prices (HICP) and contains more than 80 million price observations. The data covers between 65% and 84% of the HICP expenditure basket in the considered countries, which compares favorably to prior comparative analyses of micro price data in the Euro Area, e.g., the ones conducted shortly after inception of the Euro Area under the Eurosystem's Inflation Persistence Network. Dhyne et al. (2006), for instance, considered a larger set of Euro Area countries, but only 50 rather narrowly defined products.

Our estimates for the period 2015-2019 show that the optimal inflation rate minimizing the welfare costs associated with relative price distortions ranges between 1.1% and 2.1% in France, between 1.2% and 2.0% in Germany and between 0.8% and 1.0% in Italy.[5] The optimal inflation rates are significantly above zero but also display quite some heterogeneity.

Given the high degree of data coverage for the Euro Area, we also provide an estimate of the optimal Euro Area inflation target using the evidence

[3]In a setting without product turnover, relative price trends are naturally zero: products can (on average across products) neither appreciate nor depreciate in price against the average product. Simple models without product turnover thus conclude that the optimal inflation target is zero.

[4]This does not imply that the inflation target in the Euro Area, which takes into account also other considerations, is moved by the same amount. The desire to avoid deflation in individual countries, for instance, becomes a less strong concern for Euro Area monetary policy, if the reference inflation rate is already higher than zero.

[5]The estimate for Italy is for the period 2016-2019, for reasons discussed in the main text.

obtained from the three largest Euro Area economies, with alternative estimation approaches delivering a range between 1.1% and 1.7%. Clearly, taking into account additional considerations relevant for determining the optimal inflation target, e.g., the existence of a lower-bound constraint for nominal rates, will likely raise the optimal inflation target further. While a full quantitative analysis taking into account such additional considerations is beyond the scope of the present paper, it is an interesting subject for future research.

If we focus on a subsample comparable across countries, optimal inflation targets that minimize price and mark-up distortions differ across France, Germany and Italy, because of important differences in the relative prices trends present at the disaggregate level. In particular, we show that positive rates of inflation are mainly due to the behavior of goods prices, while service prices, but also food prices, contribute very little or make even negative contributions.

Relative price trends in goods prices are about twice as strong in France and Germany compared to Italy, which is to a large extent due to a higher trend rate in the expenditure category "clothing and footwear". As a result, the optimal inflation rate in the former two countries is considerably higher than in Italy.

Relative price trends display a considerable amount of positive correlation across France and Germany at the disaggregated level (COICOP3), but Italy looks different.[6] Relative price trends in Italy are overall weaker and covary only little with the ones in Germany at the COICOP3 level. We show that this is partly due to the fact that the rates of same-good price inflation in Italy are uncorrelated with the ones in Germany. The inflation rates, which include inflation contributions from old *and* new goods, covary nevertheless considerably between Germany and Italy at the disaggregate level.[7]

We also investigate how the optimal inflation rates have changed over time, by analyzing how efficient relative price trends changed over time. Comparing the baseline period (2015/6-2019) to equally long periods preceding the baseline period, we find that optimal inflation was either very stable over time or might have declined somewhat. A remarkable feature of the data is that there exists a strong positive correlation over time for the optimal inflation rates a disaggregate expenditure level (COICOP3) in each of the three countries. This suggests that relative price trends tend to be rather stable over time. This in turn would imply that our estimates for the optimal inflation rate in the baseline period (2015/6-2019) are also relevant for what is optimal in the not too distant future, i.e., once the effects of the

[6]COICOP (Classification of Individual Consumption by Purpose) is a product classifiation system used by statistical agencies in the Euro Area.

[7]Yet, the level of inflation is generally lower in Italy.

Covid crisis will have dissipated.

Finally, we quantify the welfare costs associated with suboptimal rates of inflation. To this end we derive a new analytic result that allows us to compute (to second-order accuracy) the consumption-equivalent welfare costs of suboptimal inflation rates in a setting with heterogeneous efficient price trends. We then compute the present value of consumption-equivalent welfare costs in the Euro Area for two alternative scenarios. In the first scenario, we assume that inflation stays permanently at its low average levels displayed over the period 2015/6-2019 in the considered countries. Aggregate welfare losses related to price distortions are overall small and do not exceed 0.5% of consumption in present-value terms. In the second scenario, we counterfactually assume that the central bank targets an inflation rate of zero percent, as would be optimal in the absence of relative price trends. Aggregate welfare losses are then substantial and range between 2.1% and 4.5% of consumption in present-value terms. This shows how welfare costs quickly rise with the deviation from the optimal target and how the normative prescriptions coming out of standard sticky price models (zero inflation) give rise to severely suboptimal outcomes.

The next section explains why positive inflation rates are optimal in a setting in which the price of products, measured relative to closely competing products, falls over the product lifetime. Section 3 derives our new analytic result characterizing the consumption-equivalent welfare losses of suboptimal inflation for a setting with heterogeneous relative price trends across expenditure categories. Section 4 describes the underlying micro price data, presents key descriptive statistics and explains how we estimate optimal inflation targets. The main results on the optimal targets and how they change over time are presented in section 5. Section 6 discusses the welfare implications of suboptimal inflation rates. Section 7 takes a closer look at the underlying heterogeneity in relative price trends that gives rise to different levels for the optimal inflation rate in the aggregate. A conclusion briefly summarizes the main findings.

2 The Argument for a Positive Inflation Target

Modern economies are characterized by a large amount of product turnover. This feature is documented in a number of micro studies (e.g., Nakamura and Steinsson (2008), Broda and Weinstein (2010)) and can have important implications for the inflation rate that minimizes price distortions. To summarize arguments made in Adam and Weber (2019), suppose it is efficient that new products are initially expensive, when measured *relative* to the average price of a narrowly-defined set of competing products, but become cheaper in relative terms over their lifetime. This may happen, for instance, due to learning-by-doing effects, which give rise to productivity gains over the product lifetime. We show, in fact, that - on average across products - the efficient relative price of products declines over their lifetime in all three economies we consider.

Minimizing relative price distortions in a setting where efficient relative prices decline over the product lifetime and nominal prices are sticky requires that the central bank targets a positive rate of inflation. To understand why this is the case, consider two alternative approaches for implementing this efficient decline in relative product prices, depicted in figure 1.

The first approach, depicted in panel (a) of figure 1, lets all newly entering products charge some high initial price $\overline{P}$ and subsequently lets them cut the nominal price at some constant rate over the product lifetime, until products exit at some lower price $\underline{P}$. With constant product entry and exit rates, the cross-sectional distribution of product prices and thus the average product price is constant over time: there is zero inflation, even though relative prices of all individual products decline over the product lifetime. Importantly, this setting requires ongoing adjustments of product prices, i.e., constant price cuts. When nominal prices are sticky, these price adjustments tend to happen inefficiently and will lead to price misalignments and thus welfare losses.

An alternative and preferable approach is to have constant nominal prices for existing products over time, as depicted in panel (b) in figure 1: individual prices then do not need to adjust. One can nevertheless implement a decline in *relative* prices, simply by having newly entering products charge a higher (but also constant) price than the average existing product. This way, relative prices decline because the average product price keeps rising over time: there is positive inflation. Provided the inflation rate in panel (b) equals the negative of the (efficient) rate of relative price decline in panel (a), individual prices do not need to adjust at all, which is desirable whenever prices are sticky, as it avoids price misalignments.[8] A positive average rate of inflation thus helps implementing an efficient decline in relative prices over the product lifetime, without requiring adjustments in the prices of individual goods.[9]

The situation depicted in figure 1 is of course idealized. It assumes that the strength of the efficient relative price decline is identical across products. In practice, the efficient rate of relative price decline varies considerably across expenditure categories. For instance, it tends to be fast for electronic goods and or products containing a fashion or news component, but slower for more conventional goods, e.g., food and beverages. The optimal inflation target must thus trade off the relative-price distortions it generates across different expenditure categories.

[8]This holds true for different forms of price stickiness, i.e., menu-costs and time-dependent pricing frictions.

[9]Adam and Weber (2020) show that this holds true even if the observed decline in relative prices is due to unaccounted quality improvements of new goods.

Figure 1: Relative price trends and the optimal inflation rate

Proposition 2 and lemma 1 in Adam and Weber (2020) show that the optimal inflation target for such a more general setting is given (to a first-order approximation) by the expenditure-weighted average of the different rates of (efficient) relative price decline:[10]

$$\Pi^{\star} = \sum_{z=1}^{Z} \psi_z \cdot \frac{\gamma_z^e}{\gamma^e} \cdot b_z, \tag{1}$$

where $\Pi^{\star}$ denotes the optimal (gross) target for aggregate inflation, ψ_z the expenditure weight of product category $z = 1, ..., Z$, γ_z^e the (efficient gross real) growth rate of expenditures in category z, γ^e the (efficient gross real) growth rate of overall expenditures, and b_z the (efficient gross) rate of price *decline* for products in expenditure category z over their lifetime, measured relative to the cross-sectional average price of products in this category, as explained in detail below.

When the efficient relative price of products declines over time, we have $b_z > 1$. This contributes to a positive inflation target in equation (1), in line with graphical arguments made in figure 1. Conversely, if it is efficient that relative prices rise, we have $b_z < 1$, which causes deflation to be optimal. Equation (1) shows that relative price trends pertaining to expenditure categories with a high expenditure weight (ψ_z) or to categories with a high relative growth rate (γ_z^e/γ^e) have a larger impact on the optimal inflation target.

We shall use equation (1) to determine country-level optimal inflation targets. Yet, the linear structure embedded in equation (1) implies that one can aggregate the nationally optimal inflation targets further to the level of

[10]Again, this holds independently of the assumed nature of price stickiness (time dependent versus state dependent stickiness).

a currency union, using country-level expenditure weights and expenditure growth rates.

The *efficient* rate of relative price decline b_z in equation (1) can be estimated from the *actual* decline in relative prices, as observed in micro price data. This is so because price-setting and other frictions cause only level distortions to relative prices, but leave their time trend unaffected.[11] We can thus estimate the efficient rate of relative price decline b_z using linear panel regressions of the form

$$\ln \frac{P_{jzt}}{P_{zt}} = f_{jz} - \ln(b_z) \cdot s_{jzt} + u_{jzt}, \tag{2}$$

where P_{jzt} denotes the price of product j in expenditure category z at time t, P_{zt} the price index in category z, f_{jz} a product and category-specific intercept term, s_{jzt} the in-sample age of the product (normalized to zero at the date of product entry), and u_{jzt} a mean zero residual potentially displaying serial and cross-sectional dependence. The coefficient of interest is the slope coefficient b_z, which measures the (gross) average rate of relative price decline over the product lifetime in expenditure category z. As stated before, we have $b_z > 1$ ($b_z < 1$) if relative prices fall (rise) over the product lifetime.

3 The Welfare Costs of Suboptimal Inflation

Equipped with an estimate of the optimal inflation target, one can seek quantifying the welfare costs associated with historically low inflation outcomes in the Euro Area and with the ECB's inflation target. To do so, this section presents a new analytic result characterizing the welfare costs of suboptimal inflation rates in a setting with heterogenous efficient trends in relative prices. The result allows to compute - to second-order accuracy - the welfare-equivalent consumption loss associated with a steady-state inflation rate Π that deviates from the country-specific optimal inflation rate $\Pi^{\star}$, as defined in equation (1).

We derive the result for the underlying theoretical setup spelled out in Adam and Weber (2020), which features sticky prices and households that have balanced-growth consistent time-separable preferences over consumption and leisure. Household consumption is a Cobb-Douglas aggregate over Z different product categories, which we interpret as COICOP5 expenditure categories. These categories enter aggregate consumption with a Cobb-Douglas expenditure weight ψ_z, which we interpret as the COICOP5 expenditure weights in the HICP basket. Each expenditure category $z \in \{1, ..., Z\}$ is itself a Dixit-Stiglitz aggregate of a continuum of individual goods with demand elasticity $\theta > 1$.

[11] See proposition 3 in Adam and Weber (2020).

Individual product prices are sticky with Calvo stickiness parameter $\alpha_z \in (0,1)$ and individual products enter and exit the economy at the exogenous rate $\delta_z \in (0,1)$ per period. The efficient lifetime trends in relative product prices, b_z, defined in equation (2), emerge due to productivity and quality trends that are present at the product level, as explained in detail in Adam and Weber (2020).[12] Sector-specific productivity trends cause real expenditure for category z to increase at the (efficient gross) balanced growth rate γ_z^e and the aggregate economy expands at the (efficient gross) balanced growth rate γ^e. Discounted steady-state utility grows at the rate $\beta(\gamma^e)^{1-\sigma} < 1$, where β is households' time discount factor and $\sigma > 0$ the coefficient of relative risk aversion. In the steady state, the government may pay an arbitrary output subsidy τ (or levy an output tax if τ is negative), which may ameliorate (amplify) the distortionary effects of monopolistic competition.

Within this setup, we can derive the following analytic result about the consumption-equivalent welfare losses associated with a suboptimal inflation rate:

Proposition 1 *Suppose the output subsidy/tax satisfies* $1+\tau \in (0, \theta/(\theta-1)]$ *and consider the limit* $\beta(\gamma^e)^{1-\sigma} \to 1$. *The per-period consumption-equivalent welfare loss associated with a deviation of the (gross) steady-state inflation rate* Π *from its optimal rate* $\Pi^\star$ *is*

$$\frac{c(\Pi) - c(\Pi^\star)}{c(\Pi^\star)} = -\frac{1}{2}\phi \left.\frac{\mu''(\Pi)}{\mu(\Pi)}\right|_{\Pi=\Pi^\star} (\Pi - \Pi^\star)^2 + O(3) \tag{3}$$

where $O(3)$ *denotes a third-order approximation error,* ϕ *is the inverse of the labor share in production, and* $\mu''(\Pi)/\mu(\Pi)$ *captures the convexity of the aggregate mark-up* μ *with respect to the inflation rate. Evaluating the latter term at the optimal inflation rate* $\Pi^\star$ *delivers*

$$\left.\frac{\mu''(\Pi)}{\mu(\Pi)}\right|_{\Pi=\Pi^\star} = \frac{\theta\tilde{\alpha}\left(\Pi^\star\right)^{\theta-3}}{\left(1-\tilde{\alpha}\left(\Pi^\star\right)^{\theta-1}\right)\left(1-\tilde{\alpha}\left(\Pi^\star\right)^{\theta-1}\right)}. \tag{4}$$

The welfare-equivalent consumption loss in equation (3) is approximated at a point where $b_z\frac{\gamma_z^e}{\gamma^e}$ *and* $\widetilde{\alpha}_z \equiv \alpha_z(1-\delta_z)(\gamma^e/\gamma_z^e)^{\theta-1}$ *are constant across across expenditure categories* $z = 1, \ldots Z$ *and is valid for first-order variations in both of these variables across categories* z.

Proof. See appendix A. ■

[12] It is straightforward to map b_z into the fundamental parameters characterizing productivity and quality trends in Adam and Weber (2020). We have $b_z = g_z/q_z$, where g_z is the (gross real) productivity growth rate due to learning-by-doing that is operating over the lifetime of the product and q_z is the (gross real) growth rate of initial quality (or productivity) associated with new product cohorts that come into the market.

Proposition 1 contains the first closed-form expression available in the literature determining the welfare losses of suboptimal inflation in an economy featuring heterogeneous lifetime trends in relative product prices.

The conditions regarding the output subsidy and the discount factor in proposition 1 are identical to the ones required for the optimal inflation rate $\Pi^{\star}$ to be given by equation (1). The conditions on the output subsidy are also rather weak, e.g., they do not require that monopoly power is eliminated by a Pigouvian output subsidy. The condition on the discount factor $\beta\left(\gamma^{e}\right)^{1-\sigma}$ insures that the optimal inflation rate simultaneously minimizes the aggregate effects of relative price and mark-up distortions, as mark-up and price distortions are then proportional to each other.[13]

Proposition 1 shows that the steady-state welfare losses are a quadratic function of the deviation of inflation from its optimal level $\Pi^{\star}$. The factors pre-multiplying the squared inflation deviation depend positively on the inverse of the labor share in production (ϕ) and positively on the convexity of the aggregate markup with respect to aggregate inflation, as captured by the term $\mu''(\Pi^{\star})/\mu(\Pi^{\star})$.

Intuitively, when labor is the only input in production ($\phi = 1$), price and mark-up distortions affect adversely only the allocation of labor across goods and expenditure categories. When capital is also a production factor ($\phi > 1$), then price and mark-up distortions also adversely affect the steady-state capital to labor ratio. This latter effect amplifies the welfare implications of price and mark-up distortions.

The mark-up term ($\mu''(\Pi^{\star})/\mu(\Pi^{\star})$) shows up as a pre-multiplying factor in equation (3) because it captures the welfare costs of suboptimal inflation in a setting in which there are no first-order costs, since the optimal inflation rate $\Pi^{\star}$ minimizes the aggregate welfare consequences of mark-up distortions, so that $\mu'(\Pi^{\star}) = 0$. The mark-up term depends itself on a small number of structural parameters, as shown by equation (4). Provided the optimal (gross) inflation rate is non-negative ($\Pi^{\star} \geq 1$), a larger price elasticity of demand (θ) increases convexity and thus welfare losses. This is so because any given amount of price distortions then causes larger demand distortions. Similarly and perhaps not surprisingly, the welfare costs also increase in the parameter $\widetilde{\alpha}$, which essentially captures the effective degree of price stickiness at the point of approximation.[14]

The remainder of the paper will use micro price data to estimate the optimal inflation rate for France, Germany and Italy, using equations (1)

[13] See lemma 2 in Adam and Weber (2020). This simplifies the analytic derivations, but is not of quantitative relevance for our findings, as long as the discount factor assumes the values close to one routinely considered in monetary economics.

[14] If all sectors grow at approximately the same rate ($\gamma_z^e \approx \gamma^e$), then $\widetilde{\alpha} \approx \alpha_z(1-\delta_z)$, where α_z is the Calvo stickiness parameter and $(1-\delta_z)$ the probability that the product continues to be present in the next period. This shows that $\widetilde{\alpha}$ captures (approximately) the effective degree of price stickiness.

and (2), and will quantify the welfare implications of suboptimal inflation rates in the Euro Area using the result in proposition 1.

4 Micro Price Data for France, Germany and Italy

This section describes the underlying data set, which consists of micro price data for the period 2012-2019 used in the construction of the Harmonized Index of Consumer Prices (HICP) in France, Germany and Italy. Data access has been provided to us via the Eurosystem's PRISMA (Price-setting Microdata Analysis) research network.

Euro Area micro price data has previously been analyzed in a period covering the inception of the Euro Area. In particular, Dhyne et al. (2006) document a number of key descriptive statistics for a common sample of 50 goods and services over the period 1998-2003. Their data coverage for France, Germany and Italy was only around 20% of the official basket, which required performing cross-country comparisons on a relatively small share of the total basket. Our data covers a much broader share of the expenditure basked in Germany (83.3%) and Italy (64.0%) and thus allows us to make cross-country comparison based on a much larger share of the expenditure basket. Like Dhyne et al. (2006), we make a significant effort to harmonize the data preparation and the empirical approach across countries, see appendix B for details. Furthermore, our main goal in this paper is to derive normative implications from the available data.

The data is collected on a monthly basis and contains product-level price information for goods and services purchased by private households. For most products, price collectors visit different types of outlets and shops, or request price information in a decentralized manner. For some products, price collection is centralized and based on publicly available sources on the internet. The data also contains survey-based information on the average expenditure shares at the national level.

Our analysis considers all price observations that enter the computation of the national CPI. We omit all price observations that are not originally sampled, i.e., we exclude all interpolated and imputed prices for seasonal products and for products that are out of stock. We do so because interpolation at the product level is often performed in a way that it does not alter the dynamics of elementary price indices and hence the aggregate CPI. This, however, can severely affect price trajectories at the product level and thereby bias estimates of relative price trends.

We also refine the product definition originally provided to us by national statistical institutes to avoid lumping products together over time that are effectively different. In particular, we split the price trajectories of the product time series, when price observations are missing for more than one month, when comparable or non-comparable product substitutions occur, and when either the product quality or the product quantity changes.

4.1 The Considered Sample Periods

Our baseline sample period uses data for the five year period from January 2015 to December 2019. For France, since data ends in September 2019, we use the period starting in October 2014 and ending in September 2019. To simplify the exposition, we refer to the French baseline sample also as covering the years 2015-2019. For Italy, we consider data from January 2016 to December 2019. We use a 4-year period because there has been a classification break for products in December 2015.[15] All in all, the baseline sample periods are quite comparable across countries and strike a balance between maximizing the sample length for each country and harmonization across countries.

We also consider an earlier sample period for the three countries. For Germany, this is the 5-year period from January 2010 to December 2014. For France, the earlier sample period comprises data from October 2009 to September 2014, so as to avoid overlap with the baseline sample period. Following similar conventions as for the baseline sample, we refer to the French sample as the 2010-2014 sample. To achieve comparability over time in Italy, we consider the 4-year sample period covering January 2012 to December 2015.

4.2 Sample Construction and Descriptive Statistics

Starting from all prices in the national CPI sample, we first eliminate all imputed prices, as discussed before. The fraction of imputed prices differs considerably across countries. For the baseline sample period (2015/6-2019), the share of imputed prices is 11.5% in France, 4.2% in Germany and 8.0% in Italy. This significant variation suggests that imputation procedures are far from being fully harmonized across the countries, which provides an additional reason for excluding imputed prices from our analysis.

Table 1 reports a number of descriptive statistics for the baseline sample period (2015/6-2019), after excluding imputed prices.[16] The reported statistics highlight differences across countries but also show that the available data is suitable for the analysis we wish to pursue.

The German sample is the most comprehensive one in terms of number of price observations, number of COICOP5 expenditure categories and the percentage of the expenditure share covered. The French sample contains nearly the same number of COICOP5 categories as the German sample,

[15]This makes it impossible in the Italian sample to trace product prices from December 2015 to January 2016 and prevents us from estimating relative price trends over the turn of the year 2015/2016, see appendix B.3 for details.

[16]Corresponding numbers for other samples, e.g., the earlier sample period are reported in appendix C.

	France	Germany	Italy
Total number of price observations	8.0m	30.1m	11.6m
Number of COICOP5 expenditure categories	223	234	168
Covered expenditure share (of total HICP basket)	67.2%	83.3%	64.0%
Number of price observations per COICOP5			
Mean	36.1k	128.8k	69.1k
Median	15.4k	55.7k	42.2k
Number of products per COICOP5			
Mean	3.3k	10.1k	3.9k
Median	1.0k	2.2k	1.8k

Table 1: Descriptive statistics (2015/6-2019, country-specific sample)

but significantly fewer price observations. This reflects different sampling strategies across the two countries, which might partly be due to the Federal structure of data collection in Germany. The Italian sample covers the smallest number of COICOP5 categories. In terms of the number of price observations it is located between Germany and France, especially when taking into account that the sample period is one year shorter.

Table 1 shows that the underlying micro price data covers a large part of the total HICP basket of consumption expenditures in each country. The coverage is not complete because a range of so-called centrally-collected prices have not been provided to us by the national statistical institutes. The covered expenditure share is highest in Germany because it includes, unlike in other countries, information on rent payments.

Table 1 also shows that the mean and median number of price observations at the COICOP5 level is sufficiently large in all countries to allow us to reliably estimate relative price trends. There is also a large mean and median number of products at the COICOP5 level.

While the country-specific samples in table 1 are the ones most representative at the level of each country, they are not comparable across countries. Therefore, to obtain meaningful cross-country comparisons, we consider in our baseline approach only COICOP5 expenditure categories that are present in all three countries and will refer to this data sample as the 'harmonized sample'. This rules out that country differences are driven purely by differences in the coverage of the underlying expenditure categories in national samples. Yet, we shall also analyze the full country-specific samples in robustness exercises.

Table 2 reports the same descriptive statistics as table 1 for the harmonized sample across countries. The harmonized sample covers 145 common COICOP5 expenditure categories. For Italy, the total number of price observations drops by merely 9% as a result of harmonization, but the drop is

	France	Germany	Italy
Total number of price observations	6.1m	24.6m	10.6m
Number of COICOP5 expenditure categories	145	145	145
Covered expenditure share (of country-specific data)	68.2%	51.0%	87.9%
Number of price observations per COICOP5			
Mean	41.8k	169.6k	72.8k
Median	24.7k	104.0k	49.7k
Number of products per COICOP5			
Mean	3.4k	14.2k	4.2k
Median	1.7k	3.6k	2.1k

Table 2: Descriptive statistics (2015/6-2019, harmonized sample)

more pronounced in France (24%) and Germany (18%), as the national data sets for these countries contain a significantly larger number of COICOP5 categories. There is also a corresponding drop in the expenditure weights vis-a-vis the full samples available to us. Again, this effect is least pronounced for the Italian sample. Interestingly, the mean and median number of price observations per COICOP5 category rises as a result of harmonization. The same holds true for the mean and median number of products per expenditure category. This shows that the harmonized sample mainly leaves out expenditure categories containing relatively few price observations and products.

Since we wish to estimate relative price trends over the product lifetime in a large number of expenditure categories, we also analyze for how long products are present on average in these categories within the harmonized baseline sample and using our refined product definition. Figure 2 reports the average number of months products are present for each of the 145 COICOP5 categories. For the vast majority of COICOP5 categories the average sample length of products is longer than 10 months, with average values slightly above 20 months for Italy and close to 30 months for France and Germany. Given this, we conclude that one can reliably estimate (relative) price trends at the product level.

Figure 3 reports a number of descriptive joint distributions for France and Italy vis-a-vis Germany at the COICOP5 level.[17] Each point in the figure represents a COICOP5 expenditure category and the dashed line is the 45 degree line. The panel on the top left shows that there is a strong positive correlation in the number of outlets that statistical agencies sample and that all three countries sample approximately the same number of outlets. The center and right panels in the top row of figure 3 illustrate that there is also a strong positive correlation in the number of price quotes per months

[17]To increase readability, the panels in the top row of figure 3 have truncated axis.

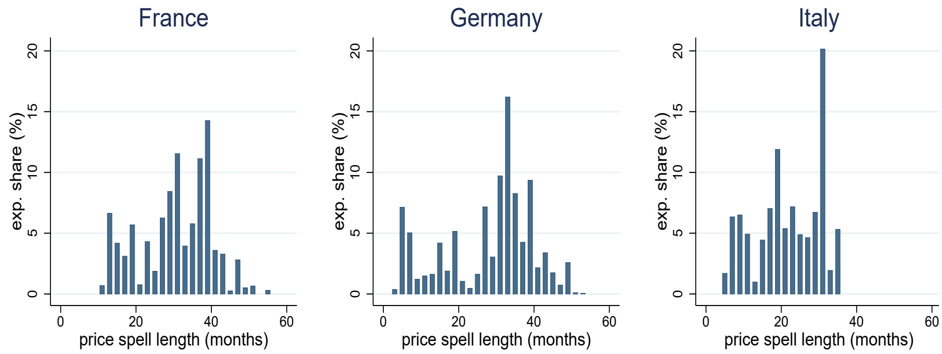

Figure 2: Average number of price observations per product at COICOP5 level (2015/6-2019, harmonized sample, expenditure-weighted distribution)

and the number of products sampled across COICOP5 categories, even if the German sample generally contains more price observations and in some cases a significantly larger number of products. The left panel in the bottom row of figure 3 shows that expenditure weights across COICOP5 categories correlate strongly across countries and are centered around the 45 degree.[18] The same holds true for the price adjustment frequencies (center panel in the bottom row) and the average product age at the time of exit from the sample (right panel in the bottom row).[19] Overall, the panels in figure 3 show that the micro price samples of the three countries share many features and thus allow to make meaningful cross-country comparisons.

4.3 The Estimation Approach

This section presents our baseline approach for estimating b_z in equation (2). Further details can be found in appendix B.

We estimate the coefficients b_z at the COICOP8 level using the monthly panel regression equation (2). We then use the resulting estimates and set ψ_z equal to the time-average of the official COICOP8 expenditure weights after normalizing them over the considered sample period. We set the relative expenditure growth term γ_z^e/γ^e in equation (1) equal to Π/Π_z, which is consistent with Cobb-Douglas aggregation, where Π_z denotes the average inflation rate in expenditure category z over the considered sample period and $\ln \Pi = \sum_z \psi_z \ln \Pi_z$ is the expenditure-weighted average inflation rate

[18]The outlier for Italy in the top right corner of this panel is COICOP 11111, "Restaurants, cafes and dancing establishments", which has a much higher expenditure weight in Italy than in Germany.

[19]One issue with computing price adjustment frequencies in the presence of product turnover is how one takes into account new products. We treat the price associated with the entry of new product as a price adjustment.

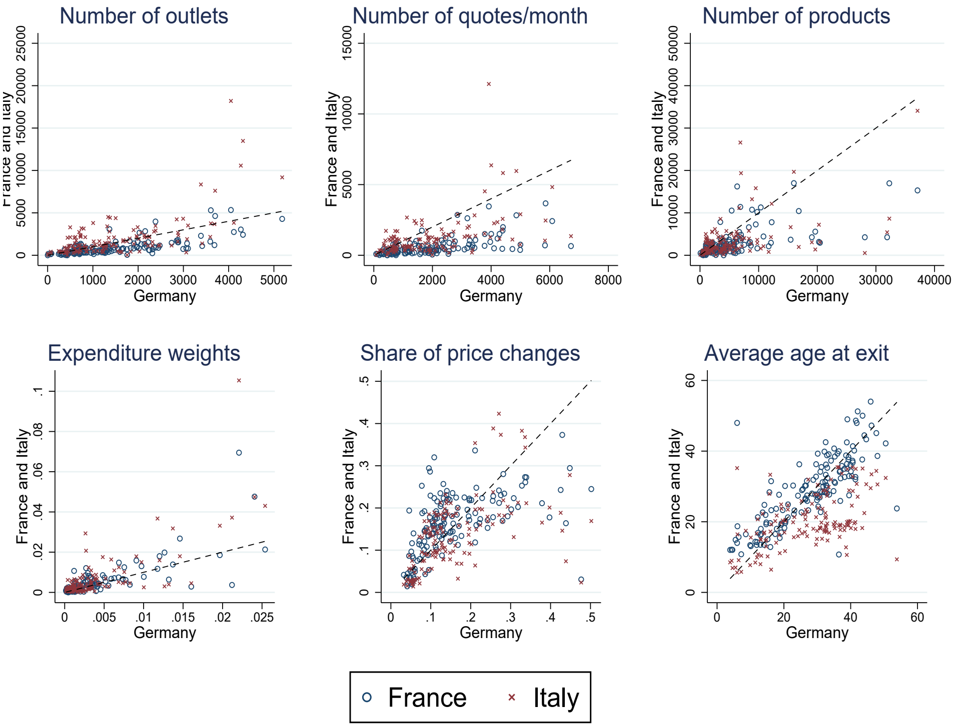

Figure 3: Descriptive joint distributions at the COICOP5 level (harmonized sample, 2015/16-2019)

across categories. When reporting results at various levels of disaggregation, e.g., at the COICOP2 level, we compute these as expenditure-weighted averages of the underlying COICOP8 level results, in line with how we compute aggregate results.[20]

For France we need to slightly deviate from the baseline approach, as official expenditure weights are only available at the COICOP6 level. We thus estimate b_z in equation (2) at the elementary level and then use, in a first step, unweighted averages to obtain an average estimate at the COICOP6 level. In a second step, we aggregate average estimates further using COICOP6 official expenditure weights. Applying the French aggregation procedure to the German data produces only minor differences to the German optimal inflation result.[21]

The baseline estimation approach uses the simple unweighted average of product prices in category z at time t as the category price level P_{zt} in equation (2), following the approach in Adam and Weber (2020). This

[20] All optimal inflation rates are reported in annual terms and in percentage points and have been computed by transforming the monthly regression coefficients from equation (1) in yearly coefficients and using annual inflation rates to determine γ_z^e/γ_z.

[21] The optimal inflation target for Germany then slightly increases by fifteen basis points.

has the advantage that we only take non-imputed prices into account in the regressions. Yet, we also consider an alternative approach which uses the official price index for P_{zt}, as computed by the statistical agencies. For Germany and Italy, these indices are available at the COICOP8 level. For France we use price indices at COICOP5 level, as official indices are not available at higher levels of disaggregation.

5 The Optimal Inflation Target: Main Results

This section describes our main findings regarding the optimal inflation targets for France, Germany and Italy and for the Euro Area.

Table 3 reports the optimal inflation targets estimated using the baseline sample period and the harmonized expenditure sample. It shows that the optimal inflation target is significantly above zero in all three countries: the presence of downward sloping efficient relative price trends thus strongly affects the optimal inflation rate implied by the presence of nominal rigidities. There is, however, a considerable degree of heterogeneity across these Euro Area countries. While the optimal target is 0.8% for Italy, it is a full percentage point higher for France and Germany. This shows that in France and Germany the (expenditure-weighted) rate of relative price decline is more than twice as strong as in Italy.[22] Understanding better the deep sources of this difference, albeit beyond the scope of this paper, is an interesting avenue for future research.

Given that France, Germany and Italy jointly account for about 64% of Euro Area GDP, we aggregate the nationally optimal inflation targets to obtain an estimate for the optimal Euro Area inflation target. We do so by weighting the optimal inflation rates of individual countries with their respective 2019 consumption expenditure shares.[23] The optimal Euro Area inflation rate thus computed is sizable and equal to 1.5%. This shows that price stickiness alone justifies targeting significantly positive inflation rates in the Euro Area. Additional considerations, e.g., the presence of a lower bound constraint on nominal rates or falling levels for the natural rates of interest may move this number even further up, e.g., see Adam, Pfaeuti and Reinelt (2020).

Table 3 also provides an Olley-Pakes decomposition of the optimal in-

[22]According to the underlying theory, this could be the case because quality progress associated with product replacements is stronger in Italy and/or because productivity improvements over the product lifetime are weaker in Italy. Identifying which force is actually at play is not possible with the available price data alone.

[23]We use final consumption expenditure by household for the year 2019. The resulting consumption shares are 42.2% for Germany, 31.1% for France and 26.7% for Italy. Strictly speaking, the aggregation result in equation (1) requires also using relative consumption growth rates (γ_z^e/γ^e). Quantitatively, however, this has only negligible effects on the result.

	France 2015-19	Germany 2015-19	Italy 2016-19	Euro Area (FR, GER, IT)
Optimal Inflation Target	1.8%	1.8%	0.8%	1.5%
Olley-Pakes Decomposition				
$E[b_z]$	1.8%	1.4%	0.7%	-
$Z \cdot cov((\gamma_z^e/\gamma^e)\,\psi_z, b_z)$	0.0%	0.4%	0.1%	-

Table 3: Optimal inflation estimates (2015/6-2019, harmonized sample, baseline approach)

flation rate in equation (1) at the COICOP5 level. Using the fact that the sum of weights $\sum_z \frac{\gamma_z^e}{\gamma^e}\psi_z$ is very close to one, we can decompose the optimal inflation rate into the contribution from the *unweighted* mean of efficient relative price declines $E[b_z]$ and the contribution from the covariance between (growth-adjusted) expenditure weighs and rates of relative price decline:

$$\Pi^\star \approx E[b_z] + Z \cdot cov((\gamma_z^e/\gamma^e)\,\psi_z, b_z)$$

where Z denotes here the number of COICOP5 categories at which the Olley-Pakes decomposition is performed.

As table 3 indicates, the contribution of the covariance term is relevant only in Germany, where it contributes 0.4% to the optimal inflation target. In the two other countries, the unweighted average of the rates of relative price decline delivers very similar conclusions for the optimal inflation rate as the weighted average.

Table 4 explores the robustness of our main findings to using alternative estimation approaches. While considered alternative approaches represent quite significant departures from our baseline approach, they yield broadly similar conclusions as the baseline approach.

The first alternative approach in table 4 uses the official price indices for P_{zt} in the panel regressions (2) instead of the simple average product price. The way statistical agencies compute price indices differs substantially from simply averaging across prices, not least because official indices use product, shop and regional weights, in addition to using nonlinear (log-exponential) aggregation formulae in some countries and/or some expenditure categories.[24] The optimal inflation rates for France and Germany then increase slightly, while the optimal rate for Italy remains largely unchanged.

[24] The official price indices also use all imputed prices, while these are excluded in our baseline approach.

As a result, the optimal inflation target for the Euro Area increases slightly to 1.7% when using official price indices to compute relative price trends.

The second robustness exercise in table 4 drops the requirement that consumption baskets must be comparable across countries, but instead makes use in each country of all available micro price data to estimate the optimal inflation target.[25] This results in a significant change in the considered expenditure baskets, see table 2. The optimal inflation target nevertheless remains unchanged in Italy, but the optimal targets for France and Germany decline considerably. In Germany, this is partly due to the fact that the German data set contains information on rent prices.[26] In France, the presence in the country-specific sample of some tobacco products and fresh food contributes to the decline in the optimal inflation. Overall, the Euro Area optimal inflation target drops to 1.1% when relying on country-specific samples.

The third robustness exercise in table 4 uses the German expenditure weights ψ_z in all countries. The optimal inflation rates in France and Italy then slightly increase by 0.2 to 0.3 percentage points. Thus, differences in expenditure weights across countries have only a modest impact on aggregate results.

The last robustness exercise in table 4 eliminates the relative growth weights γ_z^e/γ^e, setting them equal to one in all countries, instead of computing them consistent with Cobb-Douglas aggregation in household preferences ($\gamma_z^e/\gamma^e = \Pi/\Pi_z$). Inflation rates differ quite substantially across different expenditure categories, especially when considering a fine level of disaggregation (COICOP8). Thus, these weights can potentially make a large difference for results. Table 4 shows, however, that results are again very stable for Germany and Italy. The optimal inflation rate in France drops by about 0.4%, but the implied Euro Area rate drops by merely 0.1 percentage points.

Taken together, the robustness exercises show that the baseline results are very stable for Italy. The results obtained from the harmonized sample for France and Germany are roughly in the middle of the alternative approaches considered in table 4 and so is the baseline result for the optimal Euro Area inflation target.

Overall, the optimal inflation target that minimizes the welfare effects of relative price distortions in the Euro Area ranges between 1.1% and 1.7%, which is significantly larger than the zero inflation benchmark implied by monetary models that abstract from product turnover and relative price trends.

[25] As before, we drop all imputed prices.

[26] The expenditure weight on rents (nomalized and time-averaged) is sizable in Germany and equal to 11.7%. At the same time, relative price trends in this expenditure category are relatively weak, justifying inflation levels of just around 1.2%, which is considerably below the German baseline estimate of the optimal target.

	France 2015-19	Germany 2015-19	Italy 2016-19	Euro Area Average (FR, GER, IT)
Official price index for P_{zt} in equation (1):	2.1%	2.0%	0.8%	1.7%
Country-specific expenditure sample:	1.1%	1.2%	0.8%	1.1%
German expenditure weights ($\psi_z \gamma_z^e / \gamma^e$)	2.1%	1.8%	1.0%	1.7%
No relative growth weights ($\gamma_z^e / \gamma^e = 1$)	1.4%	1.8%	0.8%	1.4%

Table 4: Optimal inflation target: alternative estimation approaches and micro price samples

5.1 The Optimal Inflation Targets Over Time

This section analyzes the trend of optimal inflation targets over time in the considered countries. To this end, we compare estimates of the optimal inflation target obtained from the baseline sample period (2015/6-2019) to the corresponding estimates obtained from an earlier sample period (2010-14 for France and Germany, 2012-2015 for Italy).

The sample comparison is complicated by the fact that national statistical institutes changed the basket of expenditure categories underlying national CPIs as well as the base period at the end of 2014. In addition, the integration of European harmonized expenditure weights into national statistics took place around the same time, but introduction dates varied across countries and also depended on the level of disaggregation.

As a result of these reclassifications and changes, only a relatively small set of COICOP categories is available across all three countries and across both sample periods jointly, which makes comparisons that are valid across countries *and* across time unattractive, as they would have to rely on a rather small subset of the data. In light of this fact, we focus our analysis on a reliable time comparison, selecting for each considered country the largest set of COICOP categories that is available in both sample periods. As a result, the estimates for the baseline sample period (2015/16-2019) obtained in the present section will differ from the ones presented in table 3, as the latter table focuses on a sample that is comparable across countries but not across sample periods.

Matching the expenditure categories at the country level (COICOP8 level for Germany and Italy, elementary level for France), we cover 64.6% of the official expenditure basket for France, 74.5% for Germany, but only 27.5% for Italy.[27] To isolate the effect of changes in the slope coefficient

[27]Table 10 in Appendix C reports the descriptive statistics for the resulting samples.

	France		Germany		Italy	
	2010-14	2015-19	2010-14	2015-19	2012-15	2016-19
Baseline approach:	1.5%	1.2%	1.7%	1.2%	1.3%	1.4%
Official price index for P_{zt} in equation (1):	1.4%	1.3%	1.1%	1.1%	1.6%	1.0%

Table 5: The optimal inflation target over time (country-specific samples harmonized over time)

b_z over time, we use the expenditure weights (ψ_z) and growth rate weights (γ_z^e/γ^e) from the latter sample period (2015/6-20) to compute the optimal inflation rates in the earlier sample period.

Table 5 reports the outcomes for the optimal inflation rates over time. For the case where the slope coefficients b_z are estimated using the average price for $P_{z,t}$ in equation (2), there is a general tendency for the optimal inflation target to fall. This effect is quite pronounced in Germany but also present in France. Italy displays a very small increase, but this is based on a much smaller coverage of the expenditure basket. Yet, when the slope coefficients b_z are estimated using the official price index for $P_{z,t}$ in equation (2), the decrease in the optimal inflation targets largely disappears in France and Germany. The Italian estimates now display a considerable decrease.

Overall, these somewhat mixed results suggest that the optimal inflation rate could have declined over time, but might also be broadly stable. Reassuringly, however, the estimates for the earlier sample period are in the same ballpark as the estimates in the latter period, which shows that relative price trends tend to display considerable stability over time. This fact is further illustrated in figure 4, which depicts the optimal inflation rates at the level of COICOP3 expenditure categories across time for each of the three countries. As indicated by the 45 degree line in the picture, there is a strong positive correlation of the optimal inflation rates over time at this disaggregated expenditure level. This stability over time suggests that the baseline optimal inflation rates estimated in table 3 bear some relevance also for what is the optimal inflation rate in the not too distant future.

The table shows that for each country, the two sample periods are very similar in terms of the number of observations and the number of products.

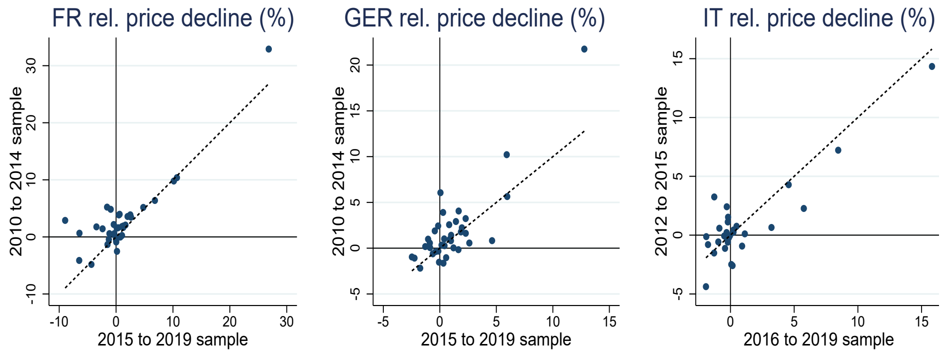

Figure 4: Optimal inflation rates at the COICOP3 level over time (country-specific samples harmonized over time)

6 The Welfare Costs of Suboptimal Inflation in the Euro Area

This section evaluates the welfare costs of suboptimal inflation rates by comparing the estimated optimal inflation rate for the Euro Area with the actual inflation rates prevailing over the considered time period and with a counterfactual in which central bank would target an inflation rate of zero, as would be optimal according to standard sticky price models.

Welfare losses are computed using proposition 1, which requires specifying only three parameters of interest, namely the demand elasticity θ, the inverse labor share ϕ and the (growth-adjusted) effective degree of price stickiness $\widetilde{\alpha} = (1-\alpha_z)\delta_z(\gamma^e/\gamma_z^e)^{\theta-1}$ at the point of approximation.

Following much of the literature in monetary economics, we set $\theta = 7$ and $\phi = 3/2$.[28] For each country, we set the effective degree of price stickiness $\widetilde{\alpha}$ equal to the median value of $(1-\alpha_z)\delta_z(\gamma^e/\gamma_z^e)^{\theta-1}$ across expenditure categories z.[29] Transforming inflation rates into monthly gross rates and using the parameter values just described, one obtains consumption-equivalent welfare losses using equation (3) in proposition 1 for each of the considered countries, which we then aggregate to a Euro Area total using the 2019 consumption weights of the three countries.[30]

[28]Welfare losses are close to proportional to the values chosen for both of these parameters. For example, setting $\theta = 3.8$ as in Bilbiie, Ghironi and Melitz (2012) would roughly halve the welfare losses.

[29]The resulting median values (at the monthly frequency) are 0.828 (France), 0.870 (Germany) and 0.862 (Italy) and thus quite similar across the three considered countries. Considering expenditure–weighted medians, instead, makes very little difference for our results.

[30]The consumption weights are 31.1% (France,) 42.2% (Germany) and 26.7% (Italy).

	Euro Area (2015/6-2019)	
	harmonized sample	country-specific sample
Optimal inflation	1.5%	1.1%
Present value of consumption-equivalent welfare losses:		
Versus actual HICP inflation	0.5%	0.0%
Versus zero inflation	4.5%	2.1%

Table 6: Welfare costs of suboptimal inflation

Table 6 reports these welfare losses by transforming them into present discounted losses using an annual real interest rate of 1%. The reported discounted losses are expressed in percent of annual consumption. Losses are computed for the optimal inflation targets implied by the harmonized samples (1.5%) and for the optimal target implied by the country-specific samples (1.1%). Given these estimates, the table reports the welfare losses implied by the actual inflation rates experienced in each of the three countries[31] and for a counterfactual in which central bank would target an inflation rate of zero.

In the first case, the welfare losses due to price rigidity turn out to be small overall and not larger than 0.5% of consumption in present value terms.

In contrast, table 6 reveals that the welfare losses of targeting an inflation rate of zero would be substantial and lie in the range between 2.1% to 4.5% of consumption, depending on the precise estimate for the optimal target used. This shows how welfare losses quickly rise with the distance from the optimal target and that targeting an inflation rate of zero would be severely suboptimal.

An important caveat in these welfare computations is that they assume that - within any considered country - differences in the (relative growth-adjusted) optimal inflation rates, $(\gamma_z^e/\gamma^e)\, b_z$, across different expenditure categories z are small (are of first order). Figure 5 below shows, however, that there exists substantial cross-sectional heterogeneity in terms of optimal inflation rates (b_z) within each of the countries. Technically, if the difference between the optimal inflation rate for individual expenditure category z and the average optimal inflation rate is large (of order zero), then deviations of inflation from its category-specific optimal level generate first-order contri-

[31] The actual HICP inflation rate was 1.25% in Germany (2015-19), 1.01% in France (2015-19), and 0.8% in Italy (2016-19).

butions to welfare rather than just second-order contributions. This has the potential to make welfare losses significantly larger. While a full exploration of these effects is generally interesting, it is beyond the scope of the present paper, as it requires a considerably more general approach for computing welfare losses associated with suboptimal inflation rates.

7 A Disaggregated View on the Optimal Inflation Targets

This section delves deeper into the underlying heterogeneities that give rise to different optimal inflation targets across countries. The next subsection reports the optimal inflation rates at the level of so-called special aggregates, which include food, (non-energy industrial) goods and services.[32] In the subsequent section, we consider how relative price trends behave at the COICOP2 expenditure level and how they contribute to the optimal aggregate inflation. Subsection 7.3 then considers even finer expenditure disaggregations (COICOP3 and COICOP5). It documents the degree of co-variation of relative price trends, trends in same good price inflation, and inflation rates across countries at the disaggregate level.

7.1 Breakdown into Food, Goods and Services

Table 7 present optimal inflation rates for food, goods and services by aggregating the underlying lower-level categories using the corresponding expenditure weights. It shows that in all three countries, the optimal inflation rates for food and services tend to be very close to zero. The only exception is the optimal inflation rate for services in Germany, which is significantly negative and indicates that services become (in relative terms) more expensive over their lifetime. Overall, however, relative price trends tend to be rather weak in the food and service categories, especially when compared to the goods category, where optimal inflation rates are close to 5% in France and Germany and about half this level in Italy. This shows that the positive optimal inflation rates at the aggregate level are driven by the behavior of goods prices, i.e., due to the fact that in the goods category, relative product prices decline over the product lifetime. This may well be due to the fact that the quality of newly introduced goods increases over time and due to the possibility that statistical agencies account only imperfectly for these quality trends. Yet, as shown in Adam and Weber (2020), the estimated optimal inflation rate is nevertheless optimal for the (potentially) imperfect measure of inflation actually computed by statistical agencies.

[32] The special aggregates usually also feature energy goods as a separate expenditure category. The harmonized sample, however, has one COICOP5 observation in this category, which has an expenditure weight below 0.5%. We thus do not report this category.

	Food		Non-energy industrial goods		Services	
	Π^*	Exp. Weight	Π^*	Exp. Weight	Π^*	Exp. Weight
France	0.2%	30.9%	4.9%	34.5%	0.1%	34.3%
Germany	-0.1%	26.5%	5.5%	39.3%	-0.9%	34.0%
Italy	0.0%	26.4%	2.6%	34.4%	-0.1%	38.7%

Table 7: Optimal inflation for broad aggregates (2015/6-2019, harmonized sample)

7.2 Considering COICOP2 Expenditure Categories

Table 8 reports the optimal inflation targets for different COICOP2 expenditure categories. The table reveals that optimal inflation is positive for the vast majority of COICOP2 expenditure categories. The only expenditure category for which optimal inflation is consistently estimated to be negative is "Restaurant & hotels". Relative prices for these items appear to slightly increase as products age.

Table 8 also shows various other patterns that are common across countries. Perhaps not surprisingly, products with a fashion or news component ("Clothing & footwear", "Recreation & culture") experience the strongest rates of relative price decline and thus have the highest optimal inflation rates. The rate of relative price decline in "clothing & footwear" in Italy, however, turns out to be only about one third as strong as the one in France and Germany.[33] This is due to the relatively strong coordination of the seasonal price declines across fashion products in Italy, which leads to less pronounced trends in relative prices.

It is unlikely that the relative price trends that can be observed in fashion-related products are driven by productivity increases, as postulated by the underlying theory. Instead it seems more plausible that these price declines are driven by the fact that the usage period shrinks as the product ages, or by a decline in the subjectively perceived product quality over time, which captures 'fashion effects'. Nevertheless, it continues to be true that the price decline is efficient[34] and monetary policy should aid the smooth adjustment of these relative price trends in the very same way as it should aid price decreases generated by productivity advances. In this sense the conclusions about the optima inflation rate are not affected by these alternative

[33] Note that, even if these products are tradeables, relative price trends can differ across countries at the same time that the price indices across countries show the same inflation rate, so that there is not arbitrage in terms of baskets of goods.

[34] For instance, the relative price of the spring collection should efficiently decline as summer approaches and the summer products enter the collection, as spring products have increasingly shorter usage times.

Expenditure Category	France	Germany	Italy
Food & non-alcoholic beverages	0.2%	-0.3%	-0.3%
Alcoholic beverages, tobacco & narcotics	0.2%	0.8%	4.6%
Clothing & footwear	10.6%	13.1%	4.2%
Housing, water, electricity, gas & other fuels	1.2%	3.1%	-1.3%
Furnishings, equipment & maintenance	2.1%	1.3%	0.7%
Health	0.7%	1.9%	0.1%
Transport	1.2%	-0.9%	0.6%
Recreation & culture	2.2%	1.6%	1.9%
Restaurants & hotels	-0.2%	-0.8%	-0.3%
Miscellaneous goods & services	1.0%	1.4%	0.3%

Table 8: Optimal inflation target for COICOP2 expenditure categories (2015/6-2019, harmonized sample)

forces that give rise to relative price declines.

Table 8 also reveals that optimal inflation rates differ strongly across countries in some expenditure categories, most notably in the category "Housing, ... & other fuels". This expenditure category, however, has only little influence on the aggregate country results, as it receives only a low expenditure weight in our sample, see table 9. This is so because rent prices are contained only in the German data and thus must be excluded to make meaningful cross-country comparisons.[35]

The expenditure weights shown in table 9 reveal that expenditure patterns are very similar across countries. The only exception is that Italy has a significantly higher expenditure share for "Restaurants & hotels" and a correspondingly smaller share for "Transport" and "Recreation & culture", compared to both France and Germany.

7.3 An Even More Disaggregated View on Heterogeneity

This section considers to which extent optimal inflation rates co-move across countries at an even more disaggregate level. It also analyzes to what extent relative price declines are related to variation in same good price inflation versus variation in overall inflation, i.e., by movements in the variable showing up in the numerator versus denominator on the left-hand side of equation (2).

Figure 5 reports the expenditure-weighted distribution of optimal inflation rates at the COICOP5 level for the considered countries.[36] It shows that

[35]Since rent contracts are long-term contracts, relative price distortions in rents may not be allocative and may thus not be relevant for optimal inflation in the first place.

[36]The corresponding figure for the country-specific samples is shown in Appendix C, see figure 7.

Expenditure Category	France	Germany	Italy
Food & non-alcoholic beverages	27.1%	22.8%	24.5%
Alcoholic beverages, tobacco & narcotics	3.8%	3.7%	1.9%
Clothing & footwear	9.5%	11.5%	14.8%
Housing, water, electricity, gas & other fuels	0.8%	1.3%	0.8%
Furnishings, equipment & maintenance	10.7%	12.1%	13.4%
Health	1.3%	2.8%	0.7%
Transport	11.9%	13.7%	8.9%
Recreation & culture	9.6%	10.9%	5.0%
Restaurants & hotels	12.7%	10.8%	20.6%
Miscellaneous goods & services	12.5%	10.5%	9.4%

Table 9: COICOP 2 expenditure weight (2015/6-2019, harmonized sample)

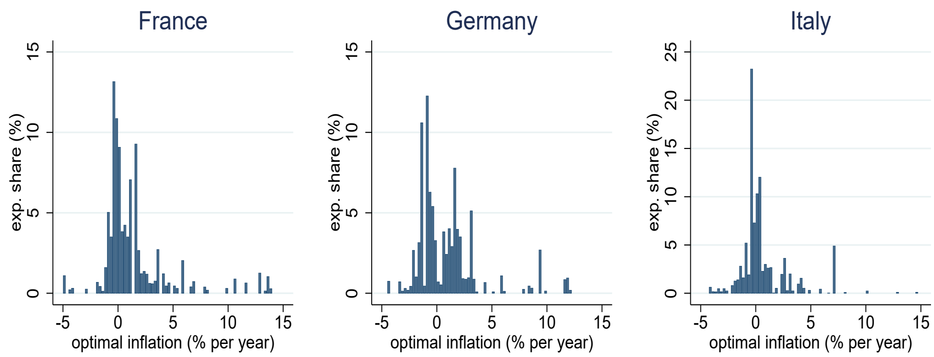

Figure 5: Optimal inflation, COICOP5 level (2015/6-2019, harmonized sample, expenditure-weighted distribution)

within each country, the optimal inflation rate varies considerably across expenditure categories, but that more expenditure weight is located in the area where optimal inflation is positive. The distributions also display a fatter tail on the right than on the left, which contributes further to making the overall optimal inflation rate positive. The right tail is partly driven by fashion products which are contained in various subcategories of "Clothing & footwear". A noteworthy feature in Italy is the fact that the distribution of optimal inflation rates is considerably less dispersed than in France and Germany.

Figure 6 goes beyond analyzing the marginal distributions of optimal inflation rates and depicts joint distributions at the COICOP3 level.[37] The

[37]To increase readability, the support for the axis has been truncated. The non-truncated version of the figure can be found in appendix C, see figure 8.

top row presents joint distributions for France and Germany and the bottom row joint distributions for Italy and Germany. Each plot also depicts the 45 degree line as a reference point for a situation with perfect alignment across countries.

The graphs in the left column of figure 6 depict the scatter plot of optimal inflation rates at the COICOP3 level, i.e., the scatter plot of rates of relative price decline. The graphs in the center column report the rate of same good price inflation at this level of disaggregation. Same good price inflation in each country is obtained by running the panel regression

$$\ln P_{jzt} = f_{jz}^{n} - \ln\left(b_{z}^{n}\right) \cdot s_{jzt} + u_{jzt}^{n},$$

which replaces $\ln P_{jzt}/P_{zt}$ on the left-hand side in equation (2) by the log nominal price.[38] Finally, the graphs in the right-hand side column of figure 6 present scatter plots of the average annual inflation rate at the COICOP3 level.

The top left graph in figure 6 illustrates that the estimated optimal inflation rates covary considerably for France and Germany and are approximately centred around the 45 degree line. The top graphs in the center and right-hand columns, however, reveal quite some differences across the two countries. While same good price inflation rates in France and Germany covary positively, most French rates are considerably lower than corresponding Germany rates. Optimal inflation rates in France are nevertheless similar to the ones in Germany because overall inflation, depicted on the right-hand side, is also lower in France. This explains why optimal inflation rates in France and Germany are nevertheless similar.

The bottom row in figure 6 compares joint distributions for Italy and Germany. The optimal inflation rates for Italy and Germany, shown in the left column, covary only weakly across COICOP3 expenditure categories. This is the case because the same good price inflation rates, shown in the center column, display little comovement across these countries. The graph on the right shows, that the overall inflation rates in Italy covary nevertheless considerably with those in Germany, even if they are on average lower.

8 Conclusions

This paper documents that - on average across products - the price of products, measured relative to closely competing products, falls over the product lifetime in France, Germany and Italy. This finding is mainly due to the behavior of goods prices, while relative price trends in services tend to be

[38] We run these regression at the same level of aggregation as our relative price regressions and then aggregate the slope coefficients b_{z}^{n} to the COICOP3 level using the same approach as used to aggregate the coefficients of the relative price regressions. Monthly gross rates have been transformed into annual net rates in percentage points.

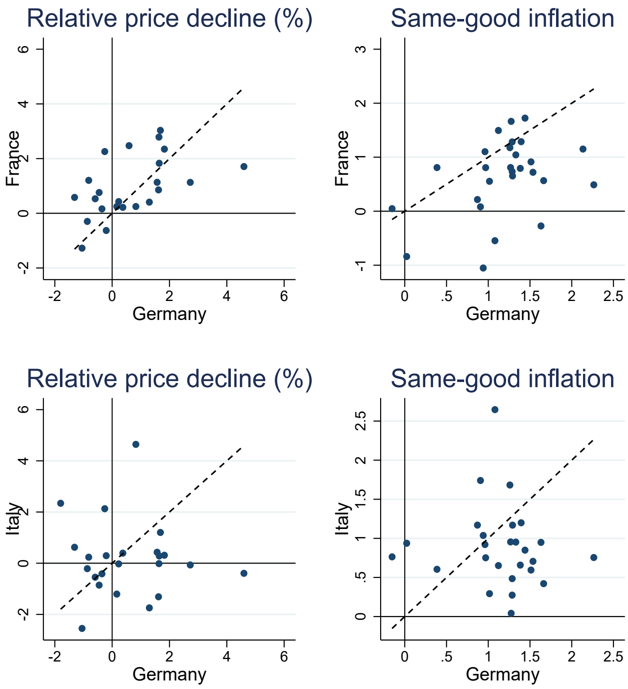

Figure 6: Joint distributions at the COICOP3 level (2015/6-2019, harmonized sample)

weak. Falling relative prices of goods causes positive rates of inflation to be optimal in these economies, whenever prices are sticky. The optimal inflation rates that minimize the welfare effects of price and mark-up distortions range from slightly below one percent to slightly above two percent. They are thus significantly larger than zero, i.e., the optimal rate emerging from models that abstract from product turnover. This has important ramifications for the optimal inflation target that a welfare maximizing central bank should pursue. In particular, our results suggest that price stickiness alone can rationalize an inflation target between 1.1% and 1.7% for the Euro Area. Other considerations not taken into account in the present paper may push up the optimal inflation targets further.

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A Proof of Proposition 1

Appendix E.2.2 in Adam and Weber (2020) shows that - under the conditions stated in the proposition - hours worked in steady-state do not depend on the steady-state inflation rate. Household welfare thus only depends on consumption, which is given by

$$c(\Pi) = K\left(\frac{1}{\mu(\Pi)}\right)^{\phi}, \tag{5}$$

where $K > 0$ is a proportionality constant and $\mu(\cdot)$ the aggregate markup. Taking a second order expansion of the previous equation at the point $\Pi = \Pi^\star$ yields:

$$\begin{aligned} c(\Pi) = c(\Pi^\star) &- \left(\phi c(\Pi)\frac{\partial\mu(\Pi)/\partial\Pi}{\mu(\Pi)}\right)\Bigg|_{\Pi=\Pi^\star}(\Pi-\Pi^\star) \\ &+\frac{1}{2}\left(\phi\,(1+\phi)\,c(\Pi)\left(\frac{\partial\mu(\Pi)/\partial\Pi}{\mu(\Pi)}\right)^2-\phi c(\Pi)\frac{\partial^2\mu(\Pi)/(\partial\Pi)^2}{\mu(\Pi)}\right)\Bigg|_{\Pi=\Pi^\star}(\Pi-\Pi^\star)^2+O(3). \end{aligned}$$

Since $\mu(\Pi)/\partial\Pi = 0$ at the point $\Pi = \Pi^\star$, we get

$$\frac{c(\Pi)-c(\Pi^\star)}{c(\Pi^\star)} = -\frac{1}{2}\phi\,\frac{\partial^2\mu(\Pi)/(\partial\Pi)^2}{\mu(\Pi)}\Bigg|_{\Pi=\Pi^\star}(\Pi-\Pi^\star)^2+O(3),$$

which is equation (3) in proposition 1. The challenge consists of determining $\frac{\partial^2\mu(\Pi)/(\partial\Pi)^2}{\mu(\Pi)}$ in terms of deep model parameters. Appendix E.2.3 in Adam and Weber (2020) shows that

$$\frac{\partial\mu(\Pi)}{\partial\Pi} = \sum_{z=1}^{Z}\psi_z\mu_z(\Pi)^{\psi_z-1}[\partial\mu_z(\Pi)/\partial\Pi]\left(\prod_{z^C}\mu_z(\Pi)^{\psi_z}\right)=0, \tag{6}$$

where z^C denotes the set of all expenditure categories except for category z. Using the definition of the aggregate markup

$$\mu(\Pi) \equiv \prod_{z=1}^{Z}\mu_z(\Pi)^{\psi_z}$$

and the notation $\mu'(\Pi) = \partial\mu(\Pi)/\partial\Pi$, one can express equation (6) as

$$\mu'(\Pi) = \mu(\Pi) \sum_{z=1}^{Z} \psi_z \frac{\mu_z'(\Pi)}{\mu_z(\Pi)}, \tag{7}$$

Taking the derivative of equation (7) with respect to Π yields

$$\mu''(\Pi) = \mu'(\Pi) \left(\sum_{z=1}^{Z} \psi_z \frac{\mu_z'(\Pi)}{\mu_z(\Pi)} \right) + \mu(\Pi) \left(\sum_{z=1}^{Z} \psi_z \frac{\mu_z'(\Pi)}{\mu_z(\Pi)} \right)'.$$

At the point of approximation $\Pi = \Pi^\star$, we have $\mu'(\Pi) = 0$, so that

$$\left.\frac{\mu''(\Pi)}{\mu(\Pi)}\right|_{\Pi=\Pi^\star} = \sum_{z=1}^{Z} \psi_z \left(\frac{\mu_z'(\Pi^\star)}{\mu_z(\Pi^\star)} \right)'. \tag{8}$$

To compute the derivatives on the r.h.s. in the previous equation, we use the third equation in Appendix E.2.3 in Adam and Weber (2020), reproduced here for convenience, using the notation $b_z \equiv g_z/q_z$:

$$\frac{\mu_z'(\Pi)}{\mu_z(\Pi)} = \Phi_z(\Pi) \left[\Pi - b_z \frac{\gamma_z^e}{\gamma^e} \right], \tag{9}$$

where

$$\Phi_z(\Pi) = \frac{\theta \tilde{\alpha}_z \Pi^{\theta-2} \left(\frac{\gamma^e}{b_z \gamma_z^e} \right)}{\left(1 - \tilde{\alpha}_z \Pi^\theta \left(\frac{\gamma^e}{b_z \gamma_z^e} \right) \right) (1 - \tilde{\alpha}_z \Pi^{\theta-1})}, \tag{10}$$

and where $\tilde{\alpha}_z = \alpha_z(1 - \delta_z)(\gamma^e/\gamma_z^e)^{\theta-1}$.

Using equation (9), we can determine the derivatives on the r.h.s. in equation (8). This yields

$$\left(\frac{\mu_z'(\Pi)}{\mu_z(\Pi)} \right)' = \Phi_z(\Pi)' \left[\Pi - b_z \frac{\gamma_z^e}{\gamma^e} \right] + \Phi_z(\Pi).$$

Substituting this expression into equation (8) yields

$$\left.\frac{\mu''(\Pi)}{\mu(\Pi)}\right|_{\Pi=\Pi^\star} = \sum_{z=1}^{Z} \psi_z \Phi_z(\Pi^\star)' \left[\Pi^\star - b_z \frac{\gamma_z^e}{\gamma^e} \right] + \sum_{z=1}^{Z} \psi_z \Phi_z(\Pi^\star). \tag{11}$$

Using the fact that $b_z\gamma_z^e/\gamma^e = \Pi^\star$ for all $z = 1, \dots Z$ at the point of approximation and the expression for $\Phi_z(\Pi)$ in equation (10), we obtain

$$\left.\frac{\mu''(\Pi)}{\mu(\Pi)}\right|_{\Pi=\Pi^\star} = \sum_{z=1}^{Z} \psi_z \frac{\theta \tilde{\alpha}_z \Pi^{\star\theta-3}}{(1 - \tilde{\alpha}_z \Pi^{\star\theta-1})(1 - \tilde{\alpha}_z \Pi^{\star\theta-1})}.$$

Using also the fact that $\widetilde{\alpha}_z \equiv \widetilde{\alpha}$ for all $z = 1, \dots Z$ at the point of approximation and that $\sum_{z=1}^{Z} \psi_z = 1$ delivers equation (4) in proposition 1.

B Appendix

This appendix describes the harmonized data transformations that we perform for all national micro price data sets alike and the country-specific characteristics of each data set (see appendices B.1, B.2 and B.3).

For each of the three economies, we employ the micro price data that underlie the official consumer price index (CPI). The data is at monthly frequency and contains product-level price information for goods and (private and public) services which are consumed by private households. For most products, price collectors visit different types of outlets and shops, or request price information and tariffs from the service sector in a decentralized manner. For some products, price collection is centralized and refers to publicly available sources such as the internet. The data also contain survey-based information on expenditure shares that a typical household in the respective country spends on a product category.

In the analysis, we consider only price observations that enter the computation of the national CPI, and omit all price observations flagged as not originally sampled, i.e., imputed or interpolated price observations. To harmonize the product definition across countries, we refine the product definition originally provided by national statistical institutes as follows. We split the price trajectory of an original product whenever price observations are missing for more than one month (including missing quotes that results from dropping imputed prices); comparable or non-comparable product substitutions occur; and product quality or quantity sold (such as package size) change. As described in the main text, we use expenditure weights to aggregate statistics across expenditure categories. We compute the normalized average expenditure weight according to

$$\psi_z = \frac{\frac{1}{T_z - t_z + 1} \sum_{t=t_z}^{T_z} \widetilde{\psi}_{zt}}{\sum_{z=1}^{Z} \frac{1}{T_z - t_z + 1} \sum_{t=t_z}^{T_z} \widetilde{\psi}_{zt}}, \tag{12}$$

where $\widetilde{\psi}_{zt}$ is the expenditure weight of category z at time t, t_z is the first observation in this category for a given economy and T_z is the last observation in this category.

B.1 French Data

We rely on the longitudinal dataset of monthly price quotes collected by the Institut National de la Statistique et des Études Économiques (INSEE) to compute the monthly French CPI and HICP. The raw data set contains about 9.5 million price quotes for the baseline period from October 2014 to September 2019 and 7.6 million price quotes for the reference period from October 2009 to September 2014. Centrally collected prices, such as car prices, administered prices (e.g. tobacco), public utility prices (e.g. electricity), and rents, are not part of the data set. Individual products are classified in about 4000 product categories at the most disaggregate (elementary) level of product classification, which is used to compute elementary price indices. These categories are grouped in 334 COICOP categories at the 6-digit level and 230 ECOICOP categories at the 5-digit level.

The price variable employed in the present analysis are the prices that enter the computation of elementary price indices (i.e., quality/quantity-adjusted prices of individual products sold in shops). The data set also contains information to recover the collected price (i.e., before quality/quantity adjustments) and various flags indicating changes in quantities or packaging. Furthermore, the data flags imputed prices. Prices are imputed for seasonal products that are out-of-season, when products are temporarily unavailable, or when products are in the process of being replaced. A qualitative variable in the data set documents the reasons for having a "non-normal" observed price (which does not necessarily mean price imputation): product is temporarily not available (6%); outlet is temporarily closed (1.5%); no valid replacement outlet is available (0.5%); no price collection (1.5%); non-comparable product substitution (3%); and comparable product substitution (2.5%).

Data for official monthly price indices, HICP expenditure weights at the 5-digit ECOICOP level and national CPI expenditure weights at the 6-digit ECOICOP level is obtained from the INSEE website.

Data preparation. We drop the price quotes that are imputed by INSEE. About 15% of all price quotes are imputed, with the bulk of imputations in food categories or non-energy industrial goods. Most prices are imputed only for very short periods of time, for example because of temporary shop closing. Longer price imputation spells are observed in categories with seasonal products, but are overall rare. Dropping imputed prices leaves us with 8 million observations in the baseline sample and 7 million observations in the sample covering the period 2009-2014.

Product definition and regression analysis. In the French data, the individual product identifier allows to track prices for a given product over time and any product replacement (comparable or not) over the period of the price collection for this product. In particular, INSEE flags a comparable or non-comparable product substitution but also provides information allowing to track by which new product an old product has been replaced (in case of forced substitution). We refine the original product identifier by splitting price trajectories into subcomponents, as described in the beginning of appendix B. This increases the number of products from about 641k products to 736k products for the 2014-2019 sample and from 489k products to 544k products for the 2010-2014 sample.

For the baseline specification of the regression equation (2), we compute relative prices using the cross-sectional average price calculated at the most disaggregate (elementary) level. For robustness, we also compute relative prices using official price indices for the 5-digit ECOICOP level.[39] For most categories in the baseline sample, slope estimates from the baseline regression correlate highly with slope estimates from the alternative specification that uses the official price index to deflate product prices. However, for some categories, substantial differences between slope estimates emerge because in these cases, price deflators exhibit different dynamics and/or volatility. Thus, for French baseline results, we drop 10 (out of 4000) elementary categories and three (out of 300) 6-digit COICOP categories ('Natural gas' 04.5.2.2.1, 'Pharmaceutical products' 06.1.1.0.1 and 'Canteens' 11.1.2.0.1). The three categories represent about 4% of total expenditure in the product basket. For the 2009-2014 sample, we drop one category ('Camper vans, caravans and trailers' 09.2.1.1.1) for the same reason.

Expenditure weights used for aggregation. We aggregate statistics from the elementary level to higher levels in three steps. First, we compute the simple average of statistics at the elementary level to obtain statistics at the 6-digit COICOP level. Second, we use national expenditure weights at 6-digit COICOP level to obtain weighted aggregate statistics at 5-digit level. Finally, we use French HICP expenditure weights at 5-digit COICOP level to obtain statistics at the 2- or 3-digit COICOP level or for the aggregate level.

B.2 German Data

We use the German monthly micro price data that underlie both the computation of the CPI and the HICP. Most price observations are collected by Statistical Offices of the German Federal States, where each statistical office collects product prices for its state.[40] In most product categories, prices are collected decentralized in physical outlets. For some product categories, however, price collection is centralized and thus takes place either at the federal level or by a single state office for all federal states together.[41] Product prices are collected in each month, preferably in the middle of the month. Information on product prices and expenditure weights is accompanied by information on quality adjustments (in Euros) and quantity adjustments of

[39]This is the most disaggregated level at which INSEE publishes official price indices at a monthly frequency.

[40]Data are provided by the Research Data Center (RDC) of the Federal
Statistical Office and Statistical Offices of the Data are provided by the Research Data Center (RDC) of the Federal Statistical Office and Statistical Offices of the Federal States, "Einzeldaten des Verbraucherpreisindex 2018," EVAS-Nummer 61111, 2010 - 2019, DOI: 10.21242/61111.2010.00.00.1.1.0 to 10.21242/61111.2019.00.00.1.1.0.

[41]The Federal Statistical Office (Destatis) also collects product prices centrally for all federal states jointly. These price observations are not part of our data set.

product prices. This information is provided by price collectors and reflects changes in product characteristics or package size. In our analysis, we only employ quality/quantity-adjusted product prices. Individual products are classified according to 10-digit COICOP.

Data preparation. The following describes preparation of the baseline sample from 2015:01 to 2019:12. Data for the 2010:01 to 2014:12 sample is prepared identically. The raw data for the baseline sample contain 36 million observations. We restrict this sample to price observations which are also used to compute the official CPI and drop observations with tiny prices (less than 5 cents) and observations for which the price deviates by more than minus 99% or plus 10000% from the average price at the stratum level.

We further restrict the sample to 10-digit COICOP categories with price observations collected for more than one outlet and more than one product to obtain meaningful relative price regressions.[42] We also exclude 10-digit COICOP categories for which official price indices are not available, which allows us to complement our baseline regression specification with an alternative specification.[43]

From the resulting sample, we drop the price observations that are imputed by Federal Statistical Offices.[44] About 5.9% of all price observations in the raw data are imputed, with a larger share of imputed price observations in categories for seasonal products, such as clothing. After these adjustments, the data set contains 30 million price observations, classified in approximately 700 expenditure categories at 10-digit COICOP level. At this stage of the analysis, the informational content of the German 10-digit COICOP is equivalent to the German 8-digit COICOP.

Product definition. In the German data, the original product identifier provided by Federal Statistical Offices yields a unique mapping of price observations to individual products. We refine the original identifier by splitting price trajectories into subcomponents as described in the beginning of appendix B. We also drop all products (refined identifier) with less than

[42]In particular, we exclude 731111100 Bahnfahrt, Nahverkehr; 820200200 Mobiltelefon ohne Vertrag; 913221100 Tintenstrahldrucker; 913221200 Laserdrucker; 1111203400 Speise zum Verzehr in öffentlichem Verkehrsmittel; 1111203500 Getränk zum Verzehr in öffentlichem Verkehrsmittel.

[43]We obtain official price indices for the baseline sample from `https://www-genesis.destatis.de/genesis/online?operation=previous&levelindex=3&step=2&titel=Tabellenaufbau&levelid=1611219556060&levelid=1611219502477#abreadcrumb`.

[44]Imputation events are the following: a seasonal product out-of-season; product temporarily not available; non-comparable product substitution; replacement product declined; abstain from replacement product; no valid replacement product available; outlet temporarily closed; replacement outlet declined; abstain from replacement outlet; no valid replacement outlet available.

two price observations. Refining the product definition in this way increases the number of products from 808k to 2.37 million.

Expenditure weights used for aggregation. We aggregate statistics from the 8-digit COICOP level to higher levels in two steps. First, we use national expenditure weights at the 8-digit COICOP level to compute weighted aggregate statistics at 5-digit COICOP level. Second, we use harmonized expenditure weights at 5-digit COICOP level to compute even more aggregate statistics, such as those in table 1 in the main text.[45]

Sample comparison. For reasons of data availability, we do not use disaggregate official price indices to compute relative product prices in equation (2) when we compare estimates of the optimal inflation rate over time (see table 5). Instead, in this case, we compute relative product prices using elementary price indices which are part of the German micro price data. For the baseline sample from January 2015 to December 2019, both elementary and official price indices are available and yield essentially identical estimates for the optimal inflation rate.

B.3 Italian Data

We use the monthly micro price data that underlie the computation of the CPI and the HICP. The data is provided to us by the Italian National Statistical Institute (ISTAT). In particular, we use prices collected locally once a month by municipal statistics offices in over 70 provincial capitals; hence our sample neither includes prices collected centrally (e.g., cars), nor those collected locally more than once a month (e.g., some unprocessed food). The baseline sample spans the 4-years period January 2016 - December 2019, and contains around 3.3 million observations per year. Prices collected belong on average to 612 10-digit COICOP categories, grouped in 263 8-digit COICOP categories. Besides information on product prices, the Italian micro data also contain information on imputation, sales and product replacement. The price variable we use in the analysis is the price collected at stores, divided by the corresponding quantity (to account for changes in packaging). The data on official indices and expenditure weights at the 8-digit COICOP level are provided by ISTAT; both indices and expenditure weights are those used to compute the official HICP index, and differ from the national CPI statistics mainly for the treatment of sales and health-related items.

We choose to consider in the baseline sample only data starting from January 2016, as between 2015 and 2016 the classification of Italian consumer

[45]Harmonized expenditure weights at 5-digit COICOP level come from the ECB statistical data warehouse, `https://www.ecb.europa.eu/stats/ecb_statistics/escb/html/table.en.html?id=JDF_ICP_COICOP_INW`.

prices data adopted by ISTAT underwent a substantial change, reflecting the wider adoption of the new classification ECOICOP (European Classification of Individual Consumption by Purpose). Before 2016, the Italian classification coincided with ECOICOP only up to the 4-digits level, while from January 2016 it also coincided at 5- and 6-digits categories, which causes some categories to non-connectable over the 2015-2016 period.[46]

Data preparation. From the raw data we drop the imputed price quotes, as indicated by imputation flags. A price is imputed by ISTAT if (i) a store is closed, either temporarily (e.g., during summer vacations) or for good; (2) an individual product sampled in a store is not present, either temporarily for reasons different from seasonality or for good; (3) the product is out-of-season (for seasonal products); (4) the price could not be collected for extraordinary reasons;[47] (5) missing observations for other reasons. Slightly less than 9% of all price observations are imputed; more than one half are imputations due to seasonality, especially concentrated in categories such as clothing. We control for outliers dropping some prices that take very high values, and dropping the observations smaller than the 1st percentile and larger than the 99th percentile of the price distribution computed for each month of the sample at the 10-digit COICOP level.

Product definition and regression analysis. The meta data available for each elementary price enable us to track the price of a product (defined at the 10-digit COICOP level) of a given brand at a given retailer over time, i.e. to trace what we call a price trajectory. We refine the original identifier by splitting price trajectories into subcomponents as described in the beginning of appendix B. Refining the product definition in this way increases the number of products from around 407k to 655k. At this stage, we also drop all price observations that belong to refined product identifiers with less than two price observations. Dropping products with less than two observations, imputed prices, and outlier observations reduces the number of observations from roughly 13.3 million to 11.7 million.

We run the regressions in equation (2) under two possible specifications; in both of them we define relative prices and run the regressions at the 8-digit COICOP level. In the baseline specification, we compute relative prices using as denominator the average of collected prices. In the second specification, we compute relative prices using official price indices as denominator. In computing aggregate results, we drop the coefficients of the 8-digit category related to garden furniture (code 05.1.1.2.0.00), as it is

[46]For more details on the classification change, see the methodological note at `https://www.istat.it/it/files//2016/02/EN_Basket_2016.pdf`.

[47]This last flag has been extensively used during the 2020 lockdown, when collectors could not go to the stores to collect prices.

	France		Germany		Italy	
	2010-14	2015-19	2010-14	2015-19	2012-15	2016-19
Total # of price quotes	6.4m	6.2m	22.8m	26.6m	2.2m	2.2m
# of COICOP5 categories	214	214	197	197	94	94
Coverage of HICP basket	.	64.6%	.	74.5%	.	27.5%
# of quotes per COICOP5						
Mean	29.8k	28.8k	115.6k	134.9k	23.4k	23.7k
Median	15.6k	13.4k	53.9k	63.8k	19.0k	19.6k
# of products per COICOP5						
Mean	2.4k	2.3k	8.9k	10.6k	1.3k	1.3k
Median	1.0k	1.0k	2.3k	2.4k	1.2k	1.1k

Table 10: Descriptive statistics for samples with harmonized set of COICOPs over time, but not across countries.

present only in 2019 and shows abnormally wide price swings, and the coefficients of a 10-digit COICOP category related to long-term public parking, as it is highly dependent on a sharp price change adopted in a single province (code 07.2.4.2.1.00.03).

C Additional Tables and Figures

This appendix provides additional descriptive statistics and figures to complement the analysis in the main text. Table 10 provides descriptive statistics for the two sample periods for each country, with harmonized set of COICOPs over time, but not across countries. These samples underlie the estimates of the optimal inflation rate in section 5.1. The table omits the covered expenditure share of the HICP basket for the early sample because harmonized expenditure weights at 5-digit COICOP level are available only for the later sample.

Figure 7 shows the expenditure-weighted distribution of optimal inflation rates at COICOP5 level using country-specific COICOP samples instead of a harmonized COICOP sample. The figure complements the analysis in section 7.3. Figure 8 presents the joint distributions of optimal inflation rates across countries at the COICOP3 level. It is the non-truncated version of figure 6 discussed in the main text in section 7.3.

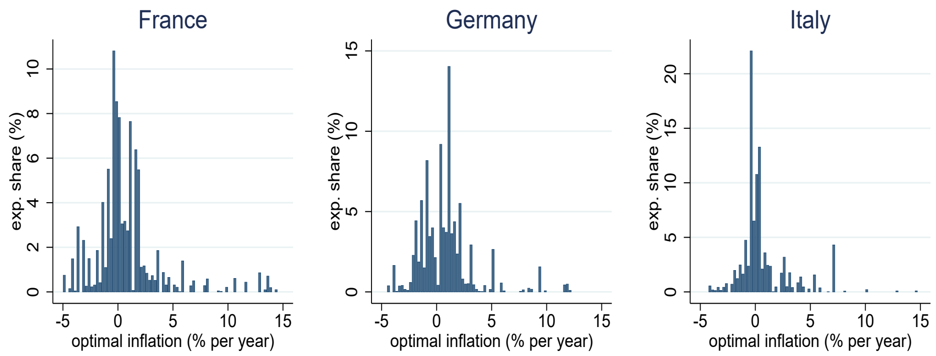

Figure 7: Optimal inflation, COICOP5 level (2015/6-2019, country-specific sample, expenditure-weighted distribution)

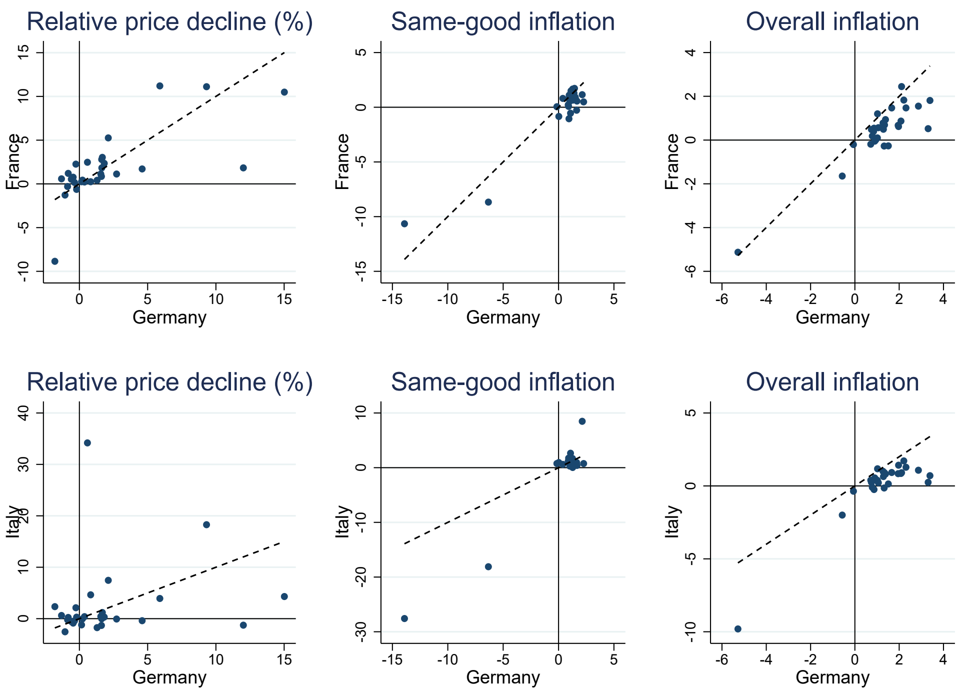

Figure 8: Non-truncated version of figure 6