

# CONDI: A Cost-Of-Nominal-Distortions Index\*

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## Abstract

We construct a PCE-based price index whose weights minimize the welfare costs of nominal distortions: a cost-of-nominal-distortions index. We compute these weights in a multi-sector New-Keynesian model, calibrated to match U.S. data on price stickiness, labor shares and inflation across sectors. The CONDI weights mostly depend on price stickiness. Moreover, CONDI stabilization leads to negligible welfare losses compared to the optimal policy and is better approximated by core rather than headline inflation targeting. An even better approximation can be obtained with an adjusted core index.

**Keywords:** core inflation, nominal rigidities, optimal monetary policy, price indexes.

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# 1 Introduction

Core inflation is at the center of many central banks’ efforts to monitor and pursue price stability. At the Federal Reserve, this focus is well reflected by the inclusion of core PCE inflation—the change in the personal consumption expenditures (PCE) price index ex food and energy—among the four macroeconomic variables featured in the “Summary of Economic Projections” published by the FOMC four times a year.<sup>1</sup>

Intuitively, the rationale for focusing on core inflation is that the prices of food and energy are among the most volatile components of headline inflation. Therefore, attempts to stabilize headline inflation in the face of shocks to non-core prices would require sharp movements in real activity. Moreover, this increased real volatility might also result in an increase, rather than in a reduction, of inflation volatility, if the shocks to non-core prices tend to dissipate faster than the time it takes monetary policy to affect overall prices.<sup>2</sup>

This argument has been formally articulated in at least two ways. First, *current core* inflation is a better predictor of *future headline* inflation than current headline inflation itself. This is a statistical statement of the idea that non-core prices are “volatile.” If this statistical statement is correct, central banks running an explicit—or implicit—form of inflation forecast targeting should pay close attention to core inflation as an indicator of future inflationary pressures.<sup>3</sup>

The second argument in favor of focusing on core inflation as a guide for monetary policy comes from New Keynesian theory. In an economy in which prices change only infrequently, and do so at different rates for different goods, the central bank should concentrate more on the stabilization of inflation in the goods with stickier prices, since it is in their production that the real distortions caused by price dispersion are larger. This “stickiness principle,” originally proposed by Goodfriend and King (1997), was formalized by Aoki (2001) in a two-good economy in which one good has perfectly flexible prices. In this case, the monetary authority should focus exclusively on stabilizing inflation in the sticky price (core) good. Benigno (2004) showed that a similar result holds in a multi-good case with an arbitrary distribution of price stickiness across goods.<sup>4</sup>

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<sup>1</sup> The other variables are headline PCE inflation, GDP growth and unemployment.

<sup>2</sup> For an extremely clear statement of this reasoning from the perspective of a policymaker see Mishkin (2007)

<sup>3</sup> This statistical underpinning for the role of core inflation in policymaking has recently received much scrutiny in the literature and in the policy debate (Blinder and Reis, 2005; Rich and Steindel, 2007; Crone et al., 2008; Kiley, 2008; and Buitier, 2008). Earlier contributions include Bryan and Cecchetti (1994), Quah and Vahey (1995), Clark (2001), and Cogley (2002).

<sup>4</sup> Benigno (2004) casts his analysis in an international context, with many heterogenous countries in a monetary union, rather than many heterogenous sectors in a closed economy. The two interpretations of his analysis are formally identical, as observed by Woodford (2003).

In practice, these theoretical results are usually interpreted as implying that central banks should target core inflation (e.g. Mishkin, 2007; Plosser, 2008), since non-core prices tend to be more flexible than those of core goods and services.<sup>5</sup>

In this paper, we revisit quantitatively the theoretical argument in support of core inflation targeting, in light of the recent detailed microeconomic evidence on the frequency of price adjustment presented by Nakamura and Steinsson (2008, NS in what follows). We also study the robustness of this argument to the presence of heterogeneity in labor shares and in the distribution of shocks among sectors, since these factors are crucial determinants, together with price stickiness, of the cross-sectional distribution of distortions.<sup>6</sup> In our economy, in fact, the volatility and persistence of sectoral shocks interact with price stickiness to determine equilibrium price dispersion. This nominal dispersion, in turn, translates into dispersion in output and labor across producers, which is the ultimate source of welfare losses. This mapping depends on the elasticity of output demand and on the curvature of the production function with respect to the labor input, parameters that we can bound using observations on the revenue share of labor across consumption sectors.

The analysis proceeds in three steps. First, we construct a database with measures of price stickiness and labor shares across PCE items, at two levels of aggregation. At the coarser level of aggregation, we only distinguish between non-core items, which include food and energy, and core items, which include everything else. At the finer level of aggregation, we consider fifteen “major types of products,” such as motor vehicles and parts, food at home and away from home, housing, and medical care. We also consider the baseline case of one homogeneous good. The construction of this database is one of the contributions of the paper, since comprehensive measures of the degree of heterogeneity in the production of personal consumption goods and in their price flexibility were not previously available.

For price stickiness, our primary source is NS, whose data refer to the frequency of price adjustment for the 270 entry level items (ELIs) in the non-shelter component of the Consumer Price Index (CPI). This data covers about 70 percent of CPI expenditures, but it excludes entirely housing services (rent and owners’ equivalent rent) and a large fraction of PCE medical care. To extend this partial evidence on CPI items to cover all the fifteen major PCE products at our finer level of aggregation, we supplement it with data from Genesove (2003) on the degree of nominal rigidity in housing rents. Moreover, we

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<sup>5</sup> In the New Keynesian model based on Calvo (1983) pricing, more flexible prices result in a more volatile inflation rate, at least under plausible assumptions on the behavior of marginal cost (Bils and Klenow, 2004). In this respect, the theoretical underpinning for core inflation targeting just described could be interpreted as another variant of the informal “volatility” argument we sketched above.

<sup>6</sup> In the model we present, each sector produces one (composite) good. Therefore in what follows we use the words sector, good and product interchangeably.

adjust the estimate of price stickiness in CPI medical care implied by NS' numbers to account for the fact that most of the price quotes used in the construction of the PCE health care index represent producer, rather than consumer prices (McCully, Moyer, and Steward, 2007). This adjustment is crude, but we think it provides a more plausible benchmark for the effective price stickiness in medical care than the CPI data alone.

As for labor shares, we compute them by applying the method proposed by Valentinyi and Herrendorf (2008) to the major PCE products in our database. This method is particularly suitable for our purposes, because it uses input-output tables to map data on factor shares at the industry level into a measure of those shares for the components of final demand, such as consumption. As a result, the labor shares we compute account for the labor used along the entire production chain, and not only as a direct input into the production of final goods and services.

The second step of our analysis is the construction of a Cost-of-Nominal-Distortions Index (CONDI). The CONDI is a Törnqvist (1936) price index—a weighted average of inflation rates—that weighs inflation in each PCE item as a function of the share of overall nominal distortions associated with its production. This is in contrast to a cost-of-living index (COLI), such as the PCE, which weighs items by their expenditure share. To quantify the contribution of each consumption sector to overall distortions, we calibrate a multi-sector extension of the textbook New Keynesian model to the evidence on sectoral heterogeneity discussed above.<sup>7</sup> In this framework, we define the CONDI as the linear combination of inflation rates whose stabilization maximizes the welfare of the model's representative agent, as in Benigno (2004).

Finally, the third step of the analysis is to compare the performance of CONDI stabilization to that of the unconstrained optimal policy, as well as to other, more familiar, approaches to monetary policy. In particular, we focus our attention on two strict inflation targeting strategies, the stabilization of headline and of core PCE inflation (i.e. PCE ex food and energy). This comparison provides a quantitative theoretical underpinning for a discussion of the relative merits of monetary policies that aim to stabilize different types of inflation.

Three main results emerge from our quantitative analysis. First, the optimal weights in the CONDI depend largely on sectoral heterogeneity in price stickiness, and only marginally on cross-sectional

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<sup>7</sup> To calibrate the persistence and volatility of the sectoral productivity shocks, we could in principle compute Solow residuals for final demand sectors by applying a methodology similar to the one we use for labor shares. We do not pursue this calibration approach here, because the mapping of productivity from industry level into final demand sectors is a very intricate operation, which would only produce TFP estimates at an annual frequency (e.g. Basu, Fernald, Fisher and Kimball, 2010). Instead, we choose the stochastic properties of the sectoral shocks to match the autocorrelation and standard deviation of aggregate and sectoral inflation.

variation in either the distribution of shocks, or in the demand and technology parameters consistent with our measure of labor shares. This finding confirms the robustness of the basic principle that monetary policy should put more emphasis on the stabilization of inflation in sectors with more rigid prices. More specifically, among non-core expenditures, the CONDI attributes almost no weight to the very flexible prices of energy goods and of food purchased for consumption at home, but a large weight to “food away from home.” At the same time, two categories that are part of core, but whose prices are very flexible, receive little weight in the CONDI: “motor vehicles” and “clothing and shoes.”

Second, CONDI stabilization provides an excellent approximation to the unconstrained optimal policy. In fact, the outcomes of the two policies are virtually indistinguishable in terms of welfare. Moreover, core PCE stabilization is a better policy than headline PCE stabilization, because core inflation on net readjusts the expenditure weights on sectoral inflation rates in a direction similar to that of the CONDI. In fact, the time series of CONDI inflation, built with the optimal weights we computed and the historical realization of sectoral prices, is highly correlated with core PCE inflation, but only moderately so with headline inflation.

Nevertheless, core inflation targeting is only a rough approximation of CONDI stabilization in terms of welfare, our third key result. This approximation, however, can be improved through a simple reclassification of major products across the core and non-core aggregates, which consists of moving “motor vehicles” and “clothing and shoes” to non-core and “food away from home” to core. Interestingly, this latter adjustment was already implemented as part of the 2009 benchmark revision of the National Income and Product Accounts. The welfare loss from a policy that stabilizes this “adjusted core PCE” inflation, compared to the optimal policy, is equivalent to a permanent increase of annual inflation in the optimal equilibrium by 0.5 percentage points. In comparison, the inflation equivalents of core and total PCE stabilization are 1.2 and 1.6 percentage points respectively.

This paper is related to a large literature on the welfare costs of price distortions in New Keynesian models, which includes the already cited work of Aoki (2001) and Benigno (2004), as well as Erceg, Henderson and Levin (2000), who consider the case of distortions in the goods and labor markets, and Huang and Liu (2005), who focus on the presence of nominal rigidities in the production of intermediate inputs.<sup>8</sup> The key lesson of this literature is that inflation stabilization is most important in the sectors in which nominal rigidities are more pronounced, since these are the sectors with larger real distortions. The contribution we add to this normative literature is the detailed quantitative dimension of our

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<sup>8</sup> See also Bodestein, Erceg and Guerrieri (2008), who study the optimal monetary policy response to a shock originating in an energy sector with perfectly flexible prices.

analysis, which was made possible by the data collection work of Bils and Klenow (2004), Klenow and Krytsov (2008) and Nakamura and Steinsson (2008).

This empirical work in turn spurred a rich literature on the positive evaluation of macroeconomic models of price rigidity, started by Klenow and Krytsov (2008) and Golosov and Lucas (2007) and now including work by Midrigan (2010), Burstein and Hellwig (2007), Gertler and Leahy (2008), and Woodford (2009), as well as by Carvalho (2006) and Nakamura and Steinsson (2009) in a multi-sector environment similar to ours. To our knowledge, none of this work includes a normative dimension, which is the focus of this paper.<sup>9</sup>

The paper closest in spirit to ours is Mankiw and Reis (2003). These authors ask the same broad question we address in this paper—what measure of inflation should a central bank target?—and do so in the context of a model of price setting with several dimensions of sectoral heterogeneity. However, their approach to the answer is significantly different from ours, in several respects. First, they consider a model with sticky information, rather than sticky prices. Second, they adopt an ad hoc, and unusual, objective for monetary policy. The central bank wants to minimize the volatility of real activity, with no regard to that of inflation. Third, their quantitative application is only meant to be suggestive, since the centerpiece of the paper is a theoretical analysis of the effect of heterogeneity on the optimal inflation target in a two-sector version of their model.<sup>10</sup>

In the rest of the paper, Section 2 describes our approach to the measurement of heterogeneity in price stickiness and labor shares across PCE categories. Section 3 presents the multi-sector model with time-dependent pricing on which we base our quantitative analysis and provides a formal definition of the CONDI. Section 4 discusses the CONDI weights we calculate under several calibrations of the model, compares the performance of CONDI stabilization to that of headline and core inflation targeting and draws some implications of this comparison for monetary policy. Section 5 concludes.

## 2 Measuring Heterogeneity Across PCE Categories

In this section, we present a dataset that includes measures of two important forms of heterogeneity in the production and pricing of PCE goods. The first, and most commonly studied, is heterogeneity in the frequency of price adjustment, an indicator of differences in the degree of nominal rigidity across

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<sup>9</sup> But see Burstein and Hellwig (2008) for the normative implications of the presence of menu costs in a one-sector model.

<sup>10</sup> Berriel and Sinigaglia (2008) characterize optimal fiscal and monetary policy in a multi-sector model very similar to ours. Their focus is on the theoretical interaction between the two policies, rather than on the quantitative characterization of an optimal stabilization objective for monetary policy.

goods. The second form of heterogeneity we consider is in the revenue share of labor, which we interpret as evidence of differences across sectors in production technology and in the average markups charged by firms. We focus on these sources of heterogeneity, because they interact with nominal rigidities to give rise to asymmetric distortions across goods. In the New Keynesian framework we adopt, these asymmetries are the reason for wishing to adjust the weights of a CONDI with respect to those of a COLI. The quantification of these optimal adjustments is the main objective of the rest of the paper.

## 2.1 Price Stickiness

The empirical study of the price-setting process at the microeconomic level is one of the most active areas of macroeconomic research of the last few years. Studies such as Bils and Klenow (2004), Klenow and Krytsov (2008) and Nakamura and Steinsson (2008) for the United States and Dhyne et al. (2006) for the Euro Area have contributed to the dissemination of a wealth of detailed evidence on the stickiness of prices, especially for consumption goods. For the United States, the primary source of this evidence is the CPI Research Database at the Bureau of Labor Statistics, which contains the product level price data used to construct the CPI.

However, the main inflation gauge for monetary policy in the United States is the PCE deflator. Therefore, this is also the price measure we use as the reference for our analysis, since the CONDI aims to be a useful input for monetary policy decisions. As a result of this choice, we must convert the available CPI-based evidence on price stickiness into measures that are definitionally consistent with the PCE deflator. We use NS' data as the basis for this conversion, because it is readily available and focuses on a period (1998-2005) in which inflation was low and stable.<sup>11</sup>

NS report the average fraction of prices that change each month for 270 Entry Level Items (ELIs) in the non-shelter component of the CPI, which covers about 70 percent of total expenditures over the period 1998-2005.<sup>12</sup> They distinguish between changes in "actual" and "regular" prices. Actual price changes include changes due to sales, as well as to substitutions of discontinued items with closely matching ones. Regular price changes, on the contrary, only include changes in non-sale prices. NS argue that the nature of sales is fundamentally different from that of other forms of price adjustments and that sales result in far less macroeconomic price flexibility than regular price changes (see also Guimaraes and Sheedy, 2010 and Kehoe and Midrigan, 2008). For this reason, we focus here on the

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<sup>11</sup> The CPI Research Database starts in 1988, but the structure of the ELIs was revised in 1998, forcing a split of the sample. According to NS, however, the estimates of the frequency of price adjustment in the two periods (1988-1997 and 1998-2005) are similar. NS also focus their discussion on the 1998-2005 sample.

<sup>12</sup> This ELI-level data is part of the supplementary material for the published version of NS, available at <http://www.columbia.edu/~en2198/papers/fivefactsELItableSup1.xls>. (URL last accessed: January 25th 2009)

frequency of price changes excluding sales, but including product substitutions, as recommended by NS when calibrating time-dependent models.<sup>13</sup>

There is one major PCE product, however, for which we deviate from NS’s estimates: medical care. The weighted median frequency of price change across the health care ELIs included in the CPI Research Database studied by NS is 3.4 percent, which implies an expected life for these prices of 29 months. This seems an unreasonable amount of nominal rigidity for the health care sector as a whole. One reason for this extreme estimate is that it is difficult to distinguish between list prices and the prices actually paid by patients, especially those covered by insurance (Newhouse, 2001). List prices are more likely to be sampled by the BLS, but probably change less often than actual transaction prices, which are bargained by insurance companies with the doctors in their networks. Some evidence suggests that these bargains often happen once a year. This is the case for Medicare, for example (Holtz-Eakin, 2004). Moreover, this frequency of price adjustment is consistent with the behavior of the producer prices for medical services, which are the primary source of the inflation estimates for medical care in the PCE (McCully, Moyer, and Steward, 2007).<sup>14</sup> In light of these considerations, we set the average duration of PCE medical care prices at one year, which implies that 8.3 percent of these prices adjust on average every month. This is clearly a crude estimate. More research to refine this number would be especially useful, given the large and growing share of expenditures—currently 16 percent in the PCE—directed towards health care, but it is outside the scope of this paper.

Figure 1 summarizes the distribution of price stickiness across goods by way of expenditure-weighted CDFs. On the horizontal axis is the average fraction of prices that change in a month, from the stickiest to the most flexible. For each point on the CDFs, the vertical axis represents the fraction of expenditures on goods whose prices adjust as or less frequently than the corresponding frequency on the horizontal axis.

The price adjustment CDF for the ELI-level CPI data is labeled “CPI” in the figure. The frequency of adjustment on the horizontal axis is from NS. The weights are the expenditure shares for each ELI, also from NS, reflatd to sum to 100 percent of CPI expenditures. The resulting expenditure-weighted median monthly frequency of price change is 12.7 percent.

We need to convert this evidence into measures of price stickiness for the fifteen major goods and

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<sup>13</sup> For clothing and shoes, we use the frequency of actual price changes, which includes both sales and substitutions. We do so, because the high product turnover due to seasonal purchasing patterns and fashion changes, which often results in sales, makes the distinction between sales and substitutions in this expenditure category ambiguous (Liegey, 1994).

<sup>14</sup> The non-seasonally adjusted inflation rates for hospitals and physicians in the PPI, which are the source for the corresponding PCE price indices, display pronounced spikes every October and January respectively. This evidence suggests that a sizable fraction of the prices underlying these time series adjust at least once a year.

services in our PCE database. The conversion involves three steps.

First, we reflate each of the ELI weights so that the sum of the weights of all the ELIs within a particular PCE major product is equal to the average PCE expenditure share on that product over the period 1998-05.<sup>15</sup> The resulting CDF is labeled “CPI - with PCE weights” in Figure 1. The implied median frequency of price change is 10.0 percent. This shift of the distribution towards less flexible prices is explained by the fact that some services, most notably medical services, receive less weight in the CPI than in the PCE, due to the difference in scope between the two price indices. The prices of these services tend to be stickier than the CPI median.

In the second step of the conversion, we fold into NS’ data some evidence on price adjustment in housing services from Genesove (2003) . Expenditures on tenant and owner-occupied housing represent a very large fraction of consumption in the United States—close to 30 percent in the CPI and about 15 percent in the PCE—but they are not included in NS’ dataset.<sup>16</sup> However, Genesove (2003) finds that 29 percent of the apartments in the Annual Housing Survey panel have no change in nominal rent from one year to the next.<sup>17</sup> Assuming a constant monthly probability of price adjustment, this number implies that the price on only 10.3 percent of rental units changes each month. We assume that this estimate of nominal rigidity would hold also if owners rented the dwellings they currently occupy. Hence, we attribute to tenant and owner-occupied housing a 10.3 percent monthly frequency of price adjustment and readjust the weights of the other ELIs within the broader housing category to be consistent with its total PCE expenditure share.

The assumption that home owners face the same effective price rigidity in housing services as renters, and that this rigidity results in identical distortions in consumption across the two groups of households is not fully satisfactory. In fact, one could argue that stickiness in rents has no bearing on the housing consumption decisions of home owners, and that the equivalent rental prices they face are perfectly flexible at the time of purchase, when most of the quantity adjustment takes place. For this reason, we also briefly discuss a calibration in which owners’ equivalent rent (OER) is perfectly flexible.

The CDF after this adjustment for the stickiness of rents is labeled “PCE disaggregated” in Figure 1. This CDF tracks the previous two very closely for the stickiest half of expenditures, but the inclusion of

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<sup>15</sup> This reflation requires a mapping from the CPI ELIs into the PCE major products, which are somewhat different from their equivalent in the CPI (McCully, Moyer, and Stewart, 2007). The details of the mapping we adopted are available upon request.

<sup>16</sup> The smaller expenditure share of housing in the PCE reflects the broader set of total expenditures covered in this index, as well as a larger adjustment of owners’ equivalent rent expenditures for depreciation and other costs of home ownership.

<sup>17</sup> Genesove’s (2003) data cover the period 1974-1981. This is a very different sample than the 1998-2005 used by NS and it covers a time of relatively high inflation, which might lead to an overstatement of the frequency of price adjustment in rents. However, this is by far the most reliable evidence on price stickiness of housing services we were able to uncover.

the data on housing, whose price flexibility is close to the CPI’s weighted median, shifts the CDF higher in its more flexible half. However, the resulting median frequency of price adjustment only goes from 10.0 percent to 10.3 percent. This relatively small change in the median illustrates well the difficulty of capturing the richness of actual distributions of price stickiness with only one measure of central tendency.

Finally, in the third step of the conversion, we propose three levels of aggregation for the evidence we have collected: (i) a baseline with one sector, (ii) a two-sector case, in which we separate core and non-core items, and (iii) a 15-sector case by major type of product. For each of these three cases, we take the expenditure-weighted median of the frequency of price change within the relevant category as its measure of price stickiness.

At the finest level of aggregation, our dataset includes the thirteen “major types of product” used by the Bureau of Economic Analysis (BEA) in the PCE NIPA tables, plus a distinction between food at home and away from home (rather than just food) and between non-core (i.e. electricity and gas) and core household operations (rather than household operations alone). The reason for including these slightly finer distinctions is that the BEA categories we split are very heterogenous in terms of price flexibility. The prices of food away from home, for example, are among the stickiest, while food at home is at the other end of the flexibility spectrum. Table 1 includes a complete list of the product categories included in our dataset.<sup>18</sup>

We do not disaggregate our data further for two main reasons. First, the input-output tables contain a limited amount of sectoral detail on final demand, which makes it impossible to construct more disaggregated measures of the labor share. Second, the 15-sector grouping we propose already captures most of the overall variation in price stickiness. In particular, the variation in the frequency of price adjustment across our 15 sectors represents about seventy percent of the total variation at the ELI level.

This fact should also be evident by a simple visual comparison of the CDF labeled “PCE 15-sector aggregates” in Figure 1 with that labeled “PCE disaggregated.” The two distributions hug each other closely. The main difference is that the former misses about 5 percent of expenditure mass in the stickiest tail, with a similar gain in the relatively flexible region to the right of the median. However,

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<sup>18</sup> We work with the major PCE categories in use before the 2009 benchmark revisions described in McCully and Teensma (2008). These are also the categories consistent with other statistics based on NIPA data used in the paper, such as the input-output tables. For example, before the recent benchmark revisions, NIPA Table 2.3.4 (Price Indexes for Personal Consumption Expenditures by Major Type of Product) included a distinction among durable goods, nondurable goods, and services, as well as among thirteen more detailed categories at the next level of disaggregation. These categories have become 15 in the revised version of this Table. One of these extra categories stems from the distinction between food consumed at home and food services, which was already included in our dataset.

these shifts do not displace housing as the median category, with a frequency of price adjustment of 10.3 percent. Overall, this evidence suggests that further disaggregation is unlikely to have a significant effect on our results.

The fourth column of Table 1 lists the frequency of price adjustment for each of the categories in the three levels of aggregation. For the one-sector baseline, we use the monthly frequency of price adjustment obtained from the disaggregated PCE categories, 10.3 percent. Looking at the two-sector case, we see that core prices adjust about two-thirds as frequently as non-core prices. This differential is largely due to the flexibility of energy prices. In fact, food prices as a whole are about as sticky as core prices, since the prices of food away from home, essentially a service, are among the stickiest in the economy.

## 2.2 Revenue Share of Labor

The second form of heterogeneity across consumption goods we wish to measure is in the average revenue share of labor, since this allows us to put bounds on the curvature of the production function and on desired markups, and thus on the elasticity of demand, in each sector. In our model, these parameters are the main determinants of the level of real distortions for any given level of inflation and price stickiness. Therefore, they represent a crucial input in the construction of the CONDI. To measure these labor shares, we need to match data on consumption goods, which are part of final demand, with data on factor inputs at the industry level. The problem is that there is no direct mapping of industries into final goods.

The literature proposes two main solutions to this problem. The first solution, followed for example by Huffman and Wynne (1999) and Bouakez, Cardia, and Ruge-Murcia (2009b), is to use a reasonable grouping of industry data and define final goods, including consumption goods, according to this grouping. This approach is not suitable for our purposes, because it results in consumption goods that are not consistent with the product categories in the PCE.

The second approach, proposed by Valentinyi and Herrendorf (2008), uses measured inter-industry relationships to reconstruct which industries produce the value added embodied in the components of final demand. Given industry-level data on factor shares, this approach then allows for the construction of measures of the labor share for consumption good categories that are consistent with the PCE classifications used in the rest of the paper. For this reason, this is the methodology we follow here. It is described in more detail in Appendix A.1. Another advantage of this approach is that the labor shares we obtain account for the labor used along the entire production chain, and not only as a direct

input into the production of final goods, since the mapping from industries into final demand is based on the input-output tables.

In our application, we focus on the major products in the PCE, rather than on the broader components of final demand considered by Valentinyi and Herrendorf (2008). Our data sources are the input-output tables published in Chentrens (2007) and data on industry factor payments from the Bureau of Economic Analysis (2008). With these inputs, we calculate a time series of annual labor shares for the PCE categories at our three levels of aggregation over the period 1998-05, the same period for which NS's price stickiness data are available. The resulting average labor shares are reported in the fifth column of Table 1.

We find that the average revenue share of labor in total PCE is 70.4 percent, somewhat higher than the 65 percent reported by Valentinyi and Herrendorf (2008). Labor shares vary substantially across consumption goods. Non-core household operations (i.e. electricity and gas) have the lowest labor share, 51.6 percent. At 83.3 percent, the labor share of medical services is the highest among all 15 PCE categories. At first glance, the variation in labor shares appears smaller than that in the frequencies of price changes. To study the implications of these two kinds of heterogeneity for monetary policy, we incorporate them into our model, which we present in the next section.

### 3 A Multi-Sector Model with Price Rigidities

In this section, we sketch a multi-sector generalization of the textbook New-Keynesian model, along the lines of Benigno (2004) and Woodford (2003). The model economy is populated by a continuum of worker-producers indexed by  $j \in [0, 1]$ . Each of these agents produces a single differentiated good within a sector  $n = 1, \dots, N$ , and consumes a composite of all goods. Each sector produces a composite consumption good that we identify with one PCE major product in the data. The size of each sector is determined by the fraction  $a_n$  of producers that belong to it, with  $\sum^N a_n = 1$ .

The production process differs across sectors in three dimensions. First, the frequency with which producers are allowed to change their prices ( $1 - \alpha_n$ ), i.e. price stickiness, as in Benigno (2004). Second, the elasticity of output with respect to changes in the labor input ( $\lambda_n^{-1}$ ), i.e. the returns to labor. Third, the elasticity of demand faced by each producer ( $-\theta_n$ ), which determines their desired (or steady state) markup. These last two parameters jointly determine the steady state revenue share of labor in each sector. They are also important determinants of the welfare costs of price dispersion, given any level of price stickiness. We introduce these two sources of sectoral heterogeneity to incorporate the evidence

on labor shares across consumption sectors presented above into our model.

There is a large literature on the positive implications of heterogeneity in nominal rigidities, especially on the transmission of monetary policy (see for example Carvalho, 2006; Nakamura and Steinsson, 2009, Carvalho and Dam, 2010; Bouakez, Cardia, and Ruge-Murcia, 2009a; as well as Carlstrom, Fuerst, Ghironi and Hernandez, 2006; Imbs, Jondeau, and Pelgrin, 2007; and Sheedy, 2007). However, to our knowledge, we are the first to model differences in labor shares stemming from either technological or demand factors in a New Keynesian framework, and to study their normative implications.<sup>19</sup>

### 3.1 Worker-Producers

Agent  $j$  in sector  $n$  maximizes lifetime utility

$$E_t \sum_{T=t}^{\infty} \beta^{T-t} \left[ \log C_T^j - \frac{h_T(j)^{1+\eta}}{1+\eta} \right],$$

subject to the flow budget constraint

$$E_t \left( Q_{t,t+1} B_{t+1}^j \right) + P_t C_t^j = B_t^j + (1 - \tau_n) p_t(j) y_t(j) + T_t,$$

where  $B_{t+1}^j$  is a portfolio of nominal assets with state contingent price  $Q_{t,t+1}$ —the stochastic discount factor.  $C_t^j$  denotes consumption of the composite good by agent  $j$  and  $P_t$  is the price of this good. With complete markets, agents can insure against idiosyncratic shocks and thus all have the same level of consumption, if their initial intertemporal budget constraint is the same. Therefore, we drop the superscript  $j$  on consumption from now on.

Agent  $j \in n$  produces a differentiated good  $y_t(j)$  and sells it at the price  $p_t(j)$ , minus a sector-specific sales tax (or subsidy)  $\tau_n$ , whose proceeds are rebated to consumers via the lump-sum transfer  $T_t$ .<sup>20</sup> Production is governed by the function

$$y_t(j) = Z_{n,t} h_t(j)^{\frac{1}{\lambda_n}}$$

where  $Z_{n,t}$  is a sector-specific productivity process,  $h_t(j)$  is the amount of labor supplied by  $j$  and  $\lambda_n^{-1} \leq 1$  is the elasticity of output with respect to changes in the labor input. This parameter is indexed

<sup>19</sup> Bouakez, Cardia and Ruge-Murcia (2009b) estimate a very rich multi-sector model with heterogeneity in price stickiness and the returns to labor, but not in desired markups. They also focus exclusively on its positive implications. Lombardo (2006), on the contrary, is a normative study of an open economy in which desired markups differ across countries, but the production function is the same.

<sup>20</sup> We assume that the sector-specific subsidy  $\tau_n$  offsets the gross markup charged by firms in steady state, so that the economy fluctuates in a neighborhood of the efficient equilibrium. This assumption significantly simplifies the derivation of a second order approximation to the utility of the representative agent, which is the welfare criterion in our normative analysis. See Woodford (2003) for details on this approach to optimal monetary policy analysis and Benigno and Woodford (2005) for an alternative approach that does not rely on the efficiency of the steady state.

by  $n$ , since it differs across sectors. It represents the first form of sectoral heterogeneity we introduce in our model.

The productivity process is AR(1) in logs

$$\ln Z_{n,t} = \rho \ln Z_{n,t-1} + \epsilon_{n,t},$$

with  $\epsilon_{n,t} \sim N(0, \sigma)$  a sector-specific innovation that is *i.i.d.* across time and sectors. Following most of the literature, we start by assuming that productivity shocks are identically distributed across sectors, to sharpen the focus on the quantification of the stickiness principle. However, we relax this assumption in section 4.2.1, in which we allow both  $\rho$  and  $\sigma$  to vary with  $n$ .

### 3.1.1 Consumption Aggregates and Price Indexes

Final consumption is a Cobb-Douglas aggregate of goods produced in each sector

$$C_t \equiv \prod_{n=1}^N (C_{n,t}/a_n)^{a_n},$$

where  $C_{n,t}$  is itself a composite defined by

$$C_{n,t} = \left[ \left( \frac{1}{a_n} \right)^{\frac{1}{\theta_n}} \int_{j \in n} c_t(j)^{\frac{\theta_n-1}{\theta_n}} dj \right]^{\frac{\theta_n}{\theta_n-1}}$$

and  $c_t(j)$  is consumption of the good produced by entrepreneur  $j$  in sector  $n$ . The parameter  $\theta_n$  governs the elasticity of substitution among the continuum of varieties within the consumption aggregate that defines sector  $n$ . These aggregates are normalized so that, in steady state,  $a_n$  represents the share of expenditures directed to the purchase of composite good  $n$ . We calibrate these shares to be consistent with the evidence, although we do not focus on them in the normative analysis, since the economic implications of this form of heterogeneity are not particularly interesting.

The minimum expenditure overall price index is therefore

$$(1) \quad P_t \equiv \prod_{n=1}^N P_{n,t}^{a_n},$$

a function of the sectoral price indexes

$$P_{n,t} \equiv \left[ \left( \frac{1}{a_n} \right) \int_{j \in n} p_t(j)^{1-\theta_n} dj \right]^{\frac{1}{1-\theta_n}},$$

where  $p_t(j)$  is the price of good  $j$ .

## 3.2 First Order Conditions

### 3.2.1 Demand Functions and Market Clearing

The consumer's intratemporal problem yields the following demand functions for each differentiated good produced by  $j \in n$  as a function of the sectoral demand  $C_{n,t}$

$$c_t(j) = \left[ \frac{p_t(j)}{P_{n,t}} \right]^{-\theta_n} \frac{1}{a_n} C_{n,t}$$

and for each sectoral consumption aggregate as a function of total consumption

$$C_{n,t} = a_n \left( \frac{P_{n,t}}{P_t} \right)^{-1} C_t.$$

Combining the two, we obtain

$$c_t(j) = \left[ \frac{p_t(j)}{P_{n,t}} \right]^{-\theta_n} (P_{n,t}^R)^{-1} C_t$$

where  $P_{n,t}^R$  denotes the relative price of sector  $n$  with respect to the overall price index.

From these formulas, we observe that  $-\theta_n$  is the elasticity of demand faced by each producer in sector  $n$ . This is the second dimension of sectoral heterogeneity we incorporate in our model.

The market for each good clears, so that  $c_t(j) = y_t(j) \forall j$ . We also define an output aggregate  $Y_t$ , with the same structure as the consumption one, so that  $Y_t = C_t$ .

### 3.2.2 Aggregate Consumption

The path of consumption for the aggregate good is described by the usual Euler equation

$$1 = E_t \left[ \frac{\beta u_C(C_{t+1})}{u_C(C_t)} \frac{R_t}{\Pi_{t+1}} \right],$$

where  $R_t$

$$R_t \equiv [E_t Q_{t,t+1}]^{-1}$$

is the gross nominal interest rate paid on one period bonds and  $\Pi_t \equiv P_t/P_{t-1}$  is the gross inflation rate in the general price level.

### 3.2.3 Pricing

Each producer  $j \in n$  faces a fixed per-period probability  $(1 - \alpha_n)$  of re-setting her price. This probability, which varies across sectors, is the third source of heterogeneity we model. When given the chance,

producer  $j$  chooses a price  $p_{n,t}$  to maximize utility, taking as given the demand function she faces and the behavior of the other agents in the economy. The pricing problem can therefore be written as

$$\begin{aligned} \max_{p_{n,t}} E_t \sum_{T=t}^{\infty} (\alpha_n \beta)^{T-t} & \left[ \frac{u_C(C_T)}{P_T} (1 - \tau_n) p_{n,t} y_{n,T} - \frac{(y_{n,T}/Z_{n,T})^{\lambda_n(1+\eta)}}{1+\eta} \right] \\ \text{s.t. } y_{n,T} & \equiv \left[ \frac{p_{n,t}}{P_{n,T}} \right]^{-\theta_n} \left( \frac{P_{n,T}}{P_T} \right)^{-\gamma} Y_T. \end{aligned}$$

The second term in the square bracket is the disutility suffered from producing a level of output  $y_{n,T}$ . This disutility is sector specific, due to the difference in production function across sectors, although the Frisch elasticity of labor supply  $\eta$  is common. We make this assumption because differences in this elasticity would be hard to pin down empirically. Moreover, they have the same qualitative effect on the dynamic behavior of the economy and on welfare as differences in  $\lambda_n$ , since the parameter that matters for both is the elasticity of marginal cost with respect to output  $\tilde{\eta}_n \equiv \lambda_n(1+\eta) - 1$ .

The first order condition with respect to the optimal price in sector  $n$  then gives

$$E_t \sum_{T=t}^{\infty} (\alpha_n \beta)^{T-t} \left\{ \left[ \frac{p_{n,t}}{P_T} - \frac{\theta_n}{(\theta_n - 1)(1 - \tau_n)} \frac{\lambda_n (y_{n,T}/Z_{n,T})^{\tilde{\eta}_n}}{U_C(C_T) Z_{n,T}} \right] y_{n,T} \right\} = 0.$$

### 3.3 Log-linearized Dynamics

Log-linearization of the first order conditions and of the aggregate price index described above yields a set of expectational difference equations in the endogenous variables  $\left[ \hat{Y}_t, \{\pi_{n,t}\}_n, \pi_t, \{\hat{P}_{n,t}^R\}_n, \hat{R}_t \right]$ , where hats denote log-deviations from steady state,  $\pi_{n,t} \equiv \log P_{n,t} - \log P_{n,t-1}$  is inflation in sector  $n$  and  $\pi_t \equiv \log P_t - \log P_{t-1}$  is aggregate inflation. These equations include the Euler equation

$$\hat{Y}_t = - \left( \hat{R}_t - E_t \pi_{t+1} \right) + E_t \hat{Y}_{t+1},$$

and a set of Phillips curves for the determination of inflation in each sector

$$(2) \quad \pi_{n,t} = \beta E_t \pi_{n,t+1} + k_n \left[ \left( \hat{Y}_t - \hat{Y}_t^f \right) - \left( \hat{P}_{n,t}^R - \hat{P}_{n,t}^{Rf} \right) \right]$$

where

$$\hat{Y}_t^f = \hat{Z}_t \equiv \sum_n a_n \log Z_{n,t}$$

and

$$\hat{P}_{n,t}^{Rf} = - \left( \hat{Z}_{n,t} - \hat{Z}_t \right)$$

are the levels of output and the relative price that would prevail under flexible prices and the slope is

$$\begin{aligned} k_n &\equiv \xi_n \frac{1 + \tilde{\eta}_n}{1 + \theta_n \tilde{\eta}_n} \\ \xi_n &\equiv (1 - \alpha_n \beta) \frac{1 - \alpha_n}{\alpha_n}. \end{aligned}$$

To these we add an equation for aggregate inflation, obtained from simple manipulation of the price index (1)

$$\pi_t = \sum_{n=1}^N a_n \pi_{n,t}$$

and the definition of the log-change in relative price

$$(3) \quad \hat{P}_{n,t}^R = \hat{P}_{n,t-1}^R + \pi_{n,t} - \pi_t.$$

We close the model with a description of monetary policy.

### 3.4 Monetary Policy

In the cashless economy with nominal rigidities presented above, monetary policy affects allocations by choice of a state contingent path for the nominal interest rate. This choice can be modeled as a simple feedback rule, in which the interest rate is set as a function of some endogenous variables, or as the result of maximization of an objective function.<sup>21</sup> This latter approach is at the center of the normative part of this study, but we follow the former when calibrating the model, since a policy rule has the best chance to provide a satisfactory empirical characterization of the observed behavior of monetary policy in the United States.

However, we do not write the policy rule explicitly in terms of the interest rate, but rather implicitly, as that rule that would result in a certain state contingent path of nominal income. In particular, we assume that nominal income,  $\mathcal{Y}_t \equiv P_t Y_t$ , which in our model is equal to consumption expenditures, follows the unit root process

$$(4) \quad \Delta \ln \mathcal{Y}_t = \epsilon_t^{\mathcal{Y}},$$

where  $\epsilon_t^{\mathcal{Y}}$  is i.i.d. with standard deviation  $\sigma^{\mathcal{Y}}$ .

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<sup>21</sup> Svensson (2000) discusses in detail various approaches to the implementation of monetary policy in this class of models.

### 3.4.1 The Policy Objective

The main objective of this paper is to compute a price index whose stabilization minimizes the cost of nominal distortions: a CONDI. The criterion we adopt for the evaluation of this cost is the unconditional expectation of the utility function of the representative, or average, worker-producer in the economy

$$W \equiv E \sum_{t=0}^{\infty} \beta^t \left[ \log C_t - \int_0^1 \frac{h_t(j)^{1+\eta}}{1+\eta} dj \right],$$

which we approximate to second order as

$$W \approx -\frac{1}{2} E \sum_{t=0}^{\infty} \beta^t L_t$$

with

$$(5) \quad L_t \equiv \begin{cases} (1 + \sum_n a_n \tilde{\eta}_n) (\hat{Y}_t - \hat{Y}_t^f)^2 + \sum_n a_n (1 + \tilde{\eta}_n) (\hat{P}_{n,t}^R - \hat{P}_{n,t}^{Rf})^2 \\ + \sum_n a_n \frac{\theta_n}{\xi_n} (1 + \theta_n \tilde{\eta}_n) \pi_{n,t}^2 - 2 \sum_n a_n \tilde{\eta}_n (\hat{P}_{n,t}^R - \hat{P}_{n,t}^{Rf}) (\hat{Y}_t - \hat{Y}_t^f). \end{cases}$$

This approximate loss function captures the three main sources of welfare losses in our economy. First, the representative household dislikes fluctuations in consumption, and thus in output. Second, the household dislikes fluctuations in hours worked, to an extent that depends on the parameter  $\eta$ , which governs the curvature of its disutility of effort. Through the sectoral demand and production functions, this disutility of effort can be mapped into a function of each sector's relative prices, giving rise to the second square term in the loss. Third, the presence of price rigidities implies that the firms within a sector charge different prices and therefore produce different amounts of output. This dispersion, which is increasing in inflation, is inefficient because those firms operate identical production functions. Hence the third term in the loss function.<sup>22</sup>

The inflation terms in (5) are by far the largest contributors to overall welfare losses.<sup>23</sup> Their coefficients, which map inflation in each sector into the amount of relative price dispersion in that sector, depend on all the sources of heterogeneity in the model. In particular, a more elastic demand (higher  $\theta_n$ ), a more concave production function (higher  $\lambda_n$  and thus higher  $\tilde{\eta}_n$ ) and a lower frequency of price adjustment (higher  $\alpha_n$  and thus lower  $\xi_n$ ), all amplify the losses from a given path of sectoral

<sup>22</sup> The fourth term in expression 5 appears in the approximation because of the heterogeneity in production functions across sectors, which is reflected in  $\tilde{\eta}_n$ . If this parameter were constant across sectors, the weighted log-deviations of relative prices from their steady state value would be zero, both in the actual and in the flexible price equilibrium, so that the cross term would disappear. In this case, and with  $\theta_n = \theta$ , we would recover an approximate loss function identical to that in Benigno (2004).

<sup>23</sup> For an "average" sector whose structural parameters are the same as those of the aggregate economy (i.e. as in the first row of Table 1), the weight on the inflation term is about ten times as large as the weights on the other terms in the loss function. The large relative role of inflation distortions is a common feature of this class of models (Woodford, 2003).

inflation. The intuition for the sign of these “partial derivatives” comes from the relationship between the heterogenous parameters and the dispersion of prices, output and hours worked across firms within each sector, for any given level of inflation. As we just pointed out, this dispersion is inefficient, and thus a source of welfare losses. More specifically, price dispersion is higher in a sector, for any given level of inflation, the higher is  $\alpha_n$ , since this results in more firms with old prices. Moreover, for a given level of price dispersion, the dispersion of demand, and thus of production is higher, the higher the elasticity of demand,  $\theta_n$ . Finally, a given distribution of production requires more hours of work to be achieved in the sectors in which the returns to labor are lower.

The period loss function in (5), together with the sectoral Phillips curves (2), highlights the nature of the policy trade-off facing the monetary authority. The flexible price equilibrium, in which all the terms in (5) are zero, is the first best in this economy. However, this efficient equilibrium is not feasible when prices are sticky (Benigno, 2004). The reason is that the inability of firms to adjust their prices at will creates an endogenous wedge between actual and flexible relative prices. This wedge, represented by  $k_n \left( \hat{P}_{n,t}^R - \hat{P}_{n,t}^{Rf} \right)$  in equation (2), creates a tension between aggregate inflation and output stabilization. With zero inflation in all sectors, in fact, relative prices must be constant, thus opening a gap between actual and flexible relative prices, which move exogenously in response to shocks. As a result, aggregate output also deviates from its first-best level.

This trade-off disappears only in the special case of identical sectors. When  $k_n = \bar{k} \forall n$ , in fact, we can “average” the sectoral Phillips curves to obtain

$$\pi_t = \beta E_t \pi_{t+1} + \bar{k} \left( \hat{Y}_t - \hat{Y}_t^f \right),$$

which implies that output gap and inflation stabilization can be achieved simultaneously, a property that Blanchard and Galí (2007) have called the “divine coincidence.” In this special case, headline inflation stabilization is the optimal policy, even if it implies inefficient movements—or rather lack of movement—in relative prices, since these movements are independent of policy (Woodford, 2003). However, a targeting rule that perfectly stabilizes an appropriate price index, the CONDI, delivers a close approximation to this optimal policy, even in the general case in which sectors are heterogenous. We now turn to a more formal description of this rule.

### 3.4.2 The CONDI

At the center of our normative analysis is a class of strict targeting rules that perfectly stabilize a weighted average of good-specific inflation rates of the form

$$(6) \quad \pi_t^{\text{target}} = \sum_{n=1}^N \phi_n \pi_{n,t} = 0, \text{ with } \phi_n \geq 0 \text{ and } \sum_{n=1}^N \phi_n = 1.$$

The CONDI is the index that corresponds to the best policy within this class. More formally

$$\pi_t^{\text{CONDI}} \equiv \sum_{n=1}^N \phi_n^* \pi_{n,t},$$

where the set of weights  $\{\phi_n^*\}_n$  is chosen to maximize  $W$ , under the constraints that embed the optimal behavior of the private sector, equations (2) and (3).<sup>24</sup>

We also consider two alternative targeting rules, headline PCE targeting and core PCE targeting. Headline PCE targeting is defined by the standard expenditure weights

$$\phi_n^{\text{PCE}} = a_n \text{ for } n = 1, \dots, N,$$

while core PCE targeting has weights

$$\phi_n^{\text{core}} = \begin{cases} 0 & \text{for } n \notin \text{core} \\ (\sum_{n' \in \text{core}} a_{n'})^{-1} a_n & \text{for } n \in \text{core} \end{cases},$$

where the set of core goods includes all types of expenditures except those on food and energy.<sup>25</sup>

The comparison of the welfare implications of the targeting rules just described forms the basis for our discussion of the relative merits of monetary policies that focus on the stabilization of core rather than headline inflation. Of course, a strict inflation target of any kind—headline, core, or CONDI—cannot be a practical recommendation for policy. Nevertheless, the comparison among targeting rules we propose can provide useful indications on the type of inflation index that central banks should monitor most closely as a gauge of the distortionary effects of inflation.

The reference point for the evaluation of the relative performance of our targeting rules is the approximate unconstrained optimal policy. This is the solution to the linear-quadratic Ramsey problem

<sup>24</sup> The CONDI is a fixed-weighted Törnqvist (1936) index because we approximate the inflation rate with the log monthly change in the price level.

<sup>25</sup> These are the most commonly considered price indices for monetary policy. Alternative indices, which are based on measures of central tendency other than the mean, are also sometimes discussed. These include the Median CPI and the Trimmed Mean CPI, published monthly by the Federal Reserve Bank of Cleveland at <http://www.clevelandfed.org/research/data/us-inflation/mcpi.cfm>. [URL last accessed 11/16/2009] These indices would be hard to represent in the log-linear framework we have adopted.

defined by the welfare function  $W$  and by the constraints (2) and (3). Under our assumptions, this solution provides a first order approximation of the optimal equilibrium, as well as a second-order approximation of welfare under this equilibrium (Woodford, 2003).<sup>26</sup>

As a metric for welfare comparisons, we follow Jensen (2002) and Dennis and Söderström (2006) and compute an “inflation equivalent” for each targeting rule. The inflation equivalent for any suboptimal policy, call it  $SO$ , is a simple monotonic transformation of the welfare differential between the optimal policy and the suboptimal alternative under consideration ( $SO$ ). As we show in Appendix A.3, this metric can be interpreted as the constant amount of inflation that would need to be added exogenously to the equilibrium path of inflation under the optimal policy to make the representative agent indifferent between this distorted equilibrium and the one that would emerge under the alternative policy  $SO$ . We also compute a consumption equivalent, the constant fraction of consumption that would have to be subtracted from the optimal flow of consumption to make the representative household similarly indifferent.

However, we prefer to concentrate the discussion on the inflation equivalent, for several reasons. First, the model focuses on inflation determination and on the effects of sectoral heterogeneity in price setting on the distortions created by price dispersion. The rest of this economy, including consumption demand, is very stylized. Partly as a consequence of this modeling choice, inflation is by far the most important source of overall welfare losses, as pointed out in the previous section. Therefore, the inflation equivalent is a more direct and natural scale to measure these losses. Moreover, this scale is likely to be more accurate in our application than one based on consumption, since we calibrate the shocks to match the volatility and autocorrelation of inflation. Finally, the inflation equivalent allows a direct comparison of the costs of stabilizing the wrong *kind* of inflation to those of stabilizing inflation around the wrong *level*. The optimal level of inflation and the costs of deviating from it have been widely debated in the literature and among policymakers at least since Friedman (1969), thus providing a useful backdrop for our discussion (see Schmitt-Grohe and Uribe (2010) for a recent survey).

### 3.5 Calibration

In this section, we use the evidence presented in Table 1 to discipline the choice of the model parameters that govern the degree of sectoral heterogeneity. For the parameters without a cross-sectional dimension, we use standard values to the extent possible. The calibration assumes that the PCE categories in

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<sup>26</sup> We solve the Ramsey plan starting in steady state. As a result, this solution is equivalent to that under the timeless perspective, since the steady state is not distorted.

Table 1 correspond to the  $n = 1, \dots, N$  consumption composites/sectors in the model and that time,  $t$ , is measured in months.

### 3.5.1 Homogenous Parameters

Our choice of the parameters that are constant across sectors is guided by Carvalho (2006) and Nakamura and Steinsson (2009), who calibrate multi-sector models with price rigidity similar to ours. We set the discount factor  $\beta$  so that the steady state annual real interest rate is 4 percent and pick an inverse Frisch elasticity of labor supply,  $\eta$ , equal to 0.5. This value is a compromise between the linear specification,  $\eta = 0$ , adopted by Nakamura and Steinsson (2009) and typical of the RBC literature (Hansen, 1985), and the low elasticities of labor supply usually estimated by the empirical labor literature, which might suggest values for  $\eta$  around 2, as in one of the specifications in Carvalho (2006).

We choose the parameters of the distribution of the productivity shocks, the standard deviation  $\sigma$  and autocorrelation  $\rho$ , to replicate the standard deviation and autocorrelation of monthly PCE inflation over the period 1998 to 2005, which are equal to 0.19 and 0.17 percent respectively. This procedure implies different values for  $\sigma$  and  $\rho$  across different quantitative renditions of the model, depending for example on the number of sectors considered and on the kinds of heterogeneity included in the specification. This is because, as in any DSGE model, the mapping from the distribution of the primitive shocks to the moments of the endogenous variables depends on the specification of the rest of the model.

For this moment matching exercise, we assume that monetary policy is conducted so that nominal income  $\mathcal{Y}_t \equiv P_t Y_t$  follows the unit root process (4), as in Nakamura and Steinsson (2009) for example. In the model, nominal income is equal to consumption expenditures, so we calibrate the standard deviation of the innovation to this process,  $\sigma_t^{\mathcal{Y}}$ , to match the standard deviation of the monthly growth rate of consumption expenditures over the period 1998-2005, which is equal to 0.51 percent. The autocorrelation of this monthly process is negative, but it is statistically zero for the quarterly growth rate, which is measured more reliably.

### 3.5.2 Heterogenous Parameters

The calibrated values for the parameters that are heterogenous across sectors are summarized in Table 1. The first form of heterogeneity we take into account is the size of each sector. In the model, this size is governed by the parameters  $\{a_n\}_n$ , which determine the steady state share of total expenditures directed to each sector. We calibrate these parameters to match the average expenditure shares of the relevant PCE categories over the period 1998-2005.

The second dimension of heterogeneity we calibrate is the frequency with which producers can adjust their prices. In the time-dependent price setting model we consider, every month a fraction  $(1 - \alpha^n)$  of the goods that belong to composite  $n$  have their price adjusted. We match this fraction to the frequency of price change data listed in the fourth column of Table 1.

The last dimension of heterogeneity we calibrate is the revenue share of labor. In the model, the steady state share of labor in the revenue generated by sales in sector  $n$ ,  $s_l^n$ , equals

$$s_l^n = \lambda_n^{-1} \frac{\theta_n - 1}{\theta_n}.$$

This share depends on the elasticity of output to changes in the labor input,  $\lambda_n^{-1}$ , and on the inverse of the gross desired markup of firms in sector  $n$ ,  $\frac{\theta_n}{\theta_n - 1}$ , which in turn is a function of the elasticity of demand faced by each firm,  $\theta_n$ . The data do not allow us to distinguish between variations in the labor share due to differences in demand or in labor elasticities. For this reason, we present results for three parametrizations, which are all consistent with the observed labor shares. The first parameterization, which we denote by *(I)*, attributes all the variation in labor shares to differences in demand elasticities,  $\theta_n$ . The second parameterization *(II)* attributes all the variation in labor shares to differences in labor elasticities,  $\lambda_n$ . The third parameterization *(III)* is the intermediate case in which half of the variation in labor shares comes from  $\theta_n$  and the other half from  $\lambda_n$ .

If the demand elasticity does not vary across goods, as in the one-sector baseline model and under parameterization *(II)*, we set  $\theta_n = \bar{\theta} = 5$ , as in one of Carvalho's (2006) specifications, which implies a steady state markup of 25 percent. This is very close to the average wholesale markup from the 1997 Census of Wholesale Trade among the industries that Bils and Klenow (2004) were able to match to consumer goods in the CPI.<sup>27</sup> A value of 5 for the elasticity of demand is intermediate between the low elasticities—in the range of 3 to 4—typically found in the IO literature and used for example by Nakamura and Steinsson (2009) and Midrigan (2010), and the higher values more often adopted in the macroeconomic literature—in the range between 7 and 10—based on the implications of these elasticities for steady state markups (Woodford, 2003; Golosov and Lucas, 2007).

If the labor elasticity of output does not vary, as in the one-sector baseline model and under parameterization *(I)*, we choose  $\lambda_n = \bar{\lambda} = 0.88$ . Given the baseline elasticity of demand  $\bar{\theta} = 5$ , this is the degree of decreasing returns to labor that is consistent with the average revenue share of labor in total PCE of 70 percent we have measured over the period 1998 to 2006.

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<sup>27</sup> We thank Mark Bils for providing us this matched dataset. The average markup in this dataset is 24%, which implies an elasticity of demand of 5.1, while the weighted average markup (weighted by CPI expenditure shares) is 20%, with an implied elasticity of demand of 5.8.

The three parametrizations corresponding to the observed heterogeneity in labor shares are explained in more detail in Appendix A.2. The resulting parameter values are listed in the last four columns of Table 1.

## 4 Results

In this section, we discuss the properties of the CONDI implied by the calibrations discussed above. We start from a two-good, two-sector version of the model, which distinguishes between core and non-core goods. The simplicity of this specification highlights the qualitative relationship between the CONDI weights and the parameters that are heterogenous across sectors and the economic intuition behind it. We then move to an empirically more realistic 15-good version of the model, in which we can study in more detail the allocation of CONDI weights within the core and non-core sectors, where a significant amount of heterogeneity remains. Finally, we consider the practical implications of our results for monetary policy.

### 4.1 The Two-Sector Model: Core and Non-Core

The results for the two-sector calibration of the model are reported in Table 2. For ease of reference, the first group of columns reports the calibrated values of the parameters that change across sectors, which we already discussed in the previous section.

The column labeled 1 reports the CONDI weights in the case in which the frequency of price adjustment and the labor share in both sectors are set to their baseline homogenous values. These weights are the same as the PCE expenditure weights: the CONDI and the COLI coincide. When the two sectors are structurally identical, there is no reason to “twist” the CONDI weights with respect to the expenditure weights, because the distortions caused by nominal rigidities are the same across sectors. Moreover, in this case, headline PCE stabilization is a way of implementing the optimal policy, as confirmed by the fact that its inflation equivalent is zero. Blanchard and Galí’s (2007) “divine coincidence” holds under this particular parameterization, as originally shown by Benigno (2004) and discussed in section 3.4.1

Stabilizing core inflation is not a good policy in these circumstances, since it implies ignoring the distortions in the non-core sector. When the two sectors share the same price stickiness, as well as all other parameters, these distortions are just as large as those in the core sector, although the core sector accounts for a much larger part of expenditures. As a result, the inflation equivalent for this policy is

about 5 percent per annum, a large loss compared to the optimum.

Column 2 considers the case in which sectors differ only in the frequency of price adjustment. According to our calculations, 12.7 percent of non-core prices change every month, as opposed to 9.6 percent in the core sector. Core inflation receives a weight of 88.6 percent in the CONDI, compared to a PCE weight of 81.4 percent. As expected, the CONDI puts more emphasis on the stabilization of inflation in the stickier sector. However, the non-core sector still receives a non-negligible weight of 11.4 percent, given that its prices are far from perfectly flexible. In terms of weights, then, the CONDI is an almost perfect average of total and core PCE.

This result does not imply that headline and core targeting are equivalent policies in terms of welfare, as we can observe from the last two rows of Column 2. Core targeting performs worse than headline stabilization under this calibration. This result suggests that the mapping from the weights in the targeting criteria to their welfare implications is not symmetric around the optimal weighting scheme: the losses increase more steeply as we shift weight towards the core sector.

The other remarkable finding in Column 2 is that the inflation equivalent of CONDI stabilization is an extremely low 0.06 percentage points per year, which corresponds to a uniform reduction in the stream of consumption associated with the optimal allocation of 0.0003 percent. In fact, CONDI stabilization delivers similarly low inflation and consumption equivalents across all the calibrations we consider in Table 2. These calculations prove the robustness of Benigno's (2004) conclusion regarding the ability of a policy that stabilizes an optimally weighted inflation rate to approximate the optimal equilibrium very closely.

An important implication of the excellent welfare performance of CONDI stabilization in our economy is that the CONDI weights we have computed would change little if we embedded their optimal choice in a more flexible policy rule, such as an interest rate feedback rule. Even then, in fact, the optimization would have to return something very similar to the strict CONDI targeting rule we have assumed at the outset, and with the same CONDI weights, since there is very little room to improve on this rule's performance.

In columns 3 through 5 of Table 2 we consider three alternative calibrations of the model, in which we allow the labor share to differ across sectors, while keeping the degree of price stickiness at its baseline level. Column 3 corresponds to parameterization (*I*). This is the case in which heterogeneity in labor shares is due exclusively to differences in markups and the curvature of the production function in all sectors is  $1/\lambda = 0.88$ . Column 4 corresponds to case (*II*), where the heterogeneity in labor shares is ascribed to differences in the labor elasticity of output, but markups are constant at  $\frac{\theta-1}{\theta} = 1.25$  across

all PCE categories. Column 5 considers the intermediate case (*III*) where half of the variance of log labor shares is due to differences in markups and the other half to the labor elasticity of output.

When the elasticity of demand, and thus markups, differ across sectors (Column 3), the CONDI weights continue to be skewed in the direction of the core sector, although to a lesser extent than in Column 2. The intuition for this result is that this calibration attributes the higher revenue share of labor in the core sector to a lower markup, due to a higher demand elasticity. A more elastic demand implies that a given degree of price dispersion translates into a higher degree of output dispersion across individual producers. As a consequence, it is optimal to counteract price dispersion, and thus inflation, more strongly in the core sector, where the welfare costs of that dispersion are higher. Quantitatively, this effect is not very strong. It leads to a more modest adjustment of the PCE weights than in the case of heterogenous price stickiness (Column 2).

We find the opposite when the elasticity of labor in the production function is different across sectors, in a manner consistent with the observed heterogeneity in labor shares and with a constant markup of 25 percent (Column 4). In this case, the core sector receives a lower weight in the CONDI than in the PCE. The reason is that the higher labor share now maps into a higher labor elasticity of output and thus into less curvature of the production function. This curvature, in turn, determines the transmission of the cross-sectional dispersion of output within the sector into the cross-sectional dispersion of hours, which, in our model, is the main source of the welfare losses associated with inflation and price dispersion. In sum, a higher labor elasticity translates into less dispersion in hours, and thus lower welfare losses, for any given level of inflation. Therefore, the optimal weighting scheme suggests to pay less attention to core inflation, since the production function is less concave in labor in this sector.

In the intermediate case of heterogeneity in both markups and labor elasticities (Column 5), the CONDI weights do not deviate much from the expenditure shares. This suggests that the countervailing effects of these two forms of heterogeneity approximately cancel out, making headline PCE a good approximation of CONDI.

In fact, the inflation equivalent of PCE stabilization in Column 5 is only 0.14 percentage points per year. More in general, PCE stabilization outperforms core stabilization by a wide margin in all the calibrations with heterogeneity in labor shares only. The reason is that the differences in labor shares in the data are too small to result in significant deviations from the expenditure weights in the CONDI, as we just saw. As a result, ignoring the non-core sector entirely, as under core targeting, amounts to ignoring about one-fifth of the allocative inefficiencies caused by sticky prices in this economy, resulting in a large welfare loss.

Next, we study the interaction between heterogeneity in price stickiness and in labor shares. Columns 6 through 8 of Table 2 again consider the three cases in which the labor shares reflect differences only in the elasticity of demand (Column 6), only in the returns to labor (Column 7), or in both (Column 8). The effects of these various kinds of heterogeneity on the CONDI weights cumulate in a fairly straightforward way. In Column 6, the core sector has a CONDI weight of 91.2 percent since it has both stickier prices and a more elastic demand. In Column 7, instead, the weight on core is down to 86.8 percent, since this sector has stickier prices, but a less concave production function. In Column 8, the weight on core is 89.0 percent, very close to the 88.6 percent it should receive on account of price stickiness alone (Column 2). This is because the effects of the calibrated degrees of heterogeneity in demand and labor elasticities approximately cancel out, as in Column 5.

In terms of welfare, the results are consistent with those for the case with heterogeneity only in price stickiness (Column 2). Headline PCE targeting continues to outperform core stabilization, except under the calibration in Column 6, in which the two policies are roughly equivalent. The distance between the two policies is equivalent to roughly 1.3 percent steady inflation per year under parameterization (*III*).

Comparison of the CONDI weights in the last three columns of Table 2 with those in Column 2 leads us to one important conclusion. The basic principle that core inflation should be stabilized more forcefully than non-core inflation is *quantitatively* robust to the inclusion of a degree of sectoral heterogeneity in labor shares consistent with the data. This is particularly true in the case represented in Column 8, which we consider the most realistic, since it admits that the measured heterogeneity in labor shares might reflect differences in both markups and the returns to labor in the production function. The difference in CONDI weights with respect to the case with only heterogeneous stickiness is only 0.4 percentage points under this parametrization. However, even in the extreme parametrizations of columns 6 and 7, the difference in weights with Column 2 is never higher than 2.6 percentage points.

The two-good example presented in this section is a useful tool to develop some intuition for the relationship between structural heterogeneity and the CONDI weights. However, accounting for the substantial heterogeneity in price stickiness and labor shares within the core and non-core sectors is important for the construction of an empirically more accurate CONDI.

## 4.2 The Fifteen-Sector Model

The CONDI weights for the 15-sector calibration of the model are reported in Table 3. Column 1 again corresponds to the homogeneous case in which stabilizing PCE inflation is the optimal policy. Hence,

the CONDI weights in that Column correspond to the PCE shares listed in Table 1.

In Column 2, which refers to the case with only heterogeneous price stickiness, several non-core entries stand out. First, “gasoline, fuel oil and other energy goods,” with a frequency of price adjustment of 87.6 percent per month, receive no weight in the CONDI, as does the energy component of “household operations.” “Food at home,” with a frequency of price adjustment of 13.0 percent, largely attributable to fresh food, also shrinks from a weight of 8.5 percent to 4.6 percent. On the other hand, “food away from home,” with a frequency of price adjustment of 5.2 percent per month, which is far lower than the median, sees its CONDI weight inflated to 15.4 percent, from its 5.2 percent PCE expenditure share.

Turning now to the weights on the core sectors, three categories stand out in terms of the deviation of their CONDI weights from their expenditure shares. The first is “other services,” for which only 7.5 percent of the prices change each month.<sup>28</sup> After food away from home, this is the PCE category with the stickiest prices and its CONDI weight, at 22.8 percent, is almost double its expenditure share. This increase in the weight of other services comes at the cost of that of two other core sectors: “motor vehicles” and “clothing and shoes.” Both of these categories receive less than a 0.5 percent weight in the CONDI because of their very flexible prices. There is clearly enough heterogeneity in stickiness, and thus in CONDI weights, within core and non-core products to justify a finer level of disaggregation.

Under the calibration of Column 2, the sum of the CONDI weights on the four non-core sectors is equal to 20.2 percent, close to their 18.6 percent expenditure share in the PCE. Perhaps surprisingly, this does not imply that the stabilization of headline inflation is a better policy than core inflation targeting, as demonstrated by the inflation equivalents at the bottom of Column 2. Headline PCE targeting produces welfare losses equivalent to a steady inflation of about 1.9 percentage points per month, or 0.30 percent of consumption, while the inflation equivalent of core targeting is 1.4 percent per year, or 0.16 percent of consumption. The reason is that headline stabilization weighs core and non-core correctly, but misallocates this weight within each category, attributing too much weight to the very flexible prices within non-core and too little to the stickier prices within core, such as other services. As it turns out, this misallocation is more severe than for core inflation, which puts no weight on the very sticky food away from home, but too much on the flexible prices within core, such as motor vehicles and clothes.

When we move to calibrations with heterogeneous labor shares, we recover similar qualitative patterns to those identified in the corresponding two-sector model. Sectors with high labor shares, most

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<sup>28</sup> Other services includes financial and legal services, education, clothing repairs and cleaning, and funeral services, among others.

notably medical care, have larger CONDI than PCE weights when those labor shares are translated into low markups (Column 3). On the contrary, the CONDI weights are smaller when large labor shares are mapped into a higher labor elasticity (Column 4). The two effects approximately cancel out in the intermediate case (Column 5), when we recover CONDI weights very similar to the expenditure shares listed in Column 1. As a consequence, the calibration that includes all forms of heterogeneity (Column 8) produces CONDI weights and a welfare ranking very similar to those with heterogenous stickiness only (Column 2). These results do not change much even under the two extreme parametrizations of the heterogeneity in labor shares reported in Columns 6 and 7.<sup>29</sup>

Once again, we can conclude that the basic principle that the stability of inflation in the goods with stickier prices should feature more prominently in the objectives of central banks is quantitatively robust to the presence of a realistic degree of dispersion in labor shares. However, a simple distinction between core and non-core prices is not sufficient for the optimal implementation of this principle, since in practice these two broad aggregates hide a fairly large amount of heterogeneity in price stickiness. In fact, core inflation targeting yields inflation equivalent welfare losses of about 1 percentage point per year, compared to losses under CONDI stabilization that are virtually indistinguishable from those under the optimal policy. Yet, core inflation targeting represents an improvement over headline inflation targeting, whose inflation equivalent is in the order of 1.5 percentage points per year.

When we assume that owners' equivalent rent, which represents about two thirds of expenditures on housing (or about 11 percent of the total), is a perfectly flexible price, the numbers change in the expected direction, as shown in Column 9 of table 3. The CONDI weight of housing falls from 12.2 percent to 3.2 percent, with the difference redistributed to the other categories more or less proportionally. Moreover, the stabilization of headline inflation produces slightly better welfare results than core stabilization, since the latter price index now includes a price—OER—which is perfectly flexible and that should therefore be allowed to fluctuate freely. This is of course what happens under CONDI stabilization, which in fact continues to outperform the other policies under consideration, although by a lesser margin in terms of inflation equivalents. This reduced margin reflects in part the lower degree of overall distortions in this economy.

We conclude this section with a comparison of realized CONDI with headline and core PCE inflation

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<sup>29</sup> One notable exception is the CONDI weight for medical care, which is 25.5 percent under parametrization (*III*), but reaches 44.2 percent under parametrization (*I*). This result is driven by the very high labor share (83.2 percent), which translates into an extremely elastic demand under parametrization (*I*). We find this parametrization implausible for this sector, since its high measured labor share is much more likely to stem from a high labor requirement in production than from a high elasticity of demand.

in the time-series, rather than the welfare dimension. We build realized CONDI inflation as

$$\pi_t^{\text{CONDI}} = \sum_{n=1}^N \phi_n^* \pi_{n,t},$$

where the weights  $\{\phi_n^*\}_n$  are those from our preferred calibration with all forms of heterogeneity (Column 8 of Table 3). The sectoral inflation rates  $\{\pi_{n,t}\}_n$  are the historical realizations of the log-price changes in the prices of the 15 PCE products in our database, as reported by the BEA.<sup>30</sup>

Figure 2 plots the annualized monthly inflation rates in the three indexes—CONDI, headline and core PCE—over the period January 1998 to December 2006. This time-series view confirms our welfare analysis. CONDI and core inflation behave quite similarly, while total PCE inflation exhibits significantly more volatility. Over this sample period, the correlation of CONDI and core inflation is 0.90, while that with headline is only 0.42. In terms of volatility, total inflation has the highest, with a standard deviation of 2.3 percent, while CONDI was historically about as volatile as core, both with standard deviations of 1.0 percent.

This ranking of volatilities reflects the emphasis of monetary policy in the United States on the stabilization of core inflation. But our welfare analysis suggests that there might be significant gains from focusing instead on the stabilization of an inflation index that takes into account more explicitly the differences in price stickiness across different consumption goods, such as the CONDI.

#### 4.2.1 The Role of Heterogenous Shock Distributions

In our calculations so far, we have assumed that the productivity process  $Z_{n,t}$  has the same distribution across sectors, even if its innovations are drawn independently across both  $n$  and  $t$ . We maintained this assumption because our main objective was to quantify the impact of structural sources of heterogeneity across sectors, such as price stickiness and labor shares, on the CONDI. Here, we take a first pass at relaxing this restriction.

In particular, we generalize the productivity process as follows,

$$\begin{aligned} Z_{n,t} &= Z_t z_{n,t} \\ \ln Z_t &= \rho \ln Z_{t-1} + \epsilon_t \\ \ln z_{n,t} &= \rho_n \ln z_{n,t-1} + \varepsilon_{n,t}, \end{aligned}$$

where  $Z_t$  is a common component across sectors, with i.i.d. innovations over time  $\epsilon_t \sim N(0, \sigma)$ , while  $z_{n,t}$  is a sector specific component, with innovations  $\varepsilon_{n,t} \sim N(0, \sigma_n)$  that are i.i.d. over time and across

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<sup>30</sup> We exclude September and October 2001, in which the price index of other PCE services fluctuated widely due to the accounting for the September 11th terrorist attacks.

sectors. We calibrate the common shock parameters  $\{\rho, \sigma\}$  and the sectoral parameters  $\{\rho_n, \sigma_n\}_n$  to match simultaneously the autocorrelation and standard deviation of inflation in each sector,  $\pi_{n,t}$ , as well as in the aggregate,  $\pi_t$ .<sup>31</sup> Given the stylized nature of our model, the objective of this calibration exercise is not to “test” the model’s ability to replicate some empirical moments, even if the procedure is very successful in this regard. Rather, the aim is to generate some empirically plausible cross-sectional variation in the distribution of shocks, conditional on the model, and to study how this variation might affect the specification and properties of the CONDI.

The results of this investigation are reported in Column 10 of Table 3, for a model that includes all forms of heterogeneity, as in Column 8. The remarkable finding is that the CONDI weights barely change with respect to the case with homogenous shock distributions. This is not because the shocks are too small to matter. In fact, the inflation equivalent losses under both headline and core PCE targeting are about four times as large as in Column 8, indicating that the new shocks are generating distortions in the economy that are hard to eliminate with traditional stabilization policies. Yet, CONDI stabilization remains very close to the optimal policy, with an inflation equivalent of only 0.14 percentage points.

This result is surprising, since in general we would expect sectors with more volatile (and possibly persistent) fundamentals to experience larger distortions, and therefore to receive a higher weight in the optimal inflation targeting criterion, for any given level of price stickiness. This last implication does not follow in our economy, though, because CONDI stabilization also results in a stable output gap, thus severing the link between policy choices and relative prices. As a consequence, the stochastic properties of the productivity shocks become almost irrelevant for the determination of the CONDI weights, since the transmission of these shocks happens through the relative prices, whose movements are close to exogenous in equilibrium.<sup>32</sup> Nevertheless, it remains true that sectors with more volatile shocks in general display more volatile relative prices, and thus more volatile inflation and larger distortions, everything else being equal. However, reducing these distortions is outside the reach of monetary policy.

An important qualification to these findings is that the invariance of the CONDI weights to the distribution of the shocks is unlikely to hold in the presence of disturbances to desired markups, since these shocks create a direct trade-off between inflation and output gap stabilization, which is not mediated by endogenous changes in relative prices. We leave a more exhaustive investigation of the

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<sup>31</sup> Matching the volatility of sectoral inflation does not automatically imply having matched that of aggregate inflation, since the sectoral inflation rates are not independent.

<sup>32</sup> Relative prices are literally exogenous under CONDI stabilization only when sectors are identical, which is also the case in which CONDI, headline inflation and output gap stabilization are all equivalent ways of implementing the optimal equilibrium, as we discussed in section 3.4.1. The equivalence of CONDI and output gap stabilization, and the resulting exogeneity of relative prices under these policies, only holds approximately in our calibrated economy with heterogenous sectors.

role of these, and other disturbances, to future research, since calibrating multiple sources of shocks would require a richer model, which could plausibly confront data on sectoral prices and quantities, as in Carvalho and Lee (2010) and Bouakez, Cardia, and Ruge-Murcia (2009a, 2009b) for example.

### 4.3 A practical recommendation: Adjusted core inflation

The key practical lesson we draw from our quantitative results is that a monetary policy that focuses on the stabilization of core inflation represents an improvement over one that targets headline inflation. Under our preferred calibration of the 15-sector model (Table 3, Column 8), headline stabilization produces welfare losses that are equivalent to an increase in average inflation of 1.6 percentage points per year, while the inflation equivalent of core targeting is 1.2 percentage points per year.

Both these numbers are fairly large. By way of comparison, Kahn, King and Wolman (2003) find that the steady state inflation rate that optimally minimizes the costs of several monetary and price distortions is -0.76 percent, or about 2 percentage points higher than Friedman’s (1969) recommendation in their model. Dennis and Södertström (2006) and Jensen (2002) find welfare gains in moving from discretion to commitment of the order of 1 percent inflation per year, while Billi (2008) calculates that the impact of the zero lower bound on nominal interest rates can be minimized by increasing average inflation from zero to around 0.5 percent per year.<sup>33</sup> Overall, these studies suggest that differences in average inflation of around 1 percent per year across policies are significant. Therefore, there is substantial scope for improvement in moving from core to CONDI targeting, even if targeting core rather than headline inflation already represents significant progress.

One drawback of CONDI stabilization is that the exact specification of the optimal inflation target is fairly sensitive to the details of one’s model. Nevertheless, the CONDI we have computed can be used as a guide to the construction of a more robust “adjusted core” inflation rate with the potential to achieve at least some of the available welfare gains. The simple adjustment we propose entails reclassifying some PCE categories within the core versus non-core framework. In particular, we would suggest moving “food away from home” from non-core to core and “motor vehicles” and “clothing and shoes” from core to non-core.

The first reclassification has already taken place as part of the benchmark revisions of the National Income and Product Accounts in 2009 (McCully and Teensma, 2008). This revision appears very sensible from the perspective of our results, given the extreme price stickiness of “food away from home,” which

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<sup>33</sup> See also Goodfriend, Mork, and Söderström’s (2007) forceful endorsement of an inflation target of 2 percent for Norges Bank, rather than the current 2.5 percent.

reflects in part its high service content. As for motor vehicles, their prices are very flexible according to most available measures, partly due to variations in the costs of financing and the incentives offered by dealers over the model year and the business cycle. Therefore, this reclassification should also be fairly uncontroversial for the purposes of monetary policy. Finally, apparel prices are the category with the largest discrepancy in the frequency of “posted” and “regular” price adjustments. Their posted prices change very often, due to sales and product substitutions related to season and fashion, while the regular prices that exclude these forms of repricing have an average life of more than two years. We argued that the effective stickiness of this category is best represented by its regular prices, whose flexibility leads us to recommend its exclusion from modified core. We would have reached the opposite conclusion had we adopted their regular frequency of price change instead.

As a result of our proposed reclassification, “adjusted core” PCE inflation would be defined as covering total expenditures excluding autos, clothing, energy, and food at home. The implications of this reclassification for welfare are illustrated in the last row of Table 3. The inflation equivalent of adjusted core targeting under our preferred calibration (Column 8) is 0.5 percentage points per year. This is a significant improvement over core inflation targeting, whose inflation equivalent is 1.2 percent per year, and represents an equivalent reduction of about 1 percentage point in inflation with respect to headline inflation targeting.

## 5 Conclusions

This paper studied quantitatively an optimally weighted price index whose stabilization minimizes the welfare costs of nominal distortions: a Cost-of-Nominal-Distortions Index (CONDI). We computed the weights on sectoral inflation rates that define this index within a multi-sector New-Keynesian model with time-dependent price setting, calibrated to U.S. evidence on the degree of heterogeneity in the frequency of price adjustment, in labor shares and in the autocorrelation and standard deviation of inflation across sectors. We focused on these three forms of heterogeneity because they reflect features of the sectors, such as price stickiness, the elasticity of demand and the returns to labor, and the distribution of underlying shocks, that might justify altering the CONDI weights with respect to the expenditure weights that define the usual PCE inflation index.

The evidence for the model’s calibration is collected in a dataset whose finer units of observation are 15 “major types of product” within Personal Consumption Expenditures. We built this dataset using as starting points Nakamura and Steinsson’s (2008) data on the frequency of price adjustment

for the non-shelter component of the CPI and the input-output tables in Chentrens (2007), from which we obtained labor shares for the PCE major products using the method of Valentinyi and Herrendorf (2008).

We can summarize the results of our analysis as follows. First, the CONDI weights across the PCE categories in our dataset mostly depend on price stickiness and are less affected by the other sources of heterogeneity we consider. Second, CONDI stabilization closely approximates the optimal policy and leads to negligible welfare losses. Third, targeting core is better than targeting headline inflation, because core inflation on net readjusts the weights on sectoral inflation rates in a direction similar to that of the CONDI. Fourth, core targeting is only a very rough approximation of CONDI stabilization in terms of welfare. However, the time series of core and realized CONDI inflation are highly correlated in U.S. data and their volatility is quite similar. Fifth, the approximation of the optimal policy provided by core targeting can be improved substantially by a simple reclassification of major products from core to non-core, and vice versa.

The calculations presented in this paper are only a preliminary step towards a comprehensive quantitative analysis of the welfare consequences of sectoral heterogeneity in nominal distortions. There are several areas in which further progress is needed. First, from a data perspective, the quality of information on the rigidity of prices is lowest in the two most important PCE categories by expenditure share: housing and medical care.

Second, in terms of calibration, we focused primarily on two sources of sectoral heterogeneity: the frequency of price adjustment and labor shares. In practice, sectors differ along many more dimensions that might be relevant for welfare, such as the degree of nominal rigidity in the markets in which firms purchase their labor and intermediate inputs, or the characteristics of shocks perturbing the environment. In this direction, we explored the quantitative role of productivity shocks, but more work is needed to enlarge the menu of shocks included in the analysis and to make the model more suitable to formal empirical evaluation.

Third, from a modeling perspective, we worked with the simplest New Keynesian specification, with the minimal enrichments required to include heterogeneity in price stickiness and labor shares. In particular, we adopted a Calvo pricing scheme that yields a simple and transparent approximation of the utility of the representative agent. The main shortcoming of this choice is that the selection effect that would be present in a menu cost version of this model might also mute the welfare costs of nominal distortions (Golosov and Lucas, 2007; Burstein and Hellwig, 2008; and Midrigan, 2010). However, we have no particular reason to believe that the selection effect would change the relative performance of

the targeting rules that we consider in our welfare analysis.

More broadly, our study rests on the assumption that price stickiness results directly and mechanically in an inefficient quantity adjustment. This is an implication of the isoelastic demand specification that underlies most New-Keynesian models and that is a key to making welfare calculations so tractable. Yet, a large share of consumption expenditures in the United States are not allocated according to this simple mechanism. For example, the stickiness of owners' equivalent rent probably has little effect on the quantity of housing services consumed by homeowners, who tend to face flexible prices at the time of purchase. Similar considerations also apply to education, where tuition levels are adjusted once a year, but so is the decision to enroll. Finally, in the case of health care, transaction prices are largely disjoint from the quantity of the service purchased, especially when insurance companies are involved, although the overall costs of the system still fall on the consumer. Taking into consideration the structural idiosyncrasies of the markets in which the different types of goods and services available in the U.S. economy are sold, and their implications for the welfare costs of nominal rigidities, is an important strand for further research, which could have a substantial impact on our views of what is an optimal inflation target.

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# A Appendix

## A.1 Calculation of Labor Shares

Let  $n$  be the number of consumption goods for which we have data. Let  $m$  be the number of commodities/sectors in the input-output tables. Let the use-matrix be given by  $\mathbf{U}$ , whose  $(i,j)$ -th element reflects the fraction of gross output of commodity  $j$  used as intermediate input by the industry that produces commodity  $i$ .<sup>34</sup> Let  $\mathbf{y}$  and  $\mathbf{v}$  be column vectors, both of length  $m$ , with gross output and value added of the industries that produce the commodities, both in current dollars. We can write the resource constraint as

$$(7) \quad \mathbf{y} = \mathbf{U}'\boldsymbol{\iota} + \mathbf{v}$$

Furthermore, consider the diagonalization operator, such that for

$$(8) \quad \mathbf{y} = \begin{bmatrix} y_1 & \dots & y_n \end{bmatrix}' : \backslash \mathbf{y} \backslash = \begin{bmatrix} y_1 & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & y_n \end{bmatrix}.$$

This allows us to define

$$(9) \quad \mathbf{A} = \mathbf{U} \backslash \mathbf{y} \backslash^{-1}$$

such that the  $(j,i)$ -th element of  $\mathbf{A}$  corresponds to the intermediate input share of input  $j$  in the production of  $i$ . Then, we can write

$$(10) \quad \mathbf{y} = \mathbf{A}\mathbf{y} + \mathbf{v} = (1 - \mathbf{A})^{-1} \mathbf{v}$$

where  $(1 - \mathbf{A})^{-1}$  is the domestic total requirements matrix. This allows us to calculate the total value added requirements for production of each commodity.

Let  $\mathbf{l}$  be a column vector with the compensation of employees in each of the sectors and let  $\mathbf{k}$  be the vector with factor payments, including profits, to factors other than labor. Then value added equals the sum of the factor payments, such that

$$(11) \quad \mathbf{v} = \mathbf{l} + \mathbf{k}.$$

Finally, let the vector  $\mathbf{c}$ , of length  $n$ , contain the amount of consumption of each of the consumption goods in current dollars. Let the matrix  $\mathbf{B}$ , of dimension  $n \times m$ , be the consumption final demand

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<sup>34</sup> Throughout, we do not account for imports. That is, we consider a closed economy version of the input-output tables and calculate domestic requirements.

matrix, where the  $(i,j)$ -th element reflects the fraction of output of commodity  $j$  that flows towards final demand of consumption good  $i$ . Then

$$(12) \quad \mathbf{c} = \mathbf{B}\mathbf{y} = \mathbf{B}(1 - \mathbf{A})^{-1}\mathbf{v} = \mathbf{B}(1 - \mathbf{A})^{-1}\mathbf{1} + \mathbf{B}(1 - \mathbf{A})^{-1}\mathbf{k} = \mathbf{c}_l + \mathbf{c}_k,$$

where  $\mathbf{c}_l$  reflects the part of consumption that can be accounted for by labor services, while  $\mathbf{c}_k$  is the part of consumption that can be attributed to other factors.

The labor share in consumption good  $i$  can then be calculated as the ratio of the  $i$ -th element of  $\mathbf{c}_l$  and the  $i$ -th element of  $\mathbf{c}$ .

## A.2 Calibration of Demand and Labor Elasticities

Let the set of parameters that attributes all of the differences in labor shares to disparities in demand elasticities be given by  $\{\theta_n^{(I)}, \bar{\lambda}\}_{n=1}^N$ . Let the set of parameter values that attributes all the variation to the heterogeneity of labor elasticities be given by  $\{\bar{\theta}, \lambda_n^{(II)}\}_{n=1}^N$ . Finally, let  $\{\theta_n^{(III)}, \lambda_n^{(III)}\}_{n=1}^N$  be the set of parameter values that splits the variation equally across both potential sources. Then, these parameter values satisfy

$$(13) \quad s_l^n = \frac{1}{\bar{\lambda}} \left( \frac{\theta_n^{(I)} - 1}{\theta_n^{(I)}} \right) = \frac{1}{\lambda_n^{(II)}} \left( \frac{\bar{\theta} - 1}{\bar{\theta}} \right),$$

and

$$(14) \quad \left( \frac{\theta_n^{(III)} - 1}{\theta_n^{(III)}} \right) = \sqrt{\left( \frac{\theta_n^{(I)} - 1}{\theta_n^{(I)}} \right) \left( \frac{\bar{\theta} - 1}{\bar{\theta}} \right)} \text{ and } \lambda_n^{(III)} = \sqrt{\bar{\lambda} \lambda_n^{(II)}}$$

such that

$$(15) \quad \text{var} \left( \ln \left( \frac{\theta_n^{(III)} - 1}{\theta_n^{(III)}} \right) \right) = \text{var} \left( \ln \lambda_n^{(III)} \right)$$

and

$$(16) \quad \text{var} (\ln s_l^n) = \text{var} \left( \ln \left( \frac{\theta_n^{(III)} - 1}{\theta_n^{(III)}} \right) \right) + \text{var} \left( -\ln \lambda_n^{(III)} \right)$$

which is the sense in which this set of parameter values apportions the variation in labor shares equally between demand and labor elasticities.

## A.3 Welfare Cost Measures

The objective is to compare welfare under any suboptimal equilibrium to that under the optimal policy. Denote the time series for the endogenous variables under the candidate suboptimal equilibrium with

superscript  $SO$  and those under the optimal policy with superscript  $O$ . Then, the approximate loss under the optimal policy is

$$\mathcal{L}^O \equiv E \left\{ \sum_{t=0}^{\infty} \beta^t \left[ \sum_n a_n \frac{\theta_n}{\xi_n} (1 + \theta_n \tilde{\eta}_n) (\pi_{n,t}^O)^2 + S_t^O \right] \right\}$$

where  $S_t^O$  collects all the terms in the loss function other than inflation. The approximate loss under the  $SO$  policy is instead

$$\mathcal{L}^{SO} \equiv E \left\{ \sum_{t=0}^{\infty} \beta^t \left[ \sum_n a_n \frac{\theta_n}{\xi_n} (1 + \theta_n \tilde{\eta}_n) (\pi_{n,t}^{SO})^2 + S_t^{SO} \right] \right\}.$$

### A.3.1 Inflation Equivalent

We define inflation equivalent for equilibrium  $SO$ ,  $\pi_{SO}^E$ , the *amount* of steady inflation that must be exogenously added to the optimal path of inflation in each sector to make the representative agent indifferent between the resulting counterfactual path and the suboptimal one.  $\pi_{SO}^E$  is thus defined by the equality

$$\begin{aligned} E \left\{ \sum_{t=0}^{\infty} \beta^t \left[ \sum_n a_n \frac{\theta_n}{\xi_n} (1 + \theta_n \tilde{\eta}_n) (\pi_{n,t}^O + \pi_{SO}^E)^2 + S_t^O \right] \right\} &= \mathcal{L}^{SO} \\ \mathcal{L}^O + E \left\{ \sum_{t=0}^{\infty} \beta^t \left[ \sum_n a_n \frac{\theta_n}{\xi_n} (1 + \theta_n \tilde{\eta}_n) \left( 2\pi_{n,t}^O \pi_{SO}^E + (\pi_{SO}^E)^2 \right) \right] \right\} &= \mathcal{L}^{SO} \\ \frac{1}{1-\beta} \sum_n a_n \frac{\theta_n}{\xi_n} (1 + \theta_n \tilde{\eta}_n) (\pi_{SO}^E)^2 &= \mathcal{L}^{SO} - \mathcal{L}^O \end{aligned}$$

where the last line uses the fact that  $E\pi_{n,t}^O = 0$ . The inflation equivalent for equilibrium  $SO$  is therefore

$$\pi_{SO}^E = \sqrt{\frac{1-\beta}{\sum_n a_n \frac{\theta_n}{\xi_n} (1 + \theta_n \tilde{\eta}_n)} (\mathcal{L}^{SO} - \mathcal{L}^O)},$$

a simple monotonic transformation of the loss differential between the suboptimal and optimal equilibria.

### A.3.2 Consumption Equivalent

Similarly, the consumption equivalent for equilibrium  $SO$ ,  $\gamma_{SO}^E$ , is the constant *fraction* of consumption that must be subtracted from the optimal consumption path to make the representative agent indifferent between this counterfactual allocation and the suboptimal one.  $\gamma_{SO}^E$  is thus defined by the equality

$$E \left\{ \sum_{t=0}^{\infty} \beta^t \left\{ \log [(1 - \gamma_{SO}^E) C_t] + Z_t^O \right\} \right\} = W^{SO}$$

where  $W^{SO}$  is now the actual, rather than the approximate, welfare under the suboptimal policy and  $Z_t^O$  collects terms that do not depend on consumption. From this we obtain

$$\log(1 - \gamma_{SO}^E) = (1 - \beta)(W^{SO} - W^O),$$

which we approximate as

$$\gamma_{SO}^E \approx 1 - \exp\left[\frac{1 - \beta}{2}(\mathcal{L}^O - \mathcal{L}^{SO})\right].$$

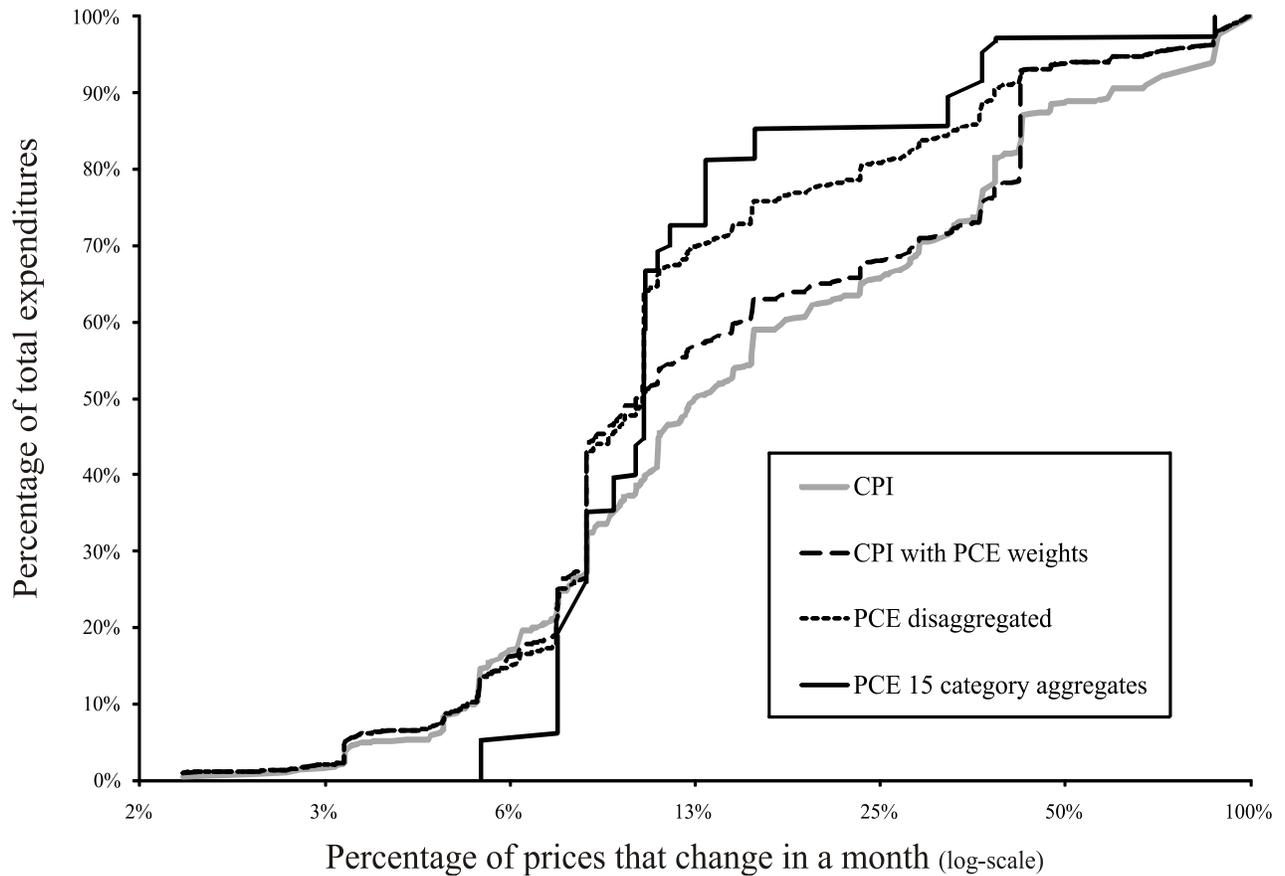


Figure 1: Expenditure weighted cumulative density functions of price stickiness for four steps of data conversion. “CPI” corresponds to the ELI-level CPI data in NS, with their expenditure weights. “CPI with PCE weights” adjusts those weights to sum to the expenditure shares of the corresponding PCE 15 major products. “PCE disaggregated” includes in this our supplementary sources on housing and medical care. “PCE 15-sector aggregates” corresponds to the weighted medians of PCE disaggregated within each major product.

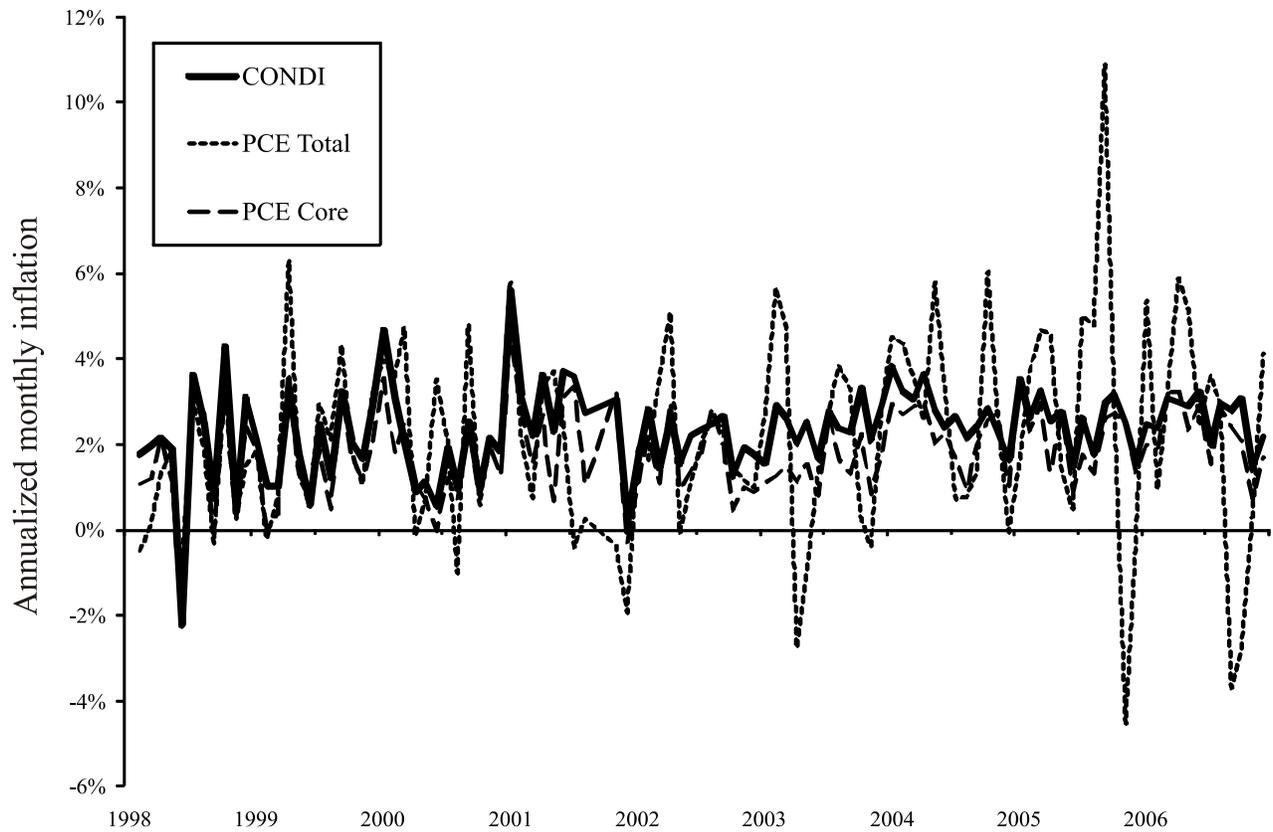


Figure 2: Time series of realized CONDI inflation, compared to headline and core PCE. We build realized CONDI inflation as the weighted average of actual inflation rates for the 15 sectors at our finest level of disaggregation, using as weights those reported in Column 8 of Table 3.

Table 1: Calibrated parameter values

Sectors	Core	PCE Share $a_n$	Freq. of Price Adj. $1 - \alpha_n$	Labor Share $\lambda_n^{-1} \frac{\theta_n - 1}{\theta_n}$	$\theta_n^{(I)}$	$1/\lambda_n^{(II)}$	$\theta_n^{(III)}$	$1/\lambda_n^{(III)}$
<u>(i) One Sector</u>								
PCE		100%	10.3%	70.4%	5.0	0.88	5.0	0.88
<u>(ii) Two Sectors</u>								
Core	■	81.4%	9.6%	72.8%	5.8	0.91	5.4	0.90
Non-core		18.6%	12.7%	66.1%	4.0	0.83	4.5	0.85
<u>(iii) Fifteen Sectors</u>								
Motor vehicles	■	5.6%	36.6%	71.9%	5.5	0.90	5.2	0.89
Furniture and household equipment	■	4.5%	9.2%	70.4%	5.0	0.88	5.0	0.88
Other durables	■	2.4%	10.9%	69.8%	4.8	0.87	4.9	0.88
Food at home		8.5%	13.0%	66.8%	4.2	0.84	4.5	0.86
Food away from home		5.2%	5.6%	70.6%	5.1	0.88	5.0	0.88
Clothing and shoes	■	4.2%	32.2%	69.3%	4.7	0.87	4.8	0.87
Gasoline, fuel oil and other energy		2.7%	87.6%	61.5%	3.3	0.77	4.0	0.82
Other non-durables	■	7.9%	10.4%	68.5%	4.5	0.86	4.7	0.87
Housing	■	15.1%	10.3%	70.0%	4.9	0.88	4.9	0.88
Household operations - Core	■	3.5%	11.4%	71.9%	5.4	0.90	5.2	0.89
Household operations - Non-core		2.2%	38.5%	51.6%	2.4	0.64	3.2	0.75
Transportation	■	4.1%	15.6%	71.5%	5.3	0.89	5.2	0.89
Medical Care	■	16.2%	8.3%	83.3%	18.9	1.00	7.7	0.94
Recreation	■	4.0%	10.0%	76.7%	7.8	0.96	6.1	0.92
Other services	■	13.8%	7.5%	76.5%	7.7	0.96	6.0	0.92
<u>Homogenous Parameters</u>								
	$\beta$	$\eta$	$\rho$ s.t.	$\sigma$ s.t.	$\sigma^{\mathcal{Y}}$			
	$(0.96)^{1/12}$	0.5	$\text{Corr}(\pi_t, \pi_{t-1}) = 0.17$	$\text{StDev}(\pi_t) = 0.19\%$	0.51%			

Table 2: CONDI weights and welfare losses under different heterogeneity cases for 2-sector economy

Heterogeneity in	Core	$1 - \alpha^n$	$\theta_n^{(I)}$	$1/\lambda_n^{(II)}$	$\theta_n^{(III)}$	$1/\lambda_n^{(III)}$	1	2	3	4	5	6	7	8
Price stickiness								■				■	■	■
Labor share								■	■	■	■	■	■	■
Set of parameters								(I)	(II)	(III)	(I)	(I)	(II)	(III)
							<u>CONDI Weights</u>							
							<u>Parameter Values</u>							
Baseline		0.103	5.0	0.88	5.0	0.88								
Core	■	0.096	5.8	0.91	5.4	0.90	81.4	88.6	85.4	78.7	82.0	91.2	86.8	89.0
Non-core		0.127	4.0	0.83	4.5	0.85	18.6	11.4	14.6	21.3	18.0	8.8	13.2	11.0
<u>Targeting</u>							<u>Welfare Loss - Inflation Equivalent</u>							
CONDI							0	0.06	0.02	0.01	0.02	0.04	0.05	0.04
Headline PCE							0	2.69	1.17	0.62	0.14	4.13	1.89	2.92
Core PCE							4.54	4.85	4.56	4.79	4.74	4.62	5.19	4.98

CONDI weights are in percentage points. Inflation equivalent welfare losses are additions to the optimal path of inflation, expressed as an annualized inflation rate in

percentage points. Column 1 reports results for a calibration with no heterogeneity. Column 2 has heterogeneity in price stickiness only. Columns 3 to 5 have heterogeneity in

labor shares only, under three alternative parametrizations. Columns 6 to 8 have heterogeneity in both price stickiness and labor shares. Under the three alternative

parametrizations, variation in labor shares is due to (I) demand elasticity (preferences), with labor elasticity at baseline value; (II) labor elasticity of output (technology),

with demand elasticity at baseline; (III) half preferences and half technology (see Appendix A.2 for details).

