The Elusive Costs of Inflation:
Price Dispersion during the U.S. Great Inflation

Emi Nakamura       Jón Steinsson
Columbia University Columbia University
Patrick Sun         Daniel Villar *
FCC                  Federal Reserve Board

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Abstract

A key policy question is: How high an inflation rate should central banks target? This depends crucially on the costs of inflation. An important concern is that high inflation will lead to inefficient price dispersion. Workhorse New Keynesian models imply that this cost of inflation is very large. An increase in steady state inflation from 0% to 10% yields a welfare loss that is an order of magnitude greater than the welfare loss from business cycle fluctuations in output in these models. We assess this prediction empirically using a new dataset on price behavior during the Great Inflation of the late 1970’s and early 1980’s in the United States. If price dispersion increases rapidly with inflation, we should see the absolute size of price changes increasing with inflation: price changes should become larger as prices drift further from their optimal level at higher inflation rates. We find no evidence that the absolute size of price changes rose during the Great Inflation. This suggests that the standard New Keynesian analysis of the welfare costs of inflation is wrong and its implications for the optimal inflation rate need to be reassessed. We also find that (nonsale) prices have not become more flexible over the past 40 years.

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1 Introduction

Recent years have seen a resurgence of interest in the question of the optimal level of inflation. In the years before the Great Recession, there was a growing consensus emerging among policymakers that good policy consisted of targeting an inflation rate close to zero. One manifestation of this was that many countries adopted explicit inflation targets concentrated around 2% per year. Within academia, prominent studies argued for still lower rates of inflation even after having explicitly taken account of the zero lower bound (ZLB) on nominal interest rates (Schmitt-Grohé and Uribe, 2011; Coibion et al., 2012). The Great Recession has led to a reconsideration of this consensus view with an increasing number of economists arguing for targeting a higher inflation rate of say 4% per year (see, e.g., Blanchard et al., 2010; Ball, 2014; Krugman, 2014; Blanco, 2015b).

An important concern with targeting higher inflation is that this will increase price dispersion and thereby distort the allocative role of the price system. Intuitively, in a high inflation environment, relative prices will fluctuate inefficiently as prices drift away from their optimal value during intervals between price adjustment. As a consequence relative prices will no longer give correct signals regarding relative costs of production, leading production efficiency to be compromised.

In standard New Keynesian models—the types of models used in most formal analysis of the optimal level of inflation—these costs are very large even for moderate levels of inflation. Calibrating such a model in a relatively standard way, we show that the consumption-equivalent welfare loss of moving from 0% inflation to 12% inflation is roughly 10%. For comparison, the welfare costs of business cycle fluctuations in output—even including large recessions like the Great Depression and Great Recession—are an order of magnitude smaller in these same models.\footnote{The models used to analyze the welfare costs of inflation in the New Keynesian literature typically assume a representative agent with constant relative risk aversion preferences and output fluctuations that are trend stationary. In this case, Lucas (2003) shows that the consumption-equivalent welfare loss of business cycle fluctuations in consumption over the period 1947-2001 are 0.05% if consumers are assumed to have log utility. Redoing Lucas’ calculation with a coefficient of relative risk aversion of 2 and considering fluctuations in annual per capita consumption around a linear trend over the period 1920-2009 implies a welfare loss of 0.4%. A substantial literature has since argued that Lucas’ calculation substantially understates the true costs of business cycle fluctuations (see, e.g., Barro, 2009; Krusell et al., 2009).}

Measuring the sensitivity of price dispersion to changes in inflation is challenging for several reasons. One challenge is the small amount of variation we have seen in the inflation rate in the U.S. over the last few decades. Existing BLS micro-data on U.S. consumer prices have been influential in establishing basic facts about the frequency and size of price changes (Bils and Klenow,
2004; Nakamura and Steinsson, 2008; Klenow and Kryvtsov, 2008). These data, however, have the substantial disadvantage that they span only the post-1987 Greenspan-Bernanke period of U.S. monetary history, when inflation was low and stable. This seriously limits their usefulness in studying how variation in inflation affects the economy.

To overcome this challenge, we have extended the BLS micro-dataset on U.S. consumer prices back to 1977. This allows us to analyze a period when inflation in the U.S. rose sharply—peaking at roughly 12% per year in 1980—and was then brought down to a lower level in dramatic fashion by the Federal Reserve under the leadership of Paul Volcker (see Figure 1). We constructed these new data from original microfilm cartridges found at the BLS by first scanning them and then converting them to a machine-readable dataset using custom optical character recognition software. This effort took several years to complete partly because the data were never allowed to leave the BLS building in Washington DC.

A second challenge to measuring the sensitivity of price dispersion to changes in inflation is the presence of a large amount of unobserved product heterogeneity. Much of the cross-sectional dispersion in prices—even within narrowly defined product categories—likely results from heterogeneity in product size and quality (e.g., a can of soda versus a 2 liter bottle, organic versus nonorganic milk, Apple’s iPhone 6S versus LG’s G4 smartphone). The simplest way to empirically assess
price dispersion is to calculate the standard deviation of prices within a narrow category. But this approach will lump together desired price dispersion resulting from product heterogeneity and inefficient price dispersion resulting from price rigidity. In fact, the amount of desired price dispersion within even narrow product categories is likely to dwarf inefficient price dispersion at moderate levels of inflation. This situation is further complicated by the fact that the recent literature has convincingly argued that desired real prices of a product vary a great deal over time (Golosov and Lucas, 2007). This means that simple reduced-form approaches to “differencing out” product heterogeneity—such as looking at the deviations of a product’s price from its long-run mean real level—will not work well.2

Earlier research seeking to study the relationship between price dispersion and inflation faced this same challenge (see, e.g., Van Hoomissen, 1988; Lach and Tsiddon, 1992). It concluded that studying price dispersion directly was not viable and focused instead on price change dispersion.3 These researchers argued that price change dispersion is an acceptable proxy for price dispersion in some simple menu cost models. This is not, however, the case even qualitatively in the more empirically realistic menu cost models used today. In these models, price change dispersion actually falls with inflation at low levels of inflation while price dispersion is roughly flat.4

To overcome this challenge, we assess the sensitivity of inefficient price dispersion to changes in inflation by looking at how the absolute size of price changes varies with inflation. Intuitively, if inflation leads prices to drift further away from their optimal level, we should see prices adjusting by larger amounts when they adjust. For this reason, if inefficient price dispersion rose during the Great Inflation period, a tell-tale sign of this should be that the absolute size of price changes should have risen during that period as well. We show that this intuition works in the Calvo model and in a Golosov-Lucas style menu cost model (i.e., one with large idiosyncratic shocks).

In the Calvo model, the average absolute size of price changes rises rapidly with inflation as does

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2Golosov and Lucas (2007) point out that large idiosyncratic shocks to desired prices are needed to explain the large frequency and size of price changes at low levels of inflation. We illustrate in section 4.1 that this makes reduced-form measurement of inefficient price dispersion challenging.

3Lach and Tsiddon (1992) state that they were thwarted in looking directly at price dispersion. Though they do not explain exactly why, they say: “the problems we run into while analyzing the relationship between this measure of price dispersion and inflation convinced us that we need a more structured and empirically oriented model to tackle this issue. Hence we do not present results on the effects of inflation on the cross-sectional dispersion of price levels.”

4The intuition for this result is simple. At low inflation rates, a significant fraction of price changes are price decreases. This leads to a widely dispersed distribution of price changes (increases and decreases). As inflation increases, the frequency of price decreases falls and the price change distribution narrows to include mostly price increases. This reduces the cross-sectional variance of price changes.
inefficient price dispersion. In the menu cost model, however, the average absolute size of price changes and inefficient price dispersion are virtually flat over the range of inflation rates relevant for our empirical work.\textsuperscript{5} Intuitively, in the menu cost model, prices never drift too far from their optimal level since firms find it optimal to pay the (relatively small) menu cost before this happens. This greatly limits the extent to which price dispersion rises with inflation in the menu cost model and, as a result, the welfare loss from increasing inflation is small in this model, a point emphasized by Burstein and Hellwig (2008).

We show that, in the data, the mean absolute size of price changes in the U.S. is essentially flat over our entire sample period. The standard deviation of the absolute size of price changes is also essentially flat. There is, thus, no evidence that prices deviated more from their optimal level during the Great Inflation period when inflation was running at higher than 10\% per year than during the more recent period when inflation has been close to 2\% per year.

We conclude from this that the main costs of inflation in the New Keynesian model are completely elusive in the data. This implies that the strong conclusions about optimality of low inflation rates reached by researchers using models of this kind need to be reassessed. It may well be that inflation rates above 2\% have other important costs. A strong consensus for low inflation being optimal must rely on these other costs outweighing the benefits of higher inflation.

Rather than seeing an increase in the absolute size of price changes during the Great Inflation, we see a substantial increase in the frequency of price change. The behavior of both the absolute size and frequency of price change as inflation varies in our sample line up much better with the predictions of menu cost models than they do with the predictions of the Calvo model. In this regard, our results reinforce results based on micro-data from several other countries (see, e.g., Gagnon, 2009; Alvarez et al., 2016).

A second dramatic result of our analysis is that, despite all of the technological change that has occurred over the past four decades, regular prices (excluding temporary sales) do not seem to have become more flexible over this period, controlling for inflation. We show that a simple menu cost model with a fixed menu cost over the entire sample period can match the empirical relationship between the frequency of price change and inflation. Menu costs are, of course, a

\textsuperscript{5}This contrasts with earlier menu cost models that abstracted from large idiosyncratic shocks. In those models, the response of the absolute size of price changes to inflation is more substantial (Barro, 1972; Sheshinski and Weiss, 1977). The reason for the difference is that the size of price changes is determined primarily by the large idiosyncratic shocks in our menu cost model and is therefore not very sensitive to inflation when inflation is low.
veil for a variety of deeper frictions in the price adjustment process arising from technological,
managerial, or customer-related factors. Whatever these costs are, they do not appear to be going
away over time.\textsuperscript{6}

In sharp contrast, we show that the frequency of temporary sales has increased substantially
over the past four decades. Temporary sales occur only in a subset of sectors. But their frequency
has increased substantially in all of these sectors. Whether this has important implications for
aggregate price flexibility is a question of active research over the past decade. The empirical
literature has emphasized that temporary sales have quite different empirical properties from those
of regular prices. Sales are much more transitory than other price changes, and less responsive to
macroeconomic conditions. These characteristics substantially limit the contribution of temporary
sales to aggregate price flexibility.\textsuperscript{7} Moreover, this growth in temporary sales leaves the large and
growing “gorilla in the room” sector—the service sector—untouched.

Relatively little work has been done on the sensitivity of price dispersion to changes in inflation
in the United States. Reinsdorf (1994) uses BLS micro data for the period 1980-1982 (a subset of
our data) and finds that price dispersion rose when inflation fell. Sheremirov (2015) uses scanner
price data for the relatively low inflation period of 2002-2012. He finds that price dispersion rises
with inflation. Alvarez et al. (2016) study the relationship between price dispersion and inflation
during the Argentinian hyperinflation in 1989-1990. They find that the elasticity of price dispersion
with inflation is roughly one third at high inflation rates, in line with a simple menu cost model.\textsuperscript{8}

The stability of the absolute size of price changes at different levels of inflation that we find in
our data is consistent with earlier work. Cecchetti (1986) analyzes magazine prices at news stands
and finds that the absolute size of price changes is stable over his sample period of 1953 to 1979.
Gagnon (2009) finds that the absolute size of price changes varies little with inflation in Mexico
during a large bout of inflation in the mid 1990’s. Wulfsberg (2016) similarly finds that the absolute
size of price changes varies very little in Norway over the Great Inflation period. Using scraped

\textsuperscript{6}When firms are asked why they don’t change their prices, they often say that the reason is “implicit contracts”
with customers (Blinder et al., 1998). There is no reason to think that customer-related pricing frictions of this kind
would be going away over time. Nakamura and Steinsson (2011) provide a recent formalization of how “customer
markets” can yield price rigidity.

\textsuperscript{7}These arguments are made in Nakamura and Steinsson (2008), Guimaraes and Sheedy (2011), Kehoe and Midrigan
(2015), Anderson et al. (2015). See also Nakamura and Steinsson (2013) for a discussion of these ideas.

\textsuperscript{8}An early literature studied the relationship between inflation and the dispersion of sectoral inflation rates (Mills,
1927; Glejser, 1965; Vining and Elwertowski, 1976; Parks, 1978; Fischer, 1981; DeBelle and Lamont, 1997). However,
such measures are very sensitive to sectoral shocks such as oil price shocks (Bomberger and Maken, 1993).
data from the internet, Cavallo (2015) finds that the absolute size of price changes does not vary much across countries with very different levels of inflation.

The paper proceeds as follows. Section 2 discusses the welfare loss resulting from inflation in different models with price rigidity. Section 3 describes the construction of our new micro-dataset on consumer prices. Section 4 presents evidence based on this data that inefficient price dispersion was no higher when inflation was high in the late 1970’s and early 1980’s than it has been since then. Section 5 discusses the evolution of the frequency of price change over our sample period. Section 6 discusses our results on the evolution of price flexibility. Section 7 concludes.

2 Costs of Inflation in Sticky Price Models

To understand what drives the large costs of inflation in standard sticky price models, it is useful to lay out a simple model of the type used in the literature. The model economy is populated by households, firms, and a government. Consider first the households. There are a continuum of identical households that seek to maximize discounted expected utility given by

$$E_t \sum_{j=0}^{\infty} \beta^j [\log C_{t+j} - L_{t+j}],$$

where $E_t$ denotes the expectations operator conditional on information known at time $t$, $C_t$ denotes household consumption of a composite consumption good, and $L_t$ denotes household supply of labor. Households discount future utility by a factor $\beta$ per period. The composite consumption good $C_t$ is an index of household consumption of individual goods produced in the economy given by

$$C_t = \left[ \int_0^1 \frac{c_t^{\theta - 1}}{\theta} d_i \right]^{\frac{1}{\theta}},$$

where $c_{it}$ denotes consumption of individual product $i$. The parameter $\theta > 1$ denotes the elasticity of substitution between different individual products.

Households earn income from two sources: their labor and ownership of the firms in the economy. The household’s budget constraint is therefore

$$P_t C_t + Q_{it} B_{it} \leq W_t L_t + (D_{it} + Q_{it}) B_{it-1},$$

where $P_t$ denotes the aggregate price index, i.e., the minimum cost of purchasing a unit of $C_t$, $W_t$ denotes the wage rate, $D_{it}$, $Q_{it}$, and $B_{it}$ denote the dividend, price, and quantity purchased and
sold of asset \( i \). The assets in the economy include ownership claims to the firms in the economy and may include other assets such as a risk-free nominal bond and Arrow securities although these will not play any role in our analysis. To rule out “Ponzi schemes”, we assume that household financial wealth must always be large enough that future income suffices to avert default.

Households take the prices of the individual goods \( p_{it} \) as given and optimally choose to minimize the cost of attaining the level of consumption \( C_t \). This implies that their demand for individual product \( i \) is given by

\[
c_{it} = \left( \frac{p_{it}}{P_t} \right)^{-\theta} C_t, \tag{4}
\]

where

\[
P_t = \left[ \int_0^1 p_{it}^{-\theta} \, di \right]^{\frac{1}{1-\theta}}. \tag{5}
\]

Optimal choice of labor by the household taking the wage \( W_t \) as given yields a labor supply equation

\[
\frac{W_t}{P_t} = C_t. \tag{6}
\]

Household optimization also yields expressions for the household’s valuation of all assets that exist in the economy. For the purpose of calculating the equilibrium in our model, it will be useful to have an expression for the household’s valuation at time \( t \) of an uncertain dividend payment from firm \( i \) at time \( t+j \), i.e., a \( j \)-period “dividend strip” for firm \( i \). We denote the value of this dividend strip as \( V_{it}^j \). Its value is

\[
V_{it}^j = \mathbb{E}_t \left[ \beta^j \left( \frac{C_{t+j}}{C_t} \right)^{-1} D_{t,t+j} \right]. \tag{7}
\]

Other conditions for household optimization do not play a role in determining the equilibrium.

There exists a continuum of firms in the economy that each produce a distinct individual product using the production function

\[
y_{it} = A_{it}L_{it}. \tag{8}
\]

Here \( A_{it} \) denotes the productivity level of firm \( i \) and \( L_{it} \) is the amount of labor demanded by firm \( i \). The logarithm of firm productivity varies over time according to the following AR(1) process

\[
\log A_{it} = \rho \log A_{it-1} + \text{ilon}_{it}, \tag{9}
\]

where \( \text{ilon}_{it} \sim \mathcal{N}(0, \sigma_{\text{ilon}}^2) \) are independent over time and across firms.

Firms commit to meet demand for their products at the price they post. They hire labor on the economy-wide labor market at wage rate \( W_t \) in order to satisfy demand. The marginal cost of
firm $i$ is $MC_{it} = \frac{W_i}{A_{it}}$. The firms are monopoly suppliers of the goods they produce. Their main decision is how to price these products. We assume that changing prices is costly and consider several different assumptions about these costs below.

Finally, to keep our model as simple as possible so that we can focus on the driving forces underlying costs of inflation in a sticky price setting, we assume that the monetary authority is able to control nominal output $S_t = P_tC_t$. Specifically, the monetary authority acts so as to make nominal output follow a random walk with drift in logs:

$$\log S_t = \mu + \log S_{t-1} + \eta_t$$

where $\eta_t \sim N(0, \sigma^2_\eta)$ are independent over time. We will refer to $S_t$ either as nominal output or as nominal aggregate demand.

### 2.1 The Flexible Price Benchmark

We begin by considering the equilibrium of this economy when prices are completely flexible. In this case, the firms will set the price of the good they produce equal to a markup over marginal cost

$$p_{it} = \frac{\theta}{\theta - 1} \frac{W_t}{A_{it}},$$

(11)

This price-setting equation can then be used to show that at the aggregate level

$$P_t = \frac{\theta}{\theta - 1} \frac{W_t}{A_f},$$

(12)

where

$$A_f = \left[ \int_0^1 A^{\theta-1} dt \right]^{\frac{1}{\theta-1}}.$$  

(13)

We refer to $A_f$ as flexible price aggregate labor productivity.\(^9\) The production function of this simple economy also aggregates easily. Using firm $i$’s production function—equation (8)—the demand curve for firm $i$’s output—equation (4)—the price setting equation for firm $i$—equation (11)—and integrating over $i$ yields the following aggregate production function

$$Y_t = A_f L_t.$$  

(14)

\(^9\)Since we abstract from aggregate productivity shocks, if the cross-sectional distribution of idiosyncratic firm productivity $A_{it}$ starts off at its ergodic distribution, the integral on the right-hand-side of equation (13) will remain constant.
where $Y_t$ denotes aggregate output (which is equal to aggregate consumption $Y_t = C_t$). See online Appendix A for derivations of equations (11)-(14).

We can now see that in this flexible price version of our model, the equilibrium values of output, labor, and real wages are determined by the following three simple equations:

**Labor Supply:**
\[
\frac{W_t}{P_t} = Y_t \quad (15a)
\]

**Production Function:**
\[
Y_t = A_f L_t \quad (15b)
\]

**Markup:**
\[
P_t = \Omega_f \frac{W_t}{A_f} . \quad (15c)
\]

where $\Omega_f = \frac{\theta}{\theta - 1}$ denotes the amount by which firms choose to markup their products’ prices over marginal costs when prices are fully flexible. Notice that these three equations only determine $\frac{W_t}{P_t}$, not the level of $P_t$ and $W_t$ individually. To pin down the level of nominal prices and wages, one must add $S_t = P_t Y_t$ to the system.

Using equations (15a)-(15c) to solve for output and labor supply yields

\[
Y_t = \Omega_f^{-1} A_f \quad (16a)
\]
\[
L_t = \Omega_f^{-1} . \quad (16b)
\]

Notice that this solution is independent of the rate of inflation and also independent of the history of shocks to nominal aggregate demand. The only distortion that moves this economy away from a first-best outcome is the monopoly power of the firms. This distortion leads the firms to set prices above marginal costs. As a consequence, output is inefficiently low.\(^\text{10}\)

### 2.2 Equilibrium with Sticky Prices

When prices are sticky, the determination of equilibrium is more complicated and will depend on the exact nature of the price adjustment costs. We will consider several different assumptions about the nature of price adjustment costs including the case of a constant fixed cost (the menu cost model) and a case where the cost is zero with some probability in each period and infinite with a complementary probability (the Calvo (1983) model). We assume that firms maximize the value of their stochastic stream of dividends. The methods we use to solve for the equilibrium in these models are described in detail in Nakamura and Steinsson (2010).

\(^\text{10}\)In a fully competitive version of the economy described above—i.e., one in which the markets for all the goods are competitive—all prices would be set equal to marginal cost and the markup $\Omega_f$ would therefore be one. Output would therefore be higher. We know from the first welfare theorem that this is the efficient level of output.
To help build understanding about the costs of inflation that result from sticky prices, it is useful to compare the equilibrium in the sticky price case with the flexible price equilibrium.\footnote{This exposition builds on related analysis in Blanco (2015a) as well as earlier work in Burstein and Hellwig (2009).} To this end, we consider an analogous set of equations to equations (15) for the sticky price case:

\begin{align*}
\text{Labor Supply:} & \quad \frac{W_t}{P_t} = Y_t \\
\text{Production Function:} & \quad Y_t = A_t(\bar{\pi})(L_t - L^p_{pc}) \\
\text{Price Setting:} & \quad P_t = \Omega_t(\bar{\pi})\frac{W_t}{A_t(\bar{\pi})},
\end{align*}

where $\bar{\pi}$ denotes the average inflation rate. The same labor supply equation continues to hold in the sticky price case. The aggregate production function—equation (17b)—however, differs from its flexible price analog—equation (15b)—in two ways. First, some labor is needed to change prices and does not produce output. We use $L^p_{pc}$ to denote this extra labor. This is one source of the costs of price rigidity. Second, aggregate labor productivity is lower in the sticky price economy than under flexible prices because in the sticky price model the relative prices of different goods do not accurately reflect the goods’ relative marginal cost of production. In Online Appendix A we show that the value of aggregate labor productivity when prices are sticky is

\begin{equation}
A_t(\bar{\pi}) = \left[ \int_0^1 \left( \frac{p_{it}}{P_t} \right)^{-\theta} A_t^{-1} dt \right]^{-1}.
\end{equation}

Note that aggregate labor productivity is not only a function of the physical productivity of the individual firms, but also a function of the relative prices of the goods they sell. This occurs because we use a utility-based definition of aggregate output (see equation (2) and note that $Y_t = C_t$) and the marginal utility households derive from consumption of a particular product falls as they consume more of that product relative to other products. Consider for simplicity a case where all products have the same physical productivity. In this case, products that have low relative prices—and are therefore consumed in greater quantities—will contribute less to aggregate output on the margin than products with high relative prices. This will lower aggregate productivity of labor.\footnote{In the special case in which all firms have equal productivity, the variance of prices is a second order approximation for aggregate labor productivity.} More generally, the more intensive consumption of the low-priced goods will lower aggregate productivity of labor, unless their lower relative prices are offset by higher physical productivity.

When prices are sticky, the relative price of a particular product drifts downward as time passes between adjustments. This is one source of divergence between relative prices and relative
productivity that results in lower aggregate labor productivity. This drift is more pronounced the higher is the level of inflation. For this reason, aggregate labor productivity is a decreasing function of the average level of inflation. To emphasize this, we make explicit the dependence of $A_t$ on $\bar{\pi}$ by writing $A_t(\bar{\pi})$.

Equation (17c) is most usefully thought of as defining $\Omega_t(\bar{\pi})$. We will refer to $\Omega_t(\bar{\pi})$ as the aggregate markup in the sticky price case. Variation in $\Omega_t(\bar{\pi})$ reflects the degree to which the price level rises more or less rapidly than $A_t(\bar{\pi})$ falls as inflation changes. However, $\Omega_t(\bar{\pi})$ does not measure how the average markup of firms over physical marginal costs change as inflation changes since $A_t(\bar{\pi})$ is not a measure of physical productivity but rather is also affected by the distribution of relative prices.

Manipulating equations (17) yields

$$Y_t = \Omega_t(\bar{\pi})^{-1}A_t(\bar{\pi}) \quad (19a)$$

$$L_t = \Omega_t(\bar{\pi})^{-1} + L_t^{rc} \quad (19b)$$

This shows that output under sticky prices will differ from its level under flexible prices for two reasons: 1) aggregate labor productivity will be lower, and 2) the aggregate markup may be different. Aggregate labor supply will also differ from its level under flexible prices for two reasons: 1) Some labor is needed to change prices, and 2) the aggregate markup may be different.

Welfare in the economy, in turn, depends on output and labor through equation (1). As is common in the literature, we will report welfare differences across models and levels of inflation in terms of consumption-equivalent welfare changes. I.e., when comparing welfare in model economy $A$ with welfare in model economy $B$ we will solve for the value of $\Lambda$ that yields

$$E \left[ \log \left( (1 + \Lambda)C_t^A \right) - L_t^A \right] = E \left[ \log \left( C_t^B \right) - L_t^B \right].$$

The value $\Lambda$ then measures the percentage change in consumption needed to make households in economy $A$ equally well off as households in economy $B$.

### 2.3 Model Calibration

Below, we calculate equilibrium outcomes for a menu cost model and a Calvo model (both with idiosyncratic productivity shocks) and compare them to the flexible price benchmark. These models are calibrated as follows. A unit of time is meant to correspond to a month. We set the subjective
discount factor to $\beta = 0.96^{\frac{1}{12}}$. The baseline value that we use for the elasticity of substitution between intermediate goods is $\theta = 4$. This value is roughly in line with estimates of the elasticity of demand for individual products in the industrial organization and international trade literatures (Berry et al., 1995; Nevo, 2001; Broda and Weinstein, 2006). This is, however, at the low end of values for $\theta$ that have been used in the macroeconomics literature on the welfare costs of inflation. We will also present results for $\theta = 7$, which is the value used by Coibion et al. (2012).

In the menu cost model, we calibrate the level of the menu cost and the standard deviation of the idiosyncratic shocks to match the median frequency of price change of 10.1% per month and the median absolute size of price changes of 7.5% over the (relatively low inflation) period 1988-2014.\(^{13}\) The resulting parameter values are $K = 0.019$ for the menu cost and $\sigma_{\text{idn}} = 0.037$ for the standard deviation of the idiosyncratic shocks.\(^{14}\) In the Calvo model, we set the frequency of price change equal to the median frequency of price change in the data and the standard deviation of the idiosyncratic shocks to the same value as in the menu cost model. In both models, we assume that the first-order autoregressive parameter of the process for idiosyncratic productivity is $\rho = 0.7$, the same value as in Nakamura and Steinsson (2010).

We calibrate the standard deviation of shocks to nominal aggregate demand to be $\sigma_{Q} = 0.0039$ based on the standard deviation of changes in U.S. nominal GDP over the period 1988-2014. We present results for a range of values of average change in nominal aggregate demand (i.e., a range of values for average inflation).

### 2.4 Numerical Results on the Costs of Inflation

Figure 2 plots the consumption-equivalent welfare loss experienced by households when prices are sticky as a function of the inflation rate. The welfare loss is calculated relative to welfare in an economy with flexible prices. The difference in results between the menu cost model and the Calvo model is striking. For the menu cost model, the welfare loss is small and virtually completely constant at about 0.4% as a function of inflation. This is true both when $\theta = 4$ and $\theta = 7$.\(^{15}\) For

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\(^{13}\)More specifically, we first calculate the average frequency and absolute size of price changes within ELIs (see section 3 for a discussion of what an ELI is) in each year. We then take a median across ELIs in each year. We then take an average of these medians over years.

\(^{14}\)This menu cost implies that 0.019 units of labor are needed to change a price. For comparison, the nonstochastic steady state level of labor each month is $\Omega^{\frac{1}{12}} = 0.75$.

\(^{15}\)These costs include the menu costs themselves, i.e., the physical cost of changing prices. However, these physical costs are small for the reasons emphasized in Mankiw (1985) and Akerlof and Yellen (1985). The physical costs of price changes rise slightly as inflation rises since the frequency of price changes rises. However, this small effect is
the Calvo model, however, the costs of price rigidity rise sharply with inflation. Consider first our baseline case of \( \theta = 4 \). When inflation is zero, these costs are similar in magnitude to those in the menu cost model. When inflation is 10% per year, these costs have risen to 2.4%; and when inflation is 16% per year, these costs are a staggering 7% per year. With \( \theta = 7 \), these welfare losses rise even faster. In this case, the welfare loss hits 10% when inflation is roughly 12%.

Clearly, the exact nature of price rigidity matters a great deal when assessing the costs of inflation. The reason for this is that the welfare costs of inaction are highly convex in the difference between a firm’s price and its static optimal price. In the menu cost model, firms always have the option to pay the (relatively small) menu cost and therefore never allow their price to drift far from its optimal level. In the Calvo model, however, some firms are stuck with a price that is very far from its optimal level and this generates large welfare losses.

The reason price rigidity leads to increased price dispersion is that a firm’s relative price drifts downward between adjustments. One way to avoid this downward drift is to index prices between offset by a slight fall in price dispersion as prices bunch in the lower half of the inaction region (i.e., in the part below the reset price) as inflation rises above zero. At higher levels of inflation, price dispersion rises and the costs of inflation rise.
Figure 3: Output and Labor Supply

Note: The left panel plots average output and the right panel plots average labor supply. In each case, these variables are plotted as a function of inflation relative to their level when prices are flexible and with $\theta = 4$.

times of reoptimization. In our model, full indexation is equivalent to having a fixed price level. The welfare costs of price rigidity with full indexation are therefore closely approximated by the welfare costs we report for zero inflation (the only difference is that inflation is not constant in our zero inflation case since we allow for small shocks to nominal aggregate demand). The welfare costs at zero inflation also provide a measure of the costs of idiosyncratic shocks in our model. For our baseline calibration of the standard deviation of idiosyncratic shocks, these costs are 0.3% in the menu cost model. If we double the size of the idiosyncratic shocks, the costs rise to 1.5%, but the average absolute size of price changes also roughly doubles.\(^\text{16}\)

It is interesting to consider the extent to which the difference between the Calvo model and the menu cost model arises because the frequency of price change is allowed to vary in the menu cost model versus because the menu cost model induces a different selection of firms to change their prices conditional on the frequency of price change. To this end, Figure A.5 in the Appendix adds results for a version of the Calvo model with a frequency of price change that varies with inflation

\(^{16}\)The corresponding welfare cost numbers for the Calvo model are 0.4% for the baseline calibration and 2.0% when we double the size of the idiosyncratic shocks. In the menu cost model, we recalibrate the menu cost to hold the frequency of price change constant when we increase the size of the idiosyncratic shocks.
and is chosen to equal the frequency of price change in the menu cost model at each level of inflation. This model generates welfare losses that are substantially smaller than the Calvo model with a fixed frequency of price change but quite a bit larger than the menu cost model. These results show that both variation in the frequency and differences in selection contribute substantially to the difference between the Calvo model and the menu cost model.\footnote{Figures A.6 - A.8 present results on the absolute size and frequency of price change for this version of the Calvo model with a varying frequency of price change in addition to the other models considered in the paper.}

To gain further insight, Figure 3 plots the level of output and labor supply in the menu cost model and the Calvo model as a function of inflation (again relative to the level of these variables when prices are flexible). This figure shows that in the Calvo model, an increase in inflation from 0\% to 10\% leads to a fall in output of about 1.5\%. But the amount of labor needed to produce this lower output is actually greater by 0.7\% due to a fall in labor productivity. As with welfare, these changes in output and labor supply grow increasingly rapidly as inflation rises above 10\%.

Figure 4 plots labor productivity directly as well as the aggregate markup (again relative to the level of these variables when prices are flexible). From this figure we see that the welfare loss that results from a higher rate of inflation in the Calvo model comes entirely from a sharp fall in labor productivity. Labor productivity falls by 2.1\% when inflation rises from 0\% to 10\%. The other two potential sources of welfare losses discussed in section 2.2 are nonexistent or actually increase welfare in the Calvo model. First, in the Calvo model, firms face no direct costs when they change their prices. Second, the aggregate markup actually falls when inflation rises (by roughly 0.9 percentage points, when inflation rises from 0\% to 10\%).\footnote{Recall that our measure of the aggregate markup is different from the average of firms’ markups over physical marginal cost (since our measure of aggregate productivity is utility based). The average markup over physical marginal costs actually rises with inflation in the Calvo model (King and Wolman, 1996).} In other words, the price level relative to the wage rate does not rise quite as rapidly as labor productivity falls implying that output does not fall as rapidly as labor productivity.\footnote{In the menu cost model we analyze, the aggregate markup does not change much with inflation over the range we consider. Bénabou (1992) studies a menu cost model with consumer search in which the higher price dispersion resulting from inflation leads to more search, which in turn makes markets more competitive and lowers markups.}

At an intuitive level, the loss of labor productivity in the Calvo model when inflation rises is due to an increase in inefficient price dispersion. In fact, these two concepts are equal up to a second order approximation when we abstract from idiosyncratic productivity shocks. To drive home this point, Figure 5 plots inefficient price dispersion in the Calvo model and the menu cost model as a function of inflation. We see that the pattern for inefficient price dispersion is very similar to the
pattern for labor productivity (and the overall welfare loss). This is useful in terms of providing us with guidance regarding what statistics we should calculate to shed empirical light on the costs of inflation.

3 New Micro-Data on Consumer Prices during the Great Inflation

Our analysis is based on a new dataset that we have developed with the help and support of staff at the Bureau of Labor Statistics.\textsuperscript{20} The dataset contains the individual price quotes underlying the U.S. Consumer Price Index for the period from May 1977 to October 1986 and May 1987 to December 1987. Prior to our project, the BLS CPI Research Database contained data starting only in 1988. It therefore had the important disadvantage that it did not cover the most eventful period in post-WWII U.S. monetary history: the “Great Inflation” of the late 1970’s and early 1980’s.

The construction of the dataset involved two main phases. First, we worked with the BLS

\textsuperscript{20}We owe a huge debt to Daniel Ginsberg, John Greenlees, Michael Horrigan, Robert McClelland, John Molino, Ted To and numerous others at the Bureau of Labor Statistics whose efforts were crucial in making this project possible.
Figure 5: Inefficient Price Dispersion

Note: The measure of inefficient price dispersion that we plot here is the standard deviation across firms of the firm’s price relative to the price it would charge if it had flexible prices and with $\theta = 4$.

staff to scan the physical microfilm cartridges to convert them to digital images. This step was difficult because the microfilm cartridges were sufficiently old that modern scanners could not read them. Fortunately, we were able to find a company that was willing and able to retrofit a modern microfilm reader to read these outdated cartridges.

The process of scanning the microfilm cartridges left us with roughly one million images of “Price Trend Listings” that needed to be converted to machine-readable form. The BLS’ high standards of confidentiality imply that all processing of the data must be done on-site at the BLS in Washington DC. This made it infeasible to outsource this step to a professional data-entry firm for manual data entry. The alternative available was to use optical character recognition (OCR) software for this conversion process. This was challenging because leading commercial software solutions turned out to be both prohibitively expensive and too slow. After considerable search, we, however, found a firm that was able to create custom software that ensured high quality and high enough speed to convert the large number of images we had.\footnote{In overcoming these practical obstacles, we benefited greatly from Patrick’s tireless work and ingenuity. The rest of us are very grateful for his efforts in this regard.}

The raw microfilm cartridges we found at the BLS contain images of Price Trend Listings,
starting in May 1977 and ending in October 1986. Each Price Trend Listing contains prices for the previous 12 months for a given product—a feature of the data that we make considerable use of in checking for errors, as we describe below. We scanned all the cartridges from the period 1977-1981, while cartridges from every other month for the period 1982-1986 were scanned. This choice was motivated by the higher quality of the images on the more recent cartridges. It is possible that even older CPI micro-data exists at the BLS. However, the CPI underwent a major revision in 1978. We conjecture that data collection was revised as a part of this revision and the May 1977 start date of our data is the start date of the new data collection system put in place at this time.

We obtained separate, already digitized data on prices for the months of May to December in 1987. This left us with a short gap in coverage for the period November 1986 to April 1987.

The information contained on the Price Trend Listing images includes 1) an internal BLS category label called an Entry Level Item or ELI, 2) a location (city) identifier, 3) an outlet identifier, 4) a product identifier, 5) the product’s price, 6) the percentage change in the product’s price between collection periods, 7) a “sales flag” indicating whether the product’s price was temporarily marked down at the time of collection, 8) an “imputation flag” indicating whether the price listed is truly a collected price or was imputed by the BLS, and 9) several additional flags that we do not use. From this we see that each product in the dataset is identified at a very detailed level—for example, a 2-Liter Diet Coke at a particular Safeway store in Chicago.

BLS employees collect the data by visiting outlets on a monthly or in some cases bimonthly basis. Somewhere between 80,000 and 100,000 observations are collected per month. Prices of all items are collected monthly in the three most populous locations (New York, Los Angeles, and Chicago). Prices of food and energy are collected monthly in all other locations as well. Prices of other items are collected bimonthly. We focus on the monthly data in our analysis.

Fortunately, there are numerous redundancies in the raw data that allow us to check for errors in our OCR procedure. The first form of redundancy arises from the fact that prices for a particular product in a particular month appear on multiple Price Trend Listings because the Price Trend Listings include 12 months of previous prices, as we note above. We can use this redundancy to verify that the price observations obtained from different Price Trend Listings are, in fact, the same. The second form of redundancy arises because each Price Trend Listing includes both the price and a percentage change variable. We can therefore verify that the percentage change in prices obtained when we calculate this directly based on the converted prices is the same as the
one reported in the percentage change variable. We describe both of these procedures in detail in Online Appendix B. We err on the side of caution: all of the price observations included in our final dataset have been “accepted” by either of the procedures described above.

The order of the Price Trend Listings allows us to check for errors in the OCR conversion of the product label and category variables. Each microfilm cartridge corresponds to a particular “collection period” when the prices were collected. On each cartridge, images are sorted first by product category (ELI), then by outlet, then by quote (a specific product, such as a 2-Liter Diet Coke), and finally by the version (used when a product is replaced by another very similar product). The order of the Price Trend Listings means that if our OCR procedure fails to convert a particular ELI value, we can easily fill it in using the surrounding values of ELI’s. We use a similar procedure to fill in missing values of the outlet, quote and version variables. The algorithm we use for this is described in Online Appendix B. Errors in converting the product identifiers will lead to a spuriously large number of products. Online Appendix B discusses this in more detail and describes a procedure we use to verify that this does not bias our results.

Finally, our process for converting the sales and imputation flag variables makes use of the limited set of values taken by these values (e.g., “I” stands for imputation). We also make use of the fact that, like in the case of prices, the flags for a given product-month appear on multiple Price Trend Listings. We discuss these procedures in greater detail in Online Appendix B.

The BLS has changed the organization of the consumer price micro-data two times since 1978. The first change occurred in 1987 and the second, more substantial change, occurred in 1998. We have created a concordance to harmonize the ELI categories across these different time periods. To do this, we first used the category descriptions to match the ELI categories used in the 1977-1986 and the ones used in 1987-1997. We then used the descriptions available in the BLS’ documentation for the CPI Research Database to match the ELI’s for 1987-1997 and 1998 onwards. A detailed set of concordances is available on our websites.

We will hand over the new dataset we have constructed to the BLS so that they can make it available to researchers in the same way the existing BLS CPI Research Database is available. The data we will make available will include the original scanned images (in JPEG and TIFF format), the raw dataset that resulted from our OCR conversion (with all the redundancies discussed above), and the final dataset we constructed using the procedures discussed above and in Online Appendix B. The availability of all three of these versions of the data will therefore allow future researchers
to improve on our data construction effort (both the OCR conversion and the accuracy verification of the OCR output).

In our analysis of this data, we drop all imputed prices. Whenever we observe a price change that is larger than one log point \( \log \left( \frac{p_t}{p_{t-1}} \right) > 1 \), we set the price change variable and price change indicator to missing (i.e., we drop these large price changes). Only 0.04% of observations are dropped because they are large. We frequently calculate weighted means and medians of various statistics across ELIs by year. In all cases, we hold fixed the expenditure weights at their value in 2000. While the accuracy of our data conversion methods seems high for most of our sample, we are not fully confident in the quality of the resulting data at the very beginning of our sample. For this reason, we drop the data from 1977. Our sample period is therefore 1978 to 2014.

4 Price Dispersion and the Size of Price Changes

We have seen in section 2 that the costs of inflation in sticky price models are largely due to increases in inefficient price dispersion. Figure 6 plots the evolution of a simple measure of price dispersion for U.S. consumer prices over the period 1978-2014. We first calculate the interquartile range of prices within Entry Level Items (ELI’s)—narrow product categories defined by the BLS such as “salad dressing”—for each year. We then take the expenditure-weighted median across ELI’s. We calculate this measure of price dispersion both including and excluding temporary sales.

Figure 6 shows that this simple measure of price dispersion has increased steadily over the past 40 years. This is driven by dramatic increases in price dispersion within ELI for unprocessed food, processed food, and travel services. This increase in dispersion is, of course, the opposite result from what one might have expected given that inflation has fallen sharply over this period (see Figure 1). As we discuss in the introduction, a key empirical challenge is that much of the cross-sectional dispersion in prices—even within narrowly defined product categories—likely results from heterogeneity in product size and quality. The observed increase in the cross-sectional dispersion in prices may therefore come from an increase in product heterogeneity as opposed to time variation in inefficient price dispersion. The pattern revealed in Figure 6 suggests that a large increase in product variety over the past 40 year—for example among food products—has led to an increase in price dispersion within ELI that has been large enough to dwarf any (relatively small) changes
in price dispersion associated with price rigidity.\footnote{Another possible source of the increase in cross-sectional price dispersion is greater dispersion of desired markups. Price dispersion of this kind is desired from the firms’ perspective but may reduce aggregate welfare.}

### 4.1 Fixed-Effects Price Gap

The notion that raw price dispersion is dominated by product heterogeneity even within narrow categories suggests that “differencing out” fixed product characteristics may yield a good measure of inefficient price dispersion. One approach to doing this is to look at the deviation of observed prices from their long-run mean real level.\footnote{We are grateful to a referee for suggesting this procedure.} Consider the following statistic, which we refer to as the “fixed-effects price gap”:

\[ x_{ijt} = \log p_{ijt} - \log P_{jt} - \frac{\sum_{\tau=t_{ij}^0}^{T_{ij}} [\log p_{ij\tau} - \log P_{j\tau}]}{T_{ij} - t_{ij}^0 + 1}. \]  

(21)

Here \( p_{ijt} \) is the price of product \( i \) in product category \( j \) at time \( t \), \( P_{jt} \) is a price index for product category \( j \), and \( t_{ij}^0 \) and \( T_{ij} \) are the first and last periods for which we observe a price for product \( ij \), respectively. The statistic \( x_{ijt} \) therefore measures the real price of product \( ij \) relative to its mean
over the entire period for which we observe a price for this product.

If products’ desired real prices were fixed over time (and each product observed for long enough in our data), then the fixed-effects price gap would difference out heterogeneity in desired prices within product category and allow us to construct a direct measure of inefficient price dispersion. The problem is that the recent literature has convincingly argued that desired real prices are far from being fixed over time. Price changes are too large, and are too often decreases, to be accounted for by aggregate shocks alone. Golosov and Lucas (2007) argue that these basic empirical features of the price data strongly suggest the presence of large idiosyncratic shocks to desired prices.  

To illustrate this problem, we simulate data from the menu cost model we describe in section 2. Recall that our objective is to find an empirical proxy for the true gap between a product’s price and its unobserved desired price. Let’s call this the “true price gap.” Figure 7 presents a scatter plot of the relationship between the fixed-effects price gap and the true price gap based on a simulation of our menu cost model. Clearly, the fixed-effects price gap is only weakly correlated

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24 It is not possible to get away from this idiosyncratic variation in prices simply by looking within categories. There is a large amount of idiosyncratic variation in the size and timing of price changes, even within ELI’s.

25 We assume that there is a constant hazard rate that products will exit the dataset. When a product exits the dataset, a new product replaces the old product and enters the dataset with a newly reoptimized price. The hazard rate of product substitution in the simulation is set equal to the frequency of product substitutions estimated in Nakamura and Steinsson (2008).
with the true price gap in our menu cost model. This arises because idiosyncratic shocks lead to large fluctuations in desired real prices. Moreover, there is a “selection effect”: the fixed-effects price gap shows a large gap for products that have not adjusted their prices for a long time. However, when idiosyncratic variation in desired real prices is large, the fact that a product’s price has not been adjusted for a long time contains information about the product’s optimal price. Products whose prices haven’t adjusted in a long time are products whose real desired prices are falling for unobserved, idiosyncratic reasons.

4.2 Absolute Size of Price Changes

To overcome the difficulties discussed above, we propose to focus on the times when prices change. At these times, a substantial amount of information is revealed about the product’s desired price and the distance a product’s price has drifted from its desired price. Intuitively, if higher inflation truly leads prices to drift further from their efficient levels due to price rigidity, we should observe larger price changes when firms finally adjust their prices. This idea suggests that the absolute size of price changes may be a good proxy for inefficient price dispersion. Importantly, this “revealed preference” argument circumvents both the problem of product heterogeneity and the problem of idiosyncratic variation in desired prices.

Figure 8 compares the relationship between inflation and the average absolute size of price changes in the Calvo model and in the menu cost model. We do this in two ways. First, we plot the steady-state average absolute size of price changes for different steady-state values of inflation. These are the two lines in the figure. For the Calvo model, the average absolute size of price changes rises sharply with inflation, while this is not the case in the menu cost model. Recall that this is exactly the pattern that holds for inefficient price dispersion. This illustrates that studying the absolute size of price changes provides an indirect, yet powerful, way to measure the extent to which inefficient price dispersion rises with inflation.

A concern with the steady-state calculation that underlies the two lines in Figure 8 is that the Great Inflation was a somewhat transitory event. Perhaps inflation was not high for long enough during the Great Inflation to create the degree of price dispersion needed to substantially raise the average absolute size of price changes. We can address this concern by simulating the response of the average absolute size of price change to the actual evolution of inflation in the U.S. in the two models over our sample period. These are the two sets of points in the figure. Each point gives the
average absolute size of price changes and the average inflation in a particular year between 1978 and 2014. This exercise, while somewhat noisier, gives results very similar to the steady state calculation discussed above.

Figure 9 plots the evolution of the absolute size of price changes over the period 1978-2014. We first calculate the mean absolute size of price changes within ELI by year and then take an expenditure-weighted median across ELIs for each year. We again report results both including and excluding temporary sales. Even though the inflation rate has fallen sharply over our sample period, the absolute size of price changes has remained essentially unchanged over this time period at roughly 8%. If anything, there is actually a slight upward trend over the sample period. The evolution of the absolute size of price changes, therefore, provides no evidence that prices strayed farther from their efficient levels during the Great Inflation than in the low-inflation Greenspan-
The welfare costs of price rigidity depend nonlinearly on the extent to which individual prices differ from their efficient level. Prices that are very far from optimal contribute disproportionately to welfare losses. The random nature of the timing of price adjustment in the Calvo model implies that as inflation rises the distribution of relative prices becomes highly dispersed. The distribution of relative prices has a long left tail with some firms having wildly inappropriate prices because they have not been able to change their price for a long period. When these prices finally change, they change by large amounts. In contrast, in the menu cost model, the absolute size of firms' price changes is small because all price changes are clustered around the sS bounds.

Conditional on the average absolute size of price changes, the standard deviation of the absolute size of price changes provides information about the dispersion of the distribution of relative price changes and, in particular, information about how many firms have wildly inappropriate prices. Figure 10 plots the standard deviation of the absolute size of price changes as a function of inflation.

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27 Figure A.1 in the Appendix shows that the average size is flat (or slightly upward sloping) within sector for six of the most important sectors in our data. Figure A.2 shows that there is nothing special about the median across ELIs. The 10th, 25th, 75th and 90th quantiles tell essentially the same story. Figure A.3 shows the absolute size of price increases and decreases at a quarterly frequency.
in the Calvo model and in the menu cost model (using the same two methods as we do for the mean absolute size of price changes in Figure 8). We see that the standard deviation of the absolute size of price changes rises by more than a factor of six in the Calvo model, as the inflation rate rises from 0% to 16% per year. In contrast, this measure rises only slightly in the menu cost model.

Figure 11 reports the standard deviation of the absolute size of price changes in the data over our sample period of 1978-2014. Like with the average absolute size statistic, we first calculate the standard deviation of the absolute size of price changes within ELI for each year and then take a weighted median across ELI’s for each year. This statistic turns out to be quite stable over time in the data. It varies between roughly 4.5% and 6% for the majority of the sample period. If anything, it displays a slight upward trend. This statistic, again, provides us with no evidence that the distribution of relative prices became more dispersed during the Great Inflation.\textsuperscript{28}

We can similarly analyze the behavior of the fixed-effects price gap discussed in section 4.1 in the Calvo and menu cost models and in the data. Even though the fixed-effects price gap does not provide a reduced form measure of price dispersion, its evolution over time may still provide useful information through the lens of the structural models. The two lines in Figure 12 plot the

\textsuperscript{28}The standard deviation of the absolute size of price changes is larger in the data than in the model. This likely reflects cross-sectional variation in menu costs that we have abstracted from in our model.
interquartile range of the fixed-effects price gap for different levels of average inflation in the menu cost model and the Calvo model. Even though the fixed-effects price gap is only weakly correlated with the true price gap (Figure 7), the interquartile range of this statistic does rise more quickly with inflation in the Calvo model than the menu cost model. However, this statistic turns out to be quite noisy in the data, perhaps because measures of dispersion are harder to estimate than means. The circles in Figure 12 are a scatter plot of the interquartile range of the fixed-effects price gap versus the inflation rate across years in our sample after adjusting for breaks associated with reclassification of the ELI product groups in 1988 and 1998.\textsuperscript{29} The large amount of noise in the fixed-effects price gap in the data limits the informativeness of this statistic in distinguishing between models in which inflation is costly and those in which it is not.

\textsuperscript{29}We use price indexes at the major group level to construct the fixed-effects price gap in the data. We first calculate the fixed-effects price gap at the product-month level and then calculate the interquartile range of this statistic at the ELI-year level. As we discuss in section 3, the BLS updated the ELI product group classification in 1988 and in 1998. This reclassification leads to obvious breaks in the interquartile range of the fixed-effects price gap in several major groups. To adjust for this, we run a regression of the interquartile range of the fixed-effects price gap at the ELI-year level on major group inflation, major group dummies, dummies for pre-1988 and post-1998, and the pre-1988 and post-1998 dummies interacted with the major group dummies. We then filter out the pre-1988 and post-1998 dummies as well as their interaction with the major group dummies. After we have done this filtering, we take a weighted median across ELI within year and plot the resulting statistics against the inflation rate in that year.
Figure 12: Fixed-Effects Price Gap in the Models and the Data

Note: The lines plot the interquartile range of the fixed-effects price gap in the menu cost and Calvo models for different levels of steady-state inflation. The circles are a scatter plot of the fixed-effects price gap versus the inflation rate across years in our sample after adjusting for breaks associated with reclassification of the ELI product groups in 1988 and 1998.

5 Frequency of Price Change

Thus far in the paper, we have focused on the size of price changes because of its relation to price dispersion and welfare. The frequency of price change is in some sense the flip side of the coin. If inflation rises but the size of price changes don’t, the frequency of price change must be changing.\textsuperscript{30}

Earlier research by Klenow and Kryvtsov (2008) and Nakamura and Steinsson (2008) has studied the time series behavior of the frequency of price change and its relationship to inflation in the U.S. using data on prices since 1988. The inference one can draw from these papers is, however, limited by the fact that inflation in the U.S. has been low and stable over the post-1988 period. The data from the Great Inflation that we analyze in this paper have much more power to distinguish among different pricing theories.\textsuperscript{31}

\textsuperscript{30} A subtlety here is that at low levels of inflation the frequency and absolute size of price changes can be relatively constant as inflation rises if the fraction of price changes that are increases is rising with inflation. In this case, the behavior of the average size and the average absolute size can be quite different. At higher levels of inflation, most price changes are increases and this distinction is less important (Gagnon, 2009).

\textsuperscript{31} Important evidence on this topic is also available from a number of other (mostly middle income) countries with more volatile inflation rates. See, in particular, Gagnon (2009) and Alvarez et al. (2016) for evidence from Mexico and Argentina, respectively, and Wulfsberg (2016) for evidence from Norway. Nakamura and Steinsson (2013) discuss this literature in more detail.
Figure 13: Frequency of Price Changes in Sticky Price Models

Note: The lines plot the frequency of price change as we vary the steady state level of inflation in the menu cost and Calvo models. The circles and squares plot the frequency of price change in the menu cost model and Calvo model, respectively, from a monthly simulation using the actual inflation rate from 1978 to 2014. Each point is the average from a particular year in the simulation.

Figure 13 plots the relationship between the frequency of price change and inflation in the menu cost model and the Calvo model. As with the size statistics discussed in section 4, we calculate this relationship for different steady-state levels of inflation (the lines in the figure) and for a simulation based on the actual history of inflation in the U.S. over the period 1978 to 2014 (the points in the figure). Not surprisingly, the menu cost model implies that the frequency of price change rises with inflation. When inflation rises from 0% to 16%, the frequency of price change rises by more than half, going from 10% to 16%. In contrast, the frequency of price change is constant in the Calvo model by assumption.

Figure 14 plots the frequency of price change for consumer prices in the U.S. over our sample period of 1978-2014 along with the CPI inflation rate. To construct this series, we first calculate the mean frequency of price change by ELI for each year. We then take an expenditure-weighted median across ELIs for each year. The figure clearly shows that the frequency of price change comoves strongly with inflation. This data therefore strongly favors the menu cost model over the Calvo model.

Figure 15 separates the frequency of price increases and the frequency of price decreases. Here
we plot the 12-month average frequency of price change at a quarterly frequency to see a bit more detail. The most striking feature of this figure is that it is the frequency of price increases that varies with the inflation rate, while the frequency of price decreases is unresponsive. Nakamura and Steinsson (2008) show that this asymmetry arises naturally in the menu cost model when prices are drifting upward due to a positive average inflation rate. In this case, prices tend to “bunch” toward the bottom of their inaction region. Because of this bunching, when there is an aggregate shock that changes desired prices, there is a large response of the frequency of price increases (reflecting the relatively large mass at the bottom of the band), but a much smaller response of the frequency of price decreases. This is the same argument as the one described by Foote (1998) for why job destruction will be more volatile than job creation in declining industries.\footnote{Figure A.4 presents figures analogous to Figure 15 for two important sectors in our data: food and services. In this figure, the inflation rate that we plot on each panel is the sectoral inflation rate in that sector. In both sectors, the frequency of price increases covaries strongly with inflation, while the frequency of price decreases is largely flat.}

One curious feature of Figure 14 is the spike in the frequency of price changes that occurs in 2008. Looking at Figure 15 and especially the analogous plot for food in Figure A.4 in the Appendix, we see however, that inflation was highly volatile in 2008. It first spiked up due to the

Figure 14: Frequency of Price Changes in U.S. Data

Note: To construct the frequency series plotted in this figure, we first calculate the mean frequency of price changes in each ELI for each year. We then take the weighted median across ELI’s.
commodity price boom early in that year, and then fell dramatically with the onset of the recession and the collapse of commodity prices. In light of this unusual volatility of inflation, the spike in the frequency of price changes in 2008 seems less puzzling.

Table 1 summarizes our findings about the frequency and absolute size of price changes during the Great Inflation / Volcker disinflation period and the subsequent low-inflation Greenspan-Bernanke period. We see that the frequency of price change has been lower in the latter period and this is driven entirely by a fall in the frequency of price increases. In sharp contrast, the average absolute size of price changes is virtually the same over the period 1978-1987 as it is over the period 1988-2014 despite the fact that inflation was much lower in the latter period.

6 Have Prices Become More Flexible over Four Decades?

The “menu cost” in the menu cost model is best thought of as a stand-in for a variety of costs associated with price adjustment. Though economists have failed to settle on what exactly this menu cost represents, many theories have been considered, including adverse customer reactions to price changes, limited managerial attention, and the actual costs of changing price tags or reprinting...
menus. Given all of the technological advancement that has occurred over the past half-century, it seems natural to conjecture that some of the costs of changing prices may have fallen, allowing prices to become more flexible.

Yet, there is no evidence that prices (excluding sales) have become more flexible over time. Figure 14 shows that the frequency of price change (excluding sales) has actually fallen over the past 40 years. Of course, the benefits of changing prices frequently have also fallen over this period since inflation has fallen. For this reason, the evolution of the frequency of price change is not an ideal measure of the evolution of price flexibility.

An alternative (arguably better) measure of price flexibility is the menu cost needed to match the frequency of price change at a particular point in time given the level of inflation at that time. If the menu cost model is able to match the frequency of price change over time with a constant menu cost, this would indicate that prices (excluding sales) have not become more flexible over time.

Figure 16 presents the results of this type of exercise. The broken lines in the figure are the frequency of price increases and decreases in the data. The solid lines are the frequency of price increases and price decreases from a simple menu cost model with a constant menu cost.\(^{33}\) Evidently, the frequency of price change in the data tracks the model-implied frequency of price change quite

\(^{33}\)For simplicity, in this exercise, we feed the inflation rate into the model directly (as opposed to feeding in a process for nominal aggregate demand and having inflation be an endogenous outcome). The model we use in this exercise is therefore a partial equilibrium model.
well over time as inflation rises and falls. If the costs of price adjustment had trended down over the past four decades, one would expect that our model would systematically underpredict the frequency of price change toward the end of the sample period. This is not the case.

Since our simple menu cost model with a fixed cost of price adjustment can explain the overall trend in the frequency of price change over the sample period, we conclude that there is no evidence that prices (excluding sales) have become more flexible over time. One might worry that these facts about price changes excluding temporary sales might be somehow contaminated by the increasing frequency of sales (discussed below); but the same downward trend in the frequency of price change is visible even in sectors with essentially no sales, such as the service sector.

Our result that prices (excluding sales) have not become more flexible over the last 40 years is, in our view, strong evidence against the notion that menu costs should be viewed as technological in nature (e.g., as physical costs of changing price labels). When asked why they did not change their prices more often, by far the most frequent answer given by firm managers is that they fear that this will “antagonize” their customers (Blinder et al., 1998).\textsuperscript{34} This suggests that customer-related

\textsuperscript{34}In Blinder et al. (1998), 64.5% of firms report that they have implicit contracts with their consumers and an overwhelming majority of these firms (79%) indicate that these implicit contracts are an important source of price rigidity. Similar surveys in a host of other countries have since confirmed that the most important reason cited by firm managers for price rigidity is that they are loathe to “damage customer relations” by changing their prices.
Frictions play an important role in price rigidity. Phelps and Winter (1970) proposed a “customer markets” model to understand price rigidity. According to Okun’s (1981) “invisible handshake” version of the customer markets idea, firms have implicit agreements with their customers not to take advantage of tight market conditions by raising their price in exchange for stable prices in weak markets. Nakamura and Steinsson (2011) provide a recent formalization of how customer markets can yield price rigidity.

One way in which prices have become more flexible over time is that the frequency of temporary sales has increased. Temporary sales are distributed very unequally across sectors, occurring frequently in processed and unprocessed food, apparel, household furnishings, and recreation goods, but quite infrequently in other sectors of the economy (see Nakamura and Steinsson, 2008). Figure 17 plots the evolution of the frequency of sales in the sectors in which sales are prevalent. In all five sectors, there has been a dramatic increase in the frequency of sales over our sample. In some categories, the increase seems to continue unabated, while in others (especially apparel and household furnishing) the frequency of sales seems to have plateaued. This trend increase in the prevalence of sales may, in fact, go back considerably before the start of our sample period. Pashigian (1988) documents a trend increase in the frequency of sales going back to the 1960’s.

Can the increasing prevalence of sales be reconciled with the customer markets view of price rigidity that we describe above? Nakamura and Steinsson (2011) show that if there is asymmetric information about a firm’s idiosyncratic shocks, then the firm-optimal pricing policy can look like a price-cap policy, i.e., regular prices with “sales.” Since an important limitation of this paper is that it does not provide any satisfying explanation for why the sales occur (they arise simply from “shocks”), we can only speculate on why the frequency of price change might increase in this model. However, the most likely interpretation for sales is probably the importance of dynamic pricing policies on the part of the firm. To the extent that such policies have become cheaper to implement (perhaps because of technological innovation in formulating or implementing dynamic pricing policies) this could potentially explain why the frequency of sales has increased so much, and yet be independent of the ultimate reasons for price rigidity in regular prices. These are interesting topics for future research.
Figure 17: Frequency of Temporary Sales

Note: To construct the series plotted in this figure, we first calculate the mean frequency of temporary sales in each ELI for each year. We then take the weighted mean across ELI's.
7 Conclusion

In this paper, we develop a new comprehensive micro-price dataset going back four decades for U.S. consumer prices to study the costs of inflation. We find little evidence that the Great Inflation of the late 1970’s and early 1980’s led to a substantial increase in price dispersion—the costs of inflation emphasized in standard New Keynesian models of the economy. We do find that the frequency of price change varies substantially with the inflation rate, in line with the predictions of standard menu cost models. We also find no evidence that regular prices have become more flexible over these four decades, despite the many technological improvements that have occurred over this period—suggesting that the barriers to price adjustment are not technological in nature.

Columbia University
Columbia University
Federal Communications Commission
Federal Reserve Board

Supplementary Material

An Online Appendix for this article can be found at The Quarterly Journal of Economics online. Data and code replicating tables and figures in this article can be found in Nakamura et al. (2018), in the Harvard Dataverse, doi:10.7910/DVN/JOZY2I.

Appendix
Figure A.1: Mean Absolute Size of Price Changes by Sector

Note: To construct the series plotted in this figure, we first calculate the mean absolute size of price changes in each ELI for each year. We then take the weighted median across ELI’s within each sector for each year.
Figure A.2: Quantiles of the Absolute Size of Price Changes

Note: To construct the series plotted in this figure, we first calculate the mean absolute size of price changes in each ELI for each year. We then calculate quantiles of the distribution of the mean absolute size of price changes across ELI’s for each year.

Figure A.3: Absolute Size of Price Increases and Decreases

Note: To construct the series plotted in this figure, we first calculate the mean absolute size of price increases and decreases in each ELI for each month. We then take the weighted median across ELI’s. Finally, for each quarter we take the average over the last 12 months.
Figure A.4: Frequency of Price Increases and Decreases for Food and Services

Note: To construct the frequency series plotted in this figure, we first calculate the mean frequency of price increases and decreases in each ELI for each month. We then take the weighted median across ELI’s for food and services separately and plot these in the two separate panels.

Figure A.5: Welfare Loss

Note: The figure plots the consumption-equivalent loss of welfare in each model as a function of the inflation rate relative to welfare when prices are completely flexible. This figure presents the same information as Figure 2 but also adds a line for a version of the Calvo model in which the frequency of price varies with inflation and is chosen to equal the frequency of price change in the menu cost model at each level of inflation.
Figure A.6: Absolute Size of Price Changes in Sticky Price Models

Note: The figure plots the mean absolute size of price changes as we vary the steady-state level of inflation in the menu cost model, the Calvo model with a fixed frequency of price change, and the Calvo model with a frequency of price change that varies with inflation and is chosen to equal the frequency of price change in the menu cost model at each level of inflation. It is comparable to Figure 8 in the paper.

Figure A.7: Standard Deviation of Absolute Size of Price Changes

Note: The figure plots the standard deviation of the absolute size of price changes as we vary the steady-state level of inflation in the menu cost, the Calvo model with a fixed frequency of price change, and the Calvo model with a frequency of price change that varies with inflation and is chosen to equal the frequency of price change in the menu cost model at each level of inflation. It is comparable to Figure 10 in the paper.
Figure A.8: Frequency of Price Change in Sticky Price Models

Note: The figure plots the frequency of price changes as we vary the steady-state level of inflation in the menu cost model, the Calvo model with a fixed frequency of price change, and the Calvo model with a frequency of price change that varies with inflation and is chosen to equal the frequency of price change in the menu cost model at each level of inflation. It is comparable to Figure 13 in the paper.
References


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