Federal Reserve Bank of New York
Staff Reports

CONDI: A Cost-of-Nominal-Distortions Index

Stefano Eusepi
Bart Hobijn
Andrea Tambalotti

CONDI: A Cost-of-Nominal-Distortions Index
Stefano Eusepi, Bart Hobijn, and Andrea Tambalotti
Federal Reserve Bank of New York Staff Reports, no. 367
March 2009
JEL classification: E31, E52, E58

Abstract

We construct a price index with weights for the prices of different PCE (personal consumption expenditures) goods chosen to minimize the welfare costs of nominal distortions. In this cost-of-nominal-distortions index (CONDI), the weights are computed in a multi-sector New Keynesian model with time-dependent price setting. The model is calibrated using U.S. data on the dispersion of price stickiness and labor shares across sectors. We find that the CONDI weights depend mostly on price stickiness and are less affected by the dispersion in labor shares. Moreover, CONDI stabilization closely approximates the optimal monetary policy and leads to negligible welfare losses. Finally, CONDI is better approximated by targeting core inflation rather than headline inflation—and is even better approximated with an adjusted core index that covers total expenditures excluding autos, clothing, energy, and food at home, but including food away from home.

Key words: core inflation, nominal rigidities, optimal monetary policy, price indexes

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.[1]

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 a reduction, in inflation volatility, if the shocks to non-core prices tend to dissipate faster than the time it takes monetary policy to affect overall prices.[2]

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.[3]

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 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.[4]

In practice, these theoretical results are usually interpreted as implying that central banks should target core inflation (e.g. Mishkin, 2007; Plosser, 2008), since the prices of non core goods tend to be

---

[1] The other variables are headline PCE inflation, GDP growth and unemployment.

[2] For an extremely clear statement of this reasoning from the perspective of a policymaker see Mishkin (2007)

[3] 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 Buiter, 2008). Earlier contributions include Bryan and Cecchetti (1994), Quah and Vahey (1995), Clark (2001), and Cogley (2002).

[4] 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).

more flexible than those of other goods and services.[5]

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 (2008a, NS in what follows). We also study the robustness of this argument to the presence of heterogeneity in labor shares across goods-producing sectors, another potentially important source of asymmetric distortions, even when all sectors share the same degree of nominal rigidity.[6] Our analysis proceeds in three steps.

First, we construct a database with measures of price stickiness and labor shares across PCE categories, at two levels of aggregation. At the coarser level of aggregation, we only distinguish between non-core goods, which include food and energy, and core goods, 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 owner's 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 use evidence on medical care services in the Producer Price Index to refine the estimate of price stickiness in medical care implied by NS' numbers. Finally, we adjust the CPI expenditure shares of the products we consider to reflect those in the PCE.

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 to the task, because it allows us to construct input shares for the components of final demand, such as consumption, taking into account the input-output structure of the U.S. economy.

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

---

[5] 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 interpeted as another variant of the informal "volatility" argument we sketched above.

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

inflation in different goods as a function of the share of overall nominal distortions associated with the production of each good. This is in contrast to a cost-of-living index (COLI), such as the PCE, which weighs goods 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. 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 variation in preferences and technology, as reflected by 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 over the period from 1998 to 2006, 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 is slated to happen 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 (Jensen, 2002) of core and total PCE stabilization are 0.8 and 1.3 percent 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.[7] 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 analysis, which was made possible by the data collection work of Bils and Klenow (2004), Klenow and Krytsov (2008) and Nakamura and Steinsson (2008a).

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 (2008), Burstein and Hellwig (2007), Gertler and Leahy (2008), and Woodford (2008), as well as by Carvalho (2006) and Nakamura and Steinsson (2008b) in a multi-sector environment similar to ours. To our knowledge, none of this work includes a normative dimension, which is instead the focus of this paper.[8]

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.

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

---

[7] 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.

[8] But see Burstein and Hellwig (2008) for the normative implications of the presence of menu costs in a one-sector model.

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.

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 the frequency of price adjustment, an indicator of differences in the degree of nominal rigidity across goods. The second is the revenue share of labor, which we interpret as evidence of differences across sectors in production technology and in the markups charged by firms. We focus on these sources of heterogeneity, because they give rise to an asymmetry across goods in the distortions stemming from nominal rigidity. In the New Keynesian framework we adopt, these asymmetries might justify adjusting the weights of a CONDI with respect to those of a COLI. The quantification of these adjustments is the main objective of this 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 (2008a) 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 Unites States is the PCE deflator. Therefore, this is also the price measure we use as the reference for our analysis, since the purpose of the CONDI is to be an 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.

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.[9] They

---

[9] 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)

distinguish between changes in "actual" and "regular" prices. Actual price changes include changes due to sales and changes due to substitutions of discontinued items with closely matching ones. Regular price changes, on the contrary, only include changes in non-sale prices from one month to the next for the same item. NS argue that sales and product substitutions are mainly driven by considerations other than the desire of firms to change their prices and thus result in far less macroeconomic price flexibility than regular price changes.[10] For this reason, we focus here on the frequency of regular price changes, with one exception.

We use the frequency of actual price changes for clothing and shoes (31 percent), because the median frequency of regular price changes is a very low 3.5 percent. This implies an average life for the price of an article of clothing of more than two years, which seems unreasonable given the high turnover in apparel due to seasonal purchasing patterns and fashion changes discussed by Liegey (1994).

Another major PCE product for which we do not follow NS is medical care. A large fraction of medical care prices in the PCE do not refer to the out-of-pocket expenses covered by the CPI, but rather to services consumed by individuals and paid by insurance companies. Therefore, the frequency of price adjustment for the medical care ELIs reported by NS is probably not an accurate measure of the degree of PCE price stickiness in this sector. Instead, anecdotal evidence suggests that the prices for medical services result from bargaining between the insurers and the health providers, which usually takes place once a year. This frequency of price adjustment is also consistent with the behavior of the non seasonally adjusted producer prices for medical services. In light of these considerations, we calibrate the average duration of PCE medical care prices to be a year, which implies that 8.3 percent of these prices adjust on average every month.

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 for NS' regular prices, except for the ELIs within clothing and shoes and medical care. For the former we use posted prices, while for the latter we use our estimate of 8.3 percent. The weights are the expenditure shares for each ELI as reported by NS. They are reflated to sum to 100 percent of CPI expenditures. The resulting expenditure-weighted median monthly frequency of price change is 10.6 percent.

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

---

[10] For the impact of sales on monetary neutrality see in particular Kehoe and Midrigan (2008).

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 1998-2006.[11] The resulting CDF is labeled "CPI - with PCE weights" in Figure 1. The implied median frequency of price change is 8.3 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 evidence from Genesove (2003) on price adjustment in housing services. Expenditures on housing services represent a very large fraction of total expenditures in the United States: close to 30 percent in the CPI and about 15 percent in the PCE. The only evidence on price stickiness for these services in NS is on "lodging away from home", while the bulk of housing expenditures in the PCE is on tenant and owner-occupied housing.[12]

Genesove (2003) estimates from the Annual Housing Survey that rents on 29 percent of apartments do not change in a year.[13] Assuming a constant probability of price adjustment in each month, this number implies that each month the rent on 10.3 percent of rental units changes. We assume that this estimate of nominal rigidity would hold also if owners rented out the dwellings they currently occupy. Hence, we attribute a 10.3 percent monthly frequency of price change to tenant and owner-occupied housing and readjust the weights of the other ELIs within housing to be consistent with its PCE expenditure share.

The resulting CDF 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 the data on housing, whose price flexibility is slightly higher than the weighted median, shifts it higher in its more flexible half. The resulting median frequency of price adjustment goes from 8.3 percent to 8.6 percent, but this small change hides in part a shift of the right side of the distribution—with frequencies between 10 and 40 percent—towards stickier prices. This is a good illustration of the difficulty to capture 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

---

[11] 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.

[12] Expenditures on owner-occupied housing are based on imputed owners' equivalent rents.

[13] Genesove (2003) uses AHS data over the period 1974-1981. This is a very different sample than the 1998-2005 used by NS and it covers a period 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 find.

non-core items (i.e. food and energy) 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 electricity and gas and other household operations (rather than household operations alone).[14] 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 hand of the flexibility spectrum. Table 1 includes a complete list of the product categories included in our dataset.

The CDF associated with our finest level of aggregation is labeled "PCE 15-sector aggregates" in Figure 1. The aggregation using medians shifts the CDF further towards more sticky prices among the relatively flexible ones (i.e. to the right of the median). As a result, the median frequency of price adjustment across the 15 aggregates is 9.0 percent.

The fourth column of Table 1 lists the resulting 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, 8.6 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 revenue share of labor. To construct these 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.

In the literature, there are two main approaches to the solution of this problem. The first approach, followed for example by Huffman and Wynne (1999) and Bouakez, Cardia, and Ruge-Murcia (2008), 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

---

[14] In NIPA Table 2.3.4 (Price Indexes for Personal Consumption Expenditures by Major Type of Product), for example, we find a distinction between durable goods, nondurable goods, and services, as well as among thirteen more detailed categories at the next level of disaggregation.

consumption goods that are not consistent with the product categories in the PCE.

The second approach, followed by Valentinyi and Herrendorf (2008), uses inter-industry relationships to reconstruct which industries produce the value added embodied in consumption goods. This approach allows to construct consumption-good-specific aggregates that are consistent with the PCE classifications and that account for the whole structure of the U.S. supply chain. For this reason, this is the methodology we follow here. This approach involves the manipulation of U.S. input-output tables and of industry data on value added and factor costs. These manipulations are summarized in Appendix A.1.

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 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 1998-2006. 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 70.3 percent, somewhat higher than the 65 percent reported by Valentinyi and Herrendorf (2008). Labor shares vary substantially across consumption goods. Energy goods have the lowest labor share, 61 percent. At 83 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).[15] 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 $n = 1, ..., N$, 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 $\left(\lambda_n^{-1}\right)$, i.e. the returns to labor. Third,

---

[15]Details on the model are available in an online appendix.

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, 2008b, Carvalho and Dam, 2008; Bouakez, Cardia, and Ruge-Murcia, 2009; 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.[16]

3.1 Worker-Producers

Agent j in sector n maximizes lifetime utility

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

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. 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 $y_t(j)$ according to the production function

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

where $Z_{n,t}$ is a sector-specific productivity process and $\lambda_n^{-1} \le 1$ is the elasticity of output with respect to changes in the labor input. This parameter is indexed 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

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

---

[16] Bouakez, Cardia and Ruge-Murcia (2008, 2009) estimate a very rich multi-sector model with heterogenity in price stickiness and the returns to labor, but not in desired markups. They also focus exclusively on its positive implications.

with $\epsilon_{n,t} \sim N(0,\sigma)$ a sector-specific shock that is *i.i.d.* across sectors and time. Finally, τ_n denotes a sector-specific sales tax (or subsidy) and T_t lump-sum transfers from the government.[17]

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

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 $C_{n,t}$

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

---

[17] We assume that the sector-specific subsidy τ_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.

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

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

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

$$\max_{p_{n,t}} E_t \sum_{T=t}^{\infty} (\alpha_n \beta)^{T-t} \left[\frac{u_C (C_T)}{P_T} (1 - \tau_n) p_{n,t} y_{n,T} - \frac{(y_{n,T}/Z_{n,T})^{\lambda_n(1+\eta)}}{1 + \eta} \right]$$

$$\text{s.t.} \quad y_{n,T} \equiv \left[\frac{p_{n,t}}{P_{n,T}} \right]^{-\theta_n} \left(\frac{P_{n,T}}{P_T} \right)^{-\gamma} Y_T.$$

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 η 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 λ_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

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

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 $\left[\hat{Y}_t, \{\pi_{n,t}\}_n, \pi_t, \left\{ \hat{P}_{n,t}^R \right\}_n, \hat{R}_t \right]$, 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

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

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

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

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.[18] 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

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

as in Nakamura and Steinsson (2008b), for example, where $\epsilon_t^{\mathcal{Y}}$ is i.i.d. with standard deviation $\sigma^{\mathcal{Y}}$.

3.4.1 The Policy Objective

The main objective of this paper is to compute a price index that 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

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

which we approximate to second order as

$$W \equiv -\frac{u_c C}{2} E \sum_{t=0}^{\infty} \beta^t L_t$$

with

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

This approximate loss function depends on the inflation rate in each sector, on the deviations of relative prices and of aggregate output from their flexible price counterparts, as well as from the

---

[18] Svensson (2000) discusses in detail various approaches to the implementation of monetary policy in this class of models.

cross-product of these two deviations. This latter term 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).

Through its parameters, the loss function depends crucially on all the sources of heterogeneity in the model. Focusing on the coefficient on inflation variability, which is the largest contributor to welfare losses, we see that a more elastic demand (higher θ_n), a more concave production function (higher λ_n and thus higher $\tilde{\eta}_n$) and a lower frequency of price adjustment, which results in a flatter Phillips curve (higher α_n and thus lower ξ_n), all amplify the losses from a given path of sectoral inflation.

The period loss function in (5), together with the sectoral Phillips curves (2), highlights fairly clearly the nature of the policy tradeoff facing the monetary authority. The flexible price equilibrium is the first best in this economy, given our assumption on the subsidy τ_n (see footnote 17). But this equilibrium is not feasible when prices are sticky (Benigno, 2004). The reason is that the constraints on the ability of firms to adjust their prices prevent them from shadowing their flexible counterparts, which move in response to productivity shocks. These movements in desired relative prices act as endogenous cost-push shocks, which cannot be offset by any choice of the unique instrument available to monetary policy. As a result, actual movements in relative prices are inefficient, leading to a misallocation of resources, even if policy can stabilize aggregate inflation and the output gap at the same time. Moreover, this "divine coincidence" between the two policy objectives of output and inflation stabilization can be achieved only in the case of symmetric price stickiness across sectors. In the more general case, in fact, the optimal policy must tradeoff all three objectives. As we will see, however, this optimal tradeoff is closely approximated by a targeting rule that perfectly stabilizes an appropriate price index, the CONDI. We now turn to its formal description.

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—a fixed weight Törnqvist (1936) index—of the form

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

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

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

15

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

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

while core PCE targeting has weights

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

where the set of core goods includes all types of expenditures except for those on food and energy.

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 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).

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 is a simple monotonic transformation of the welfare differential between the optimal and the suboptimal policy. As we show in Appendix A.3, it can be interpreted as the constant amount of inflation that would need to be added exogenously to the path of inflation under the optimal policy to make the representative agent indifferent between this distorted equilibrium and the suboptimal one. We adopt this particular measure of the distance between two policies, rather than a consumption equivalent, for example, because it results in 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) and thus they provide a useful benchmark for our discussion.[19]

---

[19] See Kahn, King and Wolman (2003) for a comprehensive study of the effect of several frictions on the optimal level of inflation in a model with price stickiness. Billi (2008) is a recent treatment focused on the role of the zero bound on nominal interest rates and includes detailed references, while Billi and Kahn (2008) contains a discussion of the related

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 Table 1 correspond to the $n = 1, \ldots, N$ 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 (2008b), who calibrate multi-sector models with price rigidity similar to ours. We set the discount factor β so that the steady state annual real interest rate is 4 percent and pick an inverse Frisch elasticity of labor supply, η, equal to 0.5. This value is a compromise between the linear specification, $\eta = 0$, adopted by Nakamura and Steinsson (2008b) 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 η 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 σ and autocorrelation ρ, to replicate the standard deviation and autocorrelation of monthly PCE inflation over the period 1998 to 2006, which are equal to 0.20 and 0.19 percent respectively. This procedure implies different values for σ and ρ 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 $\mathcal{Y}_t \equiv P_t Y_t$, which in the model is equal to consumption expenditures, follows the unit root process (4), as in Nakamura and Steinsson (2008b). 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 1998-2006, which is equal to 0.49 percent.

3.5.2 Heterogenous Parameters

The calibrated values for the parameters that are heterogenous across sectors are summarized in Table 1. The first, and least interesting, form of heterogeneity we must 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

---

policy debate in the United States. Fisher and Modigliani (1978) is a classic treatment of the costs of inflation and their sources.

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 1998-2006.

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, λ_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, θ_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, θ_n. The second parameterization (II) attributes all the variation in labor shares to differences in labor elasticities, λ_n. The third parameterization (III) is the intermediate case in which half of the variation in labor shares comes from θ_n and the other half from λ_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%. 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.[20] 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 (2008b) and Midrigan (2008), 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.

---

[20] 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 (weigthed 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 share 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 CONDIs 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, PCE stabilization is a way of implementing the optimal policy, as confirmed by the fact that its inflation equivalent is zero. In fact, the sectoral Phillips curves can be aggregated into an economy-wide Phillips curve with no tradeoff between output gap stabilization and (headline) inflation stabilization. Blanchard and Galí's (2007) "divine coincidence" holds under this particular parameterization, as originally shown by Benigno (2004). However, equilibrium relative prices are not equal to their efficient flexible counterparts even under this optimal policy, due to the constraints on their movement imposed by price stickiness. As a result, welfare losses are positive, although as small as possible.

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 0.5 percent per month, 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, 11.8 percent of non-core prices change every month, as opposed to 8.3 percent in the core sector. Hence, core inflation receives a weight of 89.9 percent in the CONDI, compared to a PCE weight of 81.3 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 10.1 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. The two policies have inflation equivalents of 0.51 and 0.36 percent respectively. These numbers suggest 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 virtually zero (0.005 percent per month). In fact, CONDI stabilization delivers similarly low inflation 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 0.02 percent per month. 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 92.2 percent since it has both stickier prices and a more elastic demand. In Column 7, instead, the weight on core is down to 88.1 percent, since this sector has stickier prices, but a less concave production function. In Column 8, the weight on core is 90.4 percent, which is very close to the 89.9 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 1.5 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 that is 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. However, the differences in the CONDI weights with respect to the case with only heterogenous stickiness remain negligible overall even in the extreme cases considered in columns 6 and 7.

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. We turn to this more detailed construction in the next section.

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 homogenous 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 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 12.3 percent, largely attributable to fresh food, also shrinks from a weight of 8.5 percent to 3.8 percent. On the other hand, "food away from home", with a frequency of price adjustment of 5.0 percent per month, which is far lower than the median, sees its CONDI weight inflated to 14.1 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 5.8 percent of the prices change each month.[21] This is the PCE category with the stickiest prices and its CONDI weight, at 28.0 percent, is 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 18.0 percent, close to their 18.7 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 0.13 percent per month, or about 1.5 percent per year, while the inflation equivalent of core targeting is less than 1 percent per year. 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 heterogenous labor shares, we recover similar qualitative patterns to those identified in the corresponding two-sector model. Sectors with high labor shares, most 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 result, the calibration that includes all forms of heterogeneity (Column 8) produces CONDI weights and welfare rankings very similar to those with heterogenous stickiness only (Column 2).

---

[21] Other services includes financial and legal services, education, clothing repairs and cleaning, and funeral services, among others.

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 0.8 percent per year, compared to losses under CONDI stabilization that are virtually indistinguishable from those under the optimal policy. Yet, core inflation targeting represents a significant improvement over headline inflation targeting, whose inflation equivalent is 1.3 percent per year.

We conclude this section with a comparison of realized CONDI with headline and core PCE inflation in the time-series, rather than the welfare dimension. We build realized CONDI inflation as

$$(7) \qquad \pi_t^{\text{CONDI}} = \sum_{n=1}^{N} \phi_n^* \pi_{n,t},$$

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.[22]

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 0.86, while that with headline is only 0.50. In terms of volatility, total inflation has the highest, with a standard deviation of 2.3 percent, while CONDI was historically somewhat more volatile than core, with standard deviations of 1.3 and 1.0 percent respectively.

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.

4.3 Implications for Monetary Policy

The key practical lesson we draw from the quantitative exploration we just discussed 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, headline stabilization

---

[22] 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.

produces welfare losses that are equivalent to an increase in average inflation of 1.3 percentage points per year, while the inflation equivalent of core targeting is 0.8 percent 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.[23]

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. . The problem is that CONDI stabilization is not a viable recipe for policy making, for at least two reasons. First, from a theoretical perspective, the exact specification of the CONDI is sensitive to the details of one's model. Second, from a policy perspective, such a construct would probably be too complicated and obscure to be communicated effectively to the public.

Nevertheless, the CONDI we have computed can be used as a guide to the construction of an 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 is actually scheduled to happen as part of the benchmark revisions of the National Income and Product Accounts in August 2009 (McCully and Teensma, 2008). This move appears very sensible from the perspective of our results, given the extreme price stickiness of "food away from home", which reflects in part its high service content. As for motor vehicles, their prices are extremely 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 for the purposes of monetary policy should also be fairly uncontroversial. 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 seasonal sales and frequent product substitutions (Liegey, 1994), while the regular prices computed by NS have an average life of more than two years. We chose to measure the stickiness of this category with regular prices, whose flexibility leads us to recommend its exclusion from modified core. We would have reached the opposite conclusion if

---

[23] See also Goodfriend, Mork, and Södertström's (2007) forceful endorsement of an inflation target of 2 percent for Norges Bank, rather than the current 2.5 percent.

we had 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 below 0.5 percent per year. This is a significant improvement over core inflation targeting, whose inflation equivalent is 0.8 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 and in labor shares across sectors. We focused on these two forms of heterogeneity because they reflect structural features of the sectors, such as price stickiness, the elasticity of demand and the returns to labor, that 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 (2008a) 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 at least three areas in which we need further progress. First, from a data perspective, we have the least information on the rigidity of prices in the two most important PCE categories by expenditure share: housing and medical care. In fact, this is not only a data collection issue. It is unclear what it means to be sticky for a notional price such as owner's equivalent rent, or for a non allocative price such as that paid by insurance companies for medical care.

Second, from a modelling 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, 2008). 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.

Third, in terms of calibration, we only considered 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 volatility and persistence of shocks and the degree of nominal rigidity in the markets on which firms purchase their labor and intermediate inputs. The exploration of the welfare consequences of these forms of heterogeneity is in our opinion an important avenue for future research.

References

[1] Aoki, Kosuke (2001), "Optimal Monetary Policy Response to Relative Price Changes," *Journal of Monetary Economics*, 48: 55-80.

[2] Benigno, Pierpaolo (2004), "Optimal Monetary Policy in a Currency Area," *Journal of International Economics,* 63: 293-320.

[3] Benigno, Pierpaolo, and Michael Woodford (2005), "Inflation Stabilization And Welfare: The Case Of A Distorted Steady State," *Journal of the European Economic Association*, 3(6): 1185-1236.

[4] Billi, Roberto (2008), "Optimal Inflation for the U.S. Economy," *mimeo*, Federal Reserve Bank of Kansas City.

[5] Billi, Roberto and George A. Kahn (2008), "What Is the Optimal Inflation Rate?" *Federal Reserve Bank of Kansas City, Economic Review*, Second Quarter.

[6] Bils, Mark, and Peter J. Klenow (2004), "Some Evidence on the Importance of Sticky Prices," *Journal of Political Economics*, 112: 947–985.

[7] Blanchard, Olivier, and Jordi Galí (2007), "Real Wage Rigidities and the New Keynesian Model," *Journal of Money, Credit, and Banking*, Supplement to Vol. 39(1): 35-66.

[8] Blinder, Alan S., and Ricardo Reis (2005), "Understanding the Greenspan Standard," *The Greenspan Era: Lessons for the Future*, 11-96, Federal Reserve Bank of Kansas City.

[9] Bodenstein, Martin, Christopher Erceg, and Luca Guerrieri (2007), "Optimal Monetary Policy in a Model with Distinct Core and Headline Inflation Rates," *Journal of Monetary Economics*, forthcoming.

[10] Bouakez, Hafedh, Emanuela Cardia, and Francisco J. Ruge-Murcia (2008), "The Transmission of Monetary Policy in a Multi-Sector Economy," *International Economic Review*, forthcoming.

[11] Bouakez, Hafedh, Emanuela Cardia, and Francisco J. Ruge-Murcia (2009), "Sectoral Price Rigidity and Aggregate Dynamics," *mimeo*, University of Montreal.

[12] Bryan, Michael F., and Stephen G. Cecchetti (1994), "Measuring Core Inflation," in N. Gregory Mankiw, ed., *Studies in Business Cycles*, vol. 29: *Monetary Policy.* Chicago: University of Chicago Press.

[13] Buiter, Willem (2008), "Central Banks and Financial Crisis," Paper presented at the Federal Reserve Bank of Kansas City symposium on "Maintaining Stability in a Changing Financial System" at Jackson Hole, Wyoming.

[14] Bureau of Economic Analysis (2008), "Industry Economic Accounts - Gross-Domestic-Product-(GDP)-by-Industry Data", http://www.bea.gov/industry/gdpbyind_data.htm.

[15] Burstein, Ariel and Christian Hellwig (2007): "Prices and Market Shares in a Menu Cost Model," *NBER Working Paper no. 13455.*

[16] Burstein, Ariel and Christian Hellwig (2008), "Welfare Costs of Inflation in a Menu Cost Model," *American Economic Review Papers and Proceedings*, May 2008.

[17] Calvo, Guillermo A. (1983), "Staggered Prices in a Utility-Maximizing Framework," *Journal of Monetary Economics*, 12: 383-398.

[18] Carlstrom, Charles T., Timothy S. Fuerst, Fabio Ghironi and Kólver Hernández (2006), "Relative Price Dynamics and the Aggregate Economy," *mimeo*, Boston College.

[19] Carvalho, Carlos (2006), "Heterogeneity in Price Stickiness and the Real Effects of Monetary Shocks," *The BE Journal of Macroeconomics*, 2, Issue 1 (Frontiers), Article 1.

[20] Carvalho, Carlos and Niels A. Dam (2008), "Estimating the Cross-sectional Distribution of Price Stickiness from Aggregate Data", *mimeo*, Federal Reserve Bank of New York.

[21] Chentrens, Carl (2007), "Employment Outlook: 2006-2016 – Layout and Description For 201-Order Input-Output Tables: 1998 through 2006 Historical and Projected 2016," *Bureau of Labor Statistics.*

[22] Clark, Todd E. (1999), "A Comparison of the CPI and the PCE Price Index," *Federal Reserve Bank of Kansas City, Economic Review*, 84(3): 15-29.

[23] Clark, Todd E. (2001), "Comparing Measures of Core Inflation," *Federal Reserve Bank of Kansas City, Economic Review*, 86(2): 5-31.

[24] Cogley, Timothy (2002), "A Simple Adaptive Measure of Core Inflation," *Journal of Money, Credit and Banking*, 34: 94-113.

[25] Dennis, Richard and Ulf Södertström (2006), "How Important Is Precommitment for Monetary Policy?" *Journal of Money, Credit and Banking*, 8(4): 847-872.

[26] Dhyne, Emmanuel, Luis J. Álvarez, Hervé Le Bihan, Giovanni Veronese, Daniel Dias, Johannes Hoffmann, Nicole Jonker, Patrick Lünnemann, Fabio Rumler and Jouko Vilmunen (2006), "Price Changes in the Euro Area and the United States: Some Facts from Individual Consumer Price Data," *Journal of Economic Perspectives*, 20: 171–192.

[27] Erceg, Christopher J. and Dale W. Henderson and Andrew T. Levin (2000), "Optimal monetary policy with staggered wage and price contracts," *Journal of Monetary Economics*, 46(2): 281-313.

[28] Fischer, Stanley, and Franco Modigliani (1978), "Towards an Understanding of the Real Effects and Costs of Inflation," *Review of World Economics*, 114: 810-833.

[29] Friedman, Milton (1969), *The Optimum Quantity of Money and Other Essays.* Chicago: Aldine.

[30] Genesove, David (2003), "The Nominal Rigidity of Apartment Rents," *Review of Economics and Statistics*, 85: 844-853.

[31] Gertler, Mark and John Leahy (2008), "A Phillips Curve with an Ss Foundation," *Journal of Political Economy*, forthcoming.

[32] Golosov, Mikhail, and Robert E. Lucas, Jr. (2007), "Menu Costs and Phillips Curves," *Journal of Political Economy*, 115(2): 171–199.

[33] Goodfriend, Marvin. and Robert G. King (1997), "The New Neoclassical Synthesis and the Role of Monetary Policy," *NBER Macroeconomics Annual*, 12: 231-283.

[34] Goodfriend, Marvin, Knut Anton Mork and Ulf Söderström (2007), "Norges Bank Watch 2007. An Independent Review of Monetary Policymaking in Norway," Norges Bank Watch Report Series No. 8, Centre for Monetary Economics, BI Norwegian School of Management.

[35] Hansen, Gary D. (1985), "Indivisible Labor and the Business Cycle," *Journal of Monetary Economics*, 16: 309-327.

[36] Huang, Kevin X.D. and Zheng Liu (2005), "Inflation targeting: What inflation rate to target?," *Journal of Monetary Economics*, 52(8): 1435-1462.

[37] Huffman, Gregory W. and Mark A. Wynne (1999), "The Role of Intratemporal Adjustment Costs in a Multisector Economy," *Journal of Monetary Economics*, 34: 317-350.

[38] Imbs, Jean, Eric Jondeau, and Florian Pelgrin (2007), "Aggregating Phillips Curves," *ECB Working Paper Series no. 785.*

[39] Jensen, Henrik (2002). "Targeting Nominal Income Growth or Inflation?" *American Economic Review,* 92: 928–956.

[40] Kahn, Aubhik, Robert G. King and Alexander L. Wolman (2003), "Optimal Monetary Policy," *Review of Economic Studies*, 70: 825-860.

[41] Kehoe, Patrick J. and Virgiliu Midrigan (2008), "Temporary Price Changes and the Real Effects of Monetary Policy," *mimeo*, New York University.

[42] Kiley, Michael (2008), "Estimating the Common Trend Rate of Inflation for Consumer Prices and Consumer Prices Excluding Food and Energy Prices," Finance and Economics Discussion Series 2008-38.

[43] Klenow, Peter J., and O. Kryvtsov (2008) "State-Dependent or Time-Dependent Pricing: Does It Matter for Recent U.S. Inflation?," *The Quarterly Journal of Economics*, 123(3): 863–904.

[44] Liegey, Paul R. (1994), "Apparel Price Indexes: Effects of Hedonic Adjustment," *Monthly Labor Review*, 117-5: 38-45.

[45] Mankiw, Gregory N., and Ricardo Reis (2003), "What Measure of Inflation Should a Central Bank Target?" *Journal of the European Economic Association*, 1(5): 1058-1086.

[46] McCully, Clinton P., Brian C. Moyer, and Kenneth J. Stewart (2007), "A Reconciliation between the Consumer Price Index and the Personal Consumption Expenditures Price Index," *mimeo*, BEA and BLS.

[47] McCully, Clinton P., and Teresita D. Teensma (2008), "Preview of the 2009 Comprehensive Revision of the National Income and Product Accounts: New Classifications for Personal Consumption Expenditures," *Survey of Current Business*, 88(5): 6-17.

[48] Midrigan, Virgiliu (2008), "Menu Costs, Multi-Product Firms and Aggregate Fluctuations," *mimeo*, New York University.

[49] Mishkin, Frederick S. (2007), "Headline versus Core Inflation in the Conduct of Monetary Policy," Speech delivered at the Business Cycles, International Transmission and Macroeconomic Policies Conference, HEC Montreal, Montreal, Canada.

[50] Nakamura, Emi, and Jón Steinsson (2008a), "Five Facts About Prices: A Reevaluation of Menu Cost Models," *The Quarterly Journal of Economics*, 123(4): 1415–1464.

[51] Nakamura, Emi, and Jón Steinsson (2008b), "Monetary Non-Neutrality in a Multi-Sector Menu Cost Model," *mimeo*, Columbia University.

[52] Plosser, Charles I. "Perspectives on the Economy, Inflation, and Monetary Policy," Remarks for the Philadelphia Business Journal Book of Lists Power Breakfast, King of Prussia, Pennsylvania.

[53] Quah, Danny, and Shaun P. Vahey (1995), "Measuring Core Inflation," *Economic Journal*, 105: 1130-44.

[54] Rich, Robert W., and Charles Steindel (2007), "A Comparison of Measures of Core Inflation," *Economic Policy Review*, 13(3): 19-38.

[55] Sheedy, Kevin (2007), "Inflation Persistence When Price Stickiness Differs Between Industries," *mimeo*, London School of Economics.

[56] Svensson, Lars E.O. (2000), "Inflation Targeting as a Monetary Policy Rule," *Journal of Monetary Economics*, 43: 607-654.

[57] Törnqvist, Leo (1936), "The Bank of Finland's Consumption Price Index," *Bank of Finland Monthly Bulletin*, 10: 1-8.

[58] Valentinyi, Ákos, and Berthold Herrendorf (2008), "Measuring Factor Income Shares at the Sectoral Level," *Review of Economic Dynamics*, 11(4): 820-835.

[59] Woodford, Michael (2003), *Interest and Prices: Foundations of a Theory of Monetary Policy*, Princeton: Princeton University Press.

[60] Woodford, Michael (2008), "Information-Constrained State-Dependent Pricing," *mimeo*, Columbia University.

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.[24] 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

$$(8) \qquad\qquad \mathbf{y} = \mathbf{U}'\boldsymbol{\iota} + \mathbf{v}$$

Futhermore, consider the diagonalization operator, such that for

$$(9) \qquad \mathbf{y} = \begin{bmatrix} y_1 & \cdots & y_n \end{bmatrix}' : \backslash\mathbf{y}\backslash = \begin{bmatrix} y_1 & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & y_n \end{bmatrix}.$$

This allows us to define

$$(10) \qquad\qquad \mathbf{A} = \mathbf{U} \, \backslash\mathbf{y}\backslash^{-1}$$

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

$$(11) \qquad\qquad \mathbf{y} = \mathbf{A}\mathbf{y} + \mathbf{v} = (1 - \mathbf{A})^{-1}\mathbf{v}$$

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

$$(12) \qquad\qquad \mathbf{v} = \mathbf{l} + \mathbf{k}.$$

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

---

[24] Throughout, we do not account for imports. That is, we consider a closed economy version of the input-output tables and calculate domestic requirements.

33

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

$$(13) \qquad \mathbf{c} = \mathbf{By} = \mathbf{B}\left(1 - \mathbf{A}\right)^{-1}\mathbf{v} = \mathbf{B}\left(1 - \mathbf{A}\right)^{-1}\mathbf{l} + \mathbf{B}\left(1 - \mathbf{A}\right)^{-1}\mathbf{k} = \mathbf{c}_l + \mathbf{c}_k,$$

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

$$(14) \qquad s_l^n = \frac{1}{\overline{\lambda}}\left(\frac{\theta_n^{(I)} - 1}{\theta_n^{(I)}}\right) = \frac{1}{\lambda_n^{(II)}}\left(\frac{\overline{\theta} - 1}{\overline{\theta}}\right),$$

and

$$(15) \qquad \left(\frac{\theta_n^{(III)} - 1}{\theta_n^{(III)}}\right) = \sqrt{\left(\frac{\theta_n^{(I)} - 1}{\theta_n^{(I)}}\right)\left(\frac{\overline{\theta} - 1}{\overline{\theta}}\right)} \text{ and } \lambda_n^{(III)} = \sqrt{\overline{\lambda}\lambda_n^{(II)}}$$

such that

$$(16) \qquad var\left(\ln\left(\frac{\theta_n^{(III)} - 1}{\theta_n^{(III)}}\right)\right) = var\left(\ln\lambda_n^{(III)}\right)$$

and

$$(17) \qquad var\left(\ln s_l^n\right) = var\left(\ln\left(\frac{\theta_n^{(III)} - 1}{\theta_n^{(III)}}\right)\right) + var\left(-\ln\lambda_n^{(III)}\right)$$

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 The Inflation Equivalent

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 loss under the optimal policy is

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

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

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

We define inflation equivalent for equilibrium SO, π_{SO}^E the amount of steady inflation that would need to be *exogenously* added to the path of inflation in each sector under the optimal equilibrium to make the representative agent indifferent between this "distorted" optimal equilibrium and the suboptimal one. π_{SO}^E is thus defined by the equality

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

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

$$\frac{1}{1-\beta}\sum_n a_n\frac{\theta_n^2}{\xi_n}\left(\theta_n^{-1}+\tilde{\eta}_n\right)\left(\pi_{SO}^E\right)^2 = \mathcal{L}^{SO}-\mathcal{L}^O$$

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

$$\pi_{SO}^E = \sqrt{\frac{1-\beta}{\sum_n a_n\frac{\theta_n^2}{\xi_n}\left(\theta_n^{-1}+\tilde{\eta}_n\right)}\left(\mathcal{L}^{SO}-\mathcal{L}^O\right)},$$

a simple monotonic transformation of the loss differential between the suboptimal and optimal equilibria.
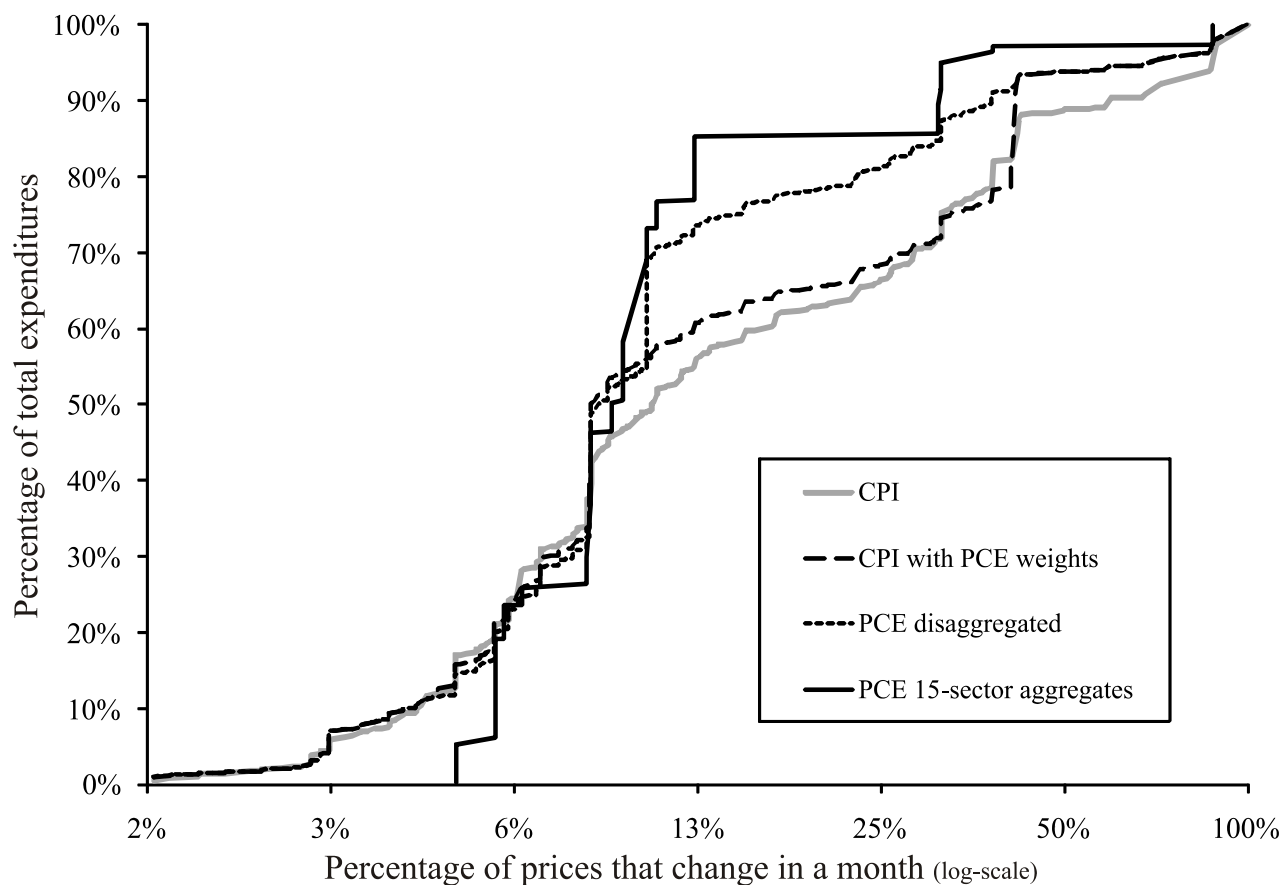
Figure 1: Expenditure weighted cumulative density functions of price stickiness for four steps of data conversion. CPI corresponds to the ELI-level CPI data in NS, with their expenditure weights. CPI with PCE weights adjusts those weights to sum to the expenditure shares of the corresponding PCE 15 major 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

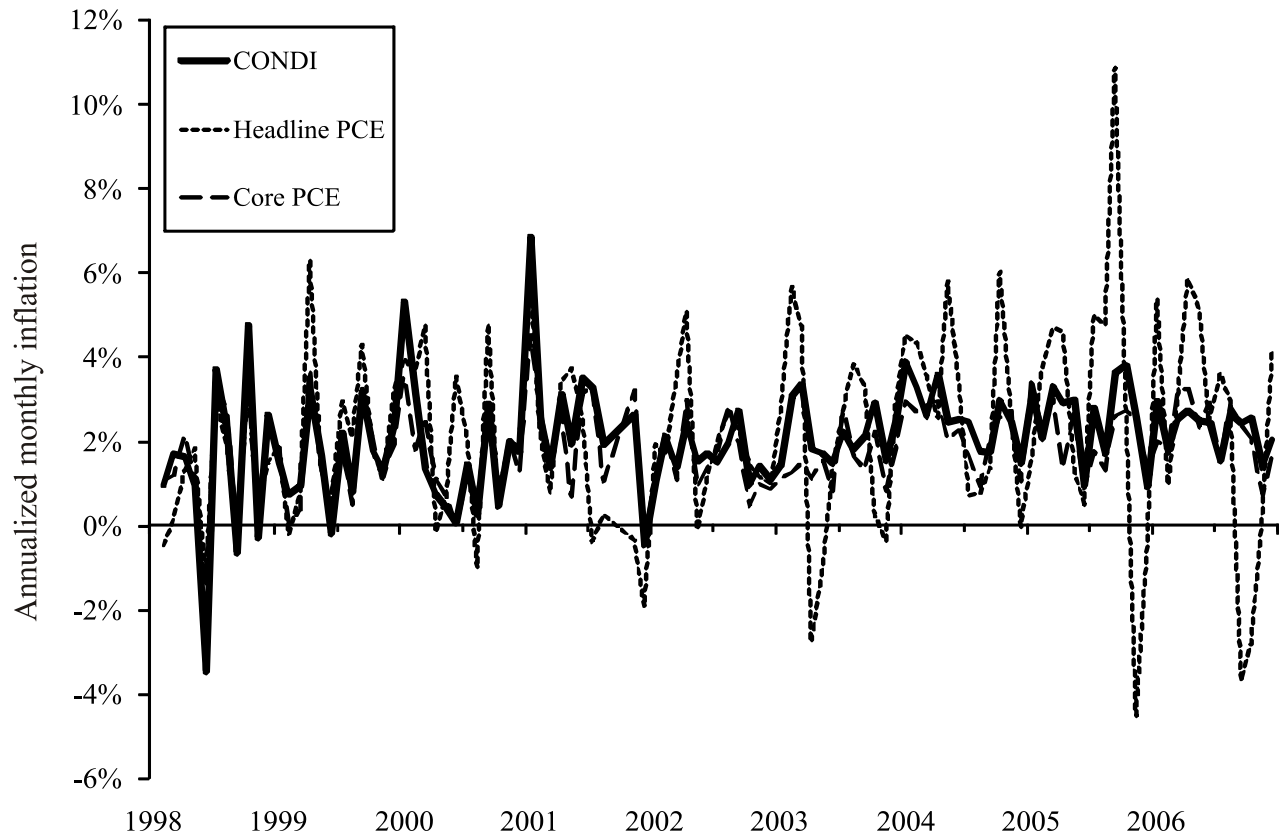| Sectors	Core	PCE Share a_n	Freq. of Price Adj. $1-\alpha_n$	Labor Share $\lambda_n^{-1}\frac{\theta_n-1}{\theta_n}$	$\theta_n^{(I)}$	$1/\lambda_n^{(II)}$	$\theta_n^{(III)}$	$1/\lambda_n^{(III)}$
			(i) One Sector					
PCE		100%	8.6%	70.3%	5.0	0.88	5.0	0.88
			(ii) Two Sectors					
Core	■	81.3%	8.3%	72.8%	5.8	0.91	5.4	0.89
Non-core		18.7%	11.8%	66.1%	4.0	0.83	4.4	0.85
			(iii) Fifteen Sectors					
Motor vehicles	■	5.5%	31.3%	72.2%	5.6	0.90	5.3	0.89
Furniture and household equipment	■	4.5%	6.0%	70.3%	5.0	0.88	5.0	0.88
Other durables	■	2.4%	6.4%	69.8%	4.8	0.87	4.9	0.88
Food at home		8.5%	12.3%	66.8%	4.1	0.83	4.5	0.86
Food away from home		5.2%	5.0%	70.4%	5.0	0.88	5.0	0.88
Clothing and shoes	■	4.2%	31.0%	69.3%	4.7	0.87	4.8	0.87
Gasoline, fuel oil and other energy goods		2.8%	87.6%	61.4%	3.3	0.77	4.0	0.82
Other non-durables	■	7.9%	9.4%	68.4%	4.5	0.85	4.7	0.87
Housing	■	15.1%	10.3%	69.9%	4.9	0.87	4.9	0.88
Household operations - Other	■	3.5%	10.7%	72.0%	5.5	0.90	5.2	0.89
Household operations - Electricity and Gas		2.2%	38.1%	51.6%	2.4	0.65	3.2	0.75
Transportation	■	4.0%	8.2%	71.7%	5.4	0.90	5.2	0.89
Medical Care	■	16.3%	8.3%	83.2%	18.5	1.00	7.7	0.94
Recreation	■	4.1%	9.0%	76.5%	7.7	0.96	6.0	0.92
Other services	■	13.9%	5.8%	76.4%	7.6	0.96	6.0	0.92

		Homogenous Parameters			
β	η	ρ s.t.		σ s.t.	$\sigma^{\mathcal{Y}}$
$(0.96)^{1/12}$	0.5	$\mathrm{Corr}(\pi_t,\pi_{t-1})=0.19$		$\mathrm{StDev}(\pi_t)=0.2\%$	0.49%

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

Heterogeneity in	Core	1 − α^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)	(II)	(III)
Parameter Values														
Baseline		0.086	5.0	0.88	5.0	0.88								
Core		0.083	5.8	0.91	5.4	0.89								
Non-core		0.118	4.0	0.83	4.4	0.85								
CONDI Weights														
Core							81.3	89.9	85.2	78.4	82.1	92.2	88.1	90.4
Non-core							18.7	10.1	14.8	21.6	17.9	7.8	11.9	9.6
Welfare Loss - Inflation Equivalent														
Targeting														
CONDI							0	0.005	0.000	0.000	0.000	0.003	0.003	0.000
Headline PCE							0	0.36	0.13	0.07	0.02	0.50	0.27	0.39
Core PCE							0.50	0.51	0.50	0.53	0.52	0.48	0.55	0.52

Note: CONDI weights are in percentage points. Inflation equivalent welfare losses are monthly inflation rates 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).

Table 3: CONDI weights and welfare losses under different heterogeneity cases for 15-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)	(II)	(III)
			Parameter Values						CONDI Weights					
Baseline		0.086	5.0	0.88	5.0	0.88	5.5	0.4	4.3	5.5	5.4	0.3	0.3	0.3
Motor vehicles	■	0.313	5.6	0.90	5.3	0.89	4.5	8.5	3.2	4.7	4.3	5.8	9.2	8.0
Furniture and household equipment	■	0.060	5.0	0.88	5.0	0.88	2.4	3.9	1.7	2.5	2.2	2.6	4.4	3.7
Other durables	■	0.064	4.8	0.87	4.9	0.88	8.5	3.8	5.3	9.8	7.9	2.2	4.5	3.5
Food at home		0.123	4.1	0.83	4.5	0.86	5.2	14.1	3.8	5.4	5.0	9.7	15.4	13.4
Food away from home		0.050	5.0	0.88	5.0	0.88	4.2	0.3	2.9	4.5	4.0	0.2	0.3	0.3
Clothing and shoes	■	0.310	4.7	0.87	4.8	0.87	2.8	0.0	1.5	3.8	2.6	0.0	0.0	0.0
Gasoline, fuel oil and other energy goods		0.876	3.3	0.77	4.0	0.82	7.9	6.1	5.3	8.7	7.5	3.8	6.9	5.6
Other non-durables	■	0.094	4.5	0.85	4.7	0.87	15.1	9.5	10.6	15.9	14.4	6.4	10.4	9.0
Housing	■	0.103	4.9	0.87	4.9	0.88	3.5	2.1	2.7	3.5	3.4	1.5	2.1	2.0
Household operations - Other	■	0.107	5.5	0.90	5.2	0.89	2.2	0.1	0.9	2.7	1.9	0.0	0.2	0.1
Household operations - Electricity and Gas		0.381	2.4	0.65	3.2	0.75	4.0	4.1	3.1	4.1	3.9	3.0	4.3	3.9
Transportation	■	0.082	5.4	0.90	5.2	0.89	16.3	15.9	36.5	13.1	19.4	34.1	13.2	18.7
Medical Care	■	0.083	18.5	1.00	7.7	0.94	4.1	3.4	4.1	3.6	4.1	3.3	3.1	3.4
Recreation	■	0.090	7.7	0.96	6.0	0.92	13.9	28.0	14.1	12.3	14.2	27.0	25.7	28.2
Other services	■	0.058	7.6	0.96	6.0	0.92								
Targeting									Welfare Loss - Inflation Equivalent					
CONDI							0	0.002	0.006	0.003	0.000	0.001	0.004	0.002
Headline PCE							0	0.13	0.41	0.22	0.14	0.07	0.14	0.11
Core PCE							0.63	0.08	0.61	0.71	0.65	0.05	0.09	0.07
Adjusted core PCE							0.73	0.04	0.67	0.80	0.74	0.03	0.04	0.04

Note: See table 2.