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Does Inflation Targeting Reduce the Dispersion of Price Setters' Inflation Expectations?*

Charlotte Paulie†

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Abstract

Using detailed Swedish micro data on prices and costs, this paper documents a decrease in the dispersion of changes in prices and markups following the introduction of an official inflation target of 2 percent. Using a structural model to decompose the change in the price-change distribution by potential explanatory factors, about 63 percent of the decrease in the price-change dispersion can be attributed to a decrease in the cross-sectional variance of inflation expectations. The lower dispersion of inflation expectations results in a lower markup dispersion and a welfare gain equivalent to a 0.79 percent increase in consumption.

Keywords: Inflation targeting, price setting, misallocation, welfare.

JEL codes: D84, E52, L11

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1 Introduction

How important is an inflation target for reducing inefficient dispersion of price changes? And what is the effect on welfare? This paper answers these questions using detailed micro data on Swedish manufacturing firms between 1990 and 2002, spanning a period both before and after the introduction of inflation targeting in 1995. Following a resurgence of interest in the question of optimal monetary policy, the growing consensus that good monetary policy is characterized by an official target of a positive, but low, inflation rate has recently been questioned. Both substantially higher and more flexible target rates have been suggested; see, e.g., Rosengren et al. (2018), Debortoli et al. (2017), and Andersson and Claussen (2017). In this context, it is important to understand what the actual benefits of inflation targeting are. A previous literature has focused on the effect of inflation targeting on average inflation expectations of price setters and its implications for the stability of the aggregate price level. In this paper, the focus is instead on the cross-sectional distribution of inflation expectations. This focus captures an additional gain of inflation targeting other than achieving a low inflation rate. While a low inflation rate reduces inefficient price dispersion caused by prices drifting away from their optimal level between price changes, a common anchor for inflation expectations can also reduce inefficient dispersion of prices that are being changed. As this paper shows, the welfare effect of reducing the dispersion of inflation expectations is substantially larger than the one from a change in the inflation rate itself.

A key value added by this study comes from the rare availability of data on both prices and costs, which allows for a separation of inefficient price dispersion and dispersion of prices warranted by cost heterogeneity among producers. Without a micro-level measure of costs, it is hard to study price dispersion without lumping these two together. From a theoretical perspective, what matters for welfare is the inefficient price dispersion. Inefficiently dispersed prices distort the price system by creating a wedge between the marginal cost of production and the marginal utility of consuming the good, resulting in misallocation from distorted production and consumption decisions. Hence, what matters for welfare is not the dispersion of prices per se, but rather how relative prices are distributed conditional on differences in

costs, i.e. welfare depends on the distribution of price-cost markups rather than prices.[1]

Studying welfare effects of price dispersion, thus, requires micro data on both prices and costs that are rarely available in broad samples. Empirical studies have therefore mainly focused on the behavior of prices and price changes without a direct welfare perspective; see, e.g., Baharad et al. (2004), Nakamura and Steinsson (2008), and Alvarez et al. (2014). One approach to get around the problem of unobserved firm heterogeneity is to study goods within narrowly defined categories, but dispersion of prices may still reflect firm-specific differences in costs. Other approaches, such as looking at the absolute size of price changes as a proxy of inefficient price dispersion, have been taken to overcome the problem of unobserved heterogeneity; see, e.g., Nakamura et al. (2018). In contrast to previous studies, this study has access to data on both prices and costs and uses a more direct measure. With the focus being on inefficient price changes, a measure of this is dervied as the observed price changes conditional on changes in costs.

Using a structural New Keynesian model where firms are heterogeneous with respect to productivity and their inflation expectations, dispersion of inefficient price changes are translated into dispersion in markups, which can be used to evaluate welfare.[2] With producers not instantly able to reset prices to their optimal levels, expectations about the future become an important part of the pricing decision. In the model used here, heterogeneity in expectations is captured by an idiosyncratic belief shock affecting firms' perception of the aggregate price level. The belief shock is interpreted as a lack of confidence in the central bank's intention and/or capability to achieve a certain inflation rate. A hypothesis is that an inflation target results in higher confidence that inflation will reach the targeted rate. In the model, this increase in confidence is reflected in firms' expectations being more tightly clustered around a common reference point, resulting in a reduction in the variance of expectations across firms.

[1] Following Galí (2008), welfare costs in a New Keynesian model depend on the level of the aggregate markup and the differences in markups across firms and goods at any point in time.

[2] If the data on costs fully captured all heterogeneity across firms, prices and costs in data could be used to measure inefficient price dispersion. However, because some heterogeneity might still persist and units in the data are not always directly comparable, relying on changes in prices and costs is a better approach.

Fitting the structural model to the micro data in a pre- and post-inflation targeting sample allows for a comparison of a steady-state economy with and without an inflation target. In a first step, the model is used to explore to what extent the change in standard deviation of price changes can be attributed to changes in costs, inflation and the degree of nominal rigidities, respectively. The residual change that cannot be explained by observables in data can be attributed to a decrease in the variance of inflation expectations. Using this indirect inference of the distribution of firms' inflation expectations, expectations are found to be dispersed across firms in line with previous literature; see, e.g., Mankiw et al. (2003).[3] The inflation target results in a reduction in the dispersion of inflation expectations. Specifically, the introduction of an official inflation target by the Swedish central bank of 2 percent results in a decrease in the dispersion (standard deviation) of inefficient price changes from about 0.199 to 0.167. The decrease in dispersion is mainly explained by a combination of nominal rigidities and a decrease in the variance of the belief shock.[4] When disentangling the effect on inefficient price-change dispersion from the change in expectations, 73.5 percent of the decrease in dispersion of inefficient price changes can be explained by the reduction in dispersion of inflation expectations. The significant effect of inflation targeting on the dispersion of inflation expectations stands in contrast to Kumar et al. (2015), which documents substantial dispersion of inflation forecasts of firm managers in New Zealand despite using inflation targeting for a long time.

In a second step, the model is used to study welfare. Using a consumption equivalent measure of welfare, the less distorted price changes after the implementation of the inflation target give rise to significant welfare gains. The distribution of inflation expectations plays an important role here. A reduction in the variance of idiosyncratic belief shocks following the introduction of the inflation target requires a 0.79 percent increase in consumption in the pre-inflation targeting period in order to achieve the same welfare gain. The main mechanism

[3]Following New Keynesian theory, prices set by firms solely reflect expectations about nominal marginal costs and the aggregate price level. Hence, the dispersion in price changes controlling for expected changes in marginal costs should reflect dispersion of expectations.

[4]Instead using the absolute size of price changes as a measure of inefficient price dispersion following Nakamura et al. (2018), leads to the same result. The average absolute size of price changes is lower in the post-inflation targeting period, indicating that inefficient price dispersion is lower.

behind this result is a compression of the markup distribution and a resulting improvement in the allocation of input factors.

The rest of the paper is organized as follows: Section 2 discusses related literature, Section 3 presents the data and time period covered, Sections 4 and 5 describe the model and map its parameters to data, Section 6 presents the results, and, finally, 7 concludes.

2 Related Literature

This paper is related to three different strands of the literature. First, it relates to studies on inflation targeting and anchoring of inflation expectations. Secondly, it speaks to studies on price setting where agents are subject to idiosyncratic shocks, in particular extensions of New Keynesian models. Finally, it is also related to a growing literature on misallocation.

When it comes to inflation targeting and anchoring of expectations, there is a large literature; see, e.g., Bernanke et al. (1999) or Blinder et al. (2008) for an overview. The meaning of anchored expectations is not obvious. In the literature it generally refers to long-run expectations being stable over time, being insensitive to macroeconomic news and/or exhibiting little cross-sectional dispersion; see, e.g., Kumar et al. (2015).[5] Only the aspect of cross-sectional dispersion is considered in this study.

The empirical results from the effects of inflation targeting are ambiguous and tend to differ depending on the samples and the expectations that are being studied.[6] In the majority of cases, measures of expectations are derived using financial market data or surveys of

[5]Kumar et al. (2015) specify five different dimensions of the anchoring of expectations; 1. Ideally anchored (close to the central bank's target), 2. Strongly anchored (low dispersion of expectations across agents), 3. Weakly anchored (little uncertainty in the long-run expectations), 4. Consistently anchored (decreasing revision of forecasts), and 5. Increasingly anchored (long-run and short-run expectations should not demonstrate much co-movement).

[6]Some studies have found significant effects on anchoring, measured as lower disagreement in expectations or smaller reactions to shocks, from the adoption of inflation targeting, while others have found the effect to be limited to developing economies or come from an increase in transparency rather than a quantified target (see, e.g., Gürkaynak et al., 2010, for the former and Capistrán and Ramos-Francia, 2010, for the latter).

professional forecasters or households. Despite the role of firms as price setters in the economy, studies on firms' inflation expectations are substantially scarce. One exception is Kumar et al. (2015). However, the study by Kumar et al. (2015) differs from this study in several ways. Most importantly, it relies on a questionnaire; in contrast, this study uses firms' actual pricing decisions. Because this study also has data from both before and after the implementation of inflation targeting, it is possible to compare the two regimes.

Overall, the majority of studies evaluating the effects of inflation targeting use expectations from surveys rather than the actual behavior of economic agents. One of the few exceptions is Fregert and Jonung (2008), who look at the length of wage contracts under different monetary regimes in Sweden between 1908 and 2008. They conclude that the inflation-targeting regime provides a credible nominal anchor based on wage agreements repeatedly being committed to non-indexed three-year agreements compared to previous periods where agreements had been both shorter and, sometimes, also indexed to inflation. As far as I am aware, no previous study has used measures of firms' expectations based on data on their actual pricing decisions. A primary reason for the lack of studies based on data on actual pricing decisions is probably the rare availability of data on both prices and cost.

The benchmark approach in the previous literature has been to assume that economic agents form homogeneous and rational expectations about the future despite empirical evidence of heterogeneity in expectations.[7] However, for models to shed light on the anchoring role of inflation targeting, price setters must have the possibility of forming heterogeneous expectations about inflation. Following the recognition of substantial dispersion of expectations among agents, some models allowing agents to form diverging expectations have emerged; see, e.g., Scheinkman and Xiong (2003), Morris and Shin (2002) and Branch and McGough (2009). Despite focusing on different questions, these models share the property that public information, through the communication and transparency of central banks, plays a central role in the formation of expectations.

[7]Dispersion of inflation expectations is documented in e.g. Mankiw et al. (2003), Kumar et al. (2015) and Capistrán and Ramos-Francia (2010). In the latter, a decrease in the dispersion of expectations following an introduction of inflation targeting is found using a panel of 25 countries, of which 14 are inflation targeters.

In an empirical analysis, Perez and Drenik (2015) study the effects of the accuracy in the provision of public information about the inflation rate on firms' price setting. Using data from Argentina between 2003 and 2012, they exploit an episode of misreporting of official inflation statistics.[8] They find that price dispersion is higher when available inflation statistics are less precise and inflation volatility is higher. Further, using a general equilibrium model of price setting with information frictions, they find that the provision of more precise information about inflation results in significant welfare gains. Focusing on a similar mechanism, this paper looks at the role of inflation targeting instead of a temporary misreporting of inflation statistics.

When it comes to the second strand of literature, most of the studies that take some kind of heterogeneity into consideration do so by allowing for idiosyncratic productivity or cost shocks. The motivation is to improve the performance of commonly used pricing models, such as Calvo or menu-cost, when it comes to replicating the price-change distribution observed in micro data. As noted in previous studies (see, e.g., Dorich, 2007; Blanco, 2016), it is necessary to introduce idiosyncratic shocks in order to get anywhere near the observed distribution of price changes. However, the parameters describing these productivity shocks are commonly calibrated to match features in the price data rather than any measure of productivity; see, e.g., Golosov and Lucas (2007) and Midrigan (2011). However, looking at Swedish data which has measures of costs available, only introducing idiosyncratic productivity shocks calibrated to match firms' costs is not enough to replicate the price-change distribution observed in data.[9] A similar conclusion is drawn in Nakamura and Steinsson (2010), where an idiosyncratic productivity shock is matched to replicate the size and frequency of price changes in U.S. data. They find that the magnitude of the variance of the shock is considerably larger than the observed variation of firm productivity. The need for sizable idiosyncratic productivity shocks in order to match data on prices is also emphasized

[8] They consider this to be a period during which the accuracy of aggregate information about the inflation rate is lower.

[9] As a firm's production cost depends on the prices of its inputs and its level of productivity, under competitive factor markets, differences in costs of production across firms directly reflect differences in productivity. Hence, in the rest of the paper, when discussing changes in the productivity distribution, this applies equally to changes in the distribution of costs.

in other studies; see, e.g., Klenow and Willis (2016).[10] Although the introduction of idiosyncratic productivity shocks can be a useful shortcut to help models match the distribution of price changes observed in micro data, the correct identification of price dispersion is critical for a welfare analysis. As shown in this paper, an increase in price dispersion caused by more dispersed productivity can enhance welfare while an increase in price dispersion caused by distortions will reduce it. A second reason for distinguishing between different idiosyncratic shocks is the implications for policy. As shown in Dorich (2007), it is not possible to remove price dispersion through monetary policy in New Keynesian models with idiosyncratic productivity shocks as long as some firms are not able to freely adjust their prices following shocks. However, if heterogeneity across firms also reflects distortion in their price setting, as in this set-up with respect to expectations, the role of monetary policy is less limited. Instead, monetary policy could have a significant effect on welfare by affecting inefficient price dispersion.

Finally, this paper is related to a growing literature on welfare costs of misallocation. Recent contributions to this literature include Hopenhayn (2014), Hsieh and Klenow (2009), Bartelsman et al. (2013), and Restuccia and Rogerson (2008). Although not focusing on the effects of inflation targeting, these studies also consider distortions to the allocation of resources among producers, giving rise to dispersion of markups. Thereby, they provide a useful framework for this study when it comes to analyzing welfare.

3 Data and Method

This section starts out by presenting the data used in the empirical analysis. As mentioned in the introduction, the focus is on price changes in order to reduce the risk of capturing unobserved firm heterogeneity that can prevail in the level of prices. Looking at price changes,

[10] Studies with more reasonable values of the variance of the productivity shock often assume that there is a probability of having a zero shock following some distribution (e.g. Gertler and Leahy, 2008; Midrigan, 2011; Karadi and Reiff, 2014). However, this still results in the variance conditional on a shock being of a higher order of magnitude.

and thereby excluding the effect of firms' specific characteristics, is consistent with the model used in this study, where there is no time-invariant firm heterogeneity. The presentation of data is followed by a description of the economic environment that prevailed when the inflation target was adopted and changes in the economic environment during the sample period. We then turn to the empirical analysis, which presents the evolution of the dispersion of price changes and changes in markups observed in the data.

3.1 Description of Data

The empirical analysis is based on micro data on firms' prices and costs between the years 1990-2002. The specific data used is product-level data drawn from the Swedish IVP (Industrins Varuproduktion) that has been merged with information on the firm's production level, inputs and costs from the IS (Industristatistiken) survey. The data is described below, but for a more thorough description, see Carlsson and Nordström Skans (2012) and Carlsson (2017), who rely on exactly the same data. The data covers manufacturing firms; hence the analysis is limited to the manufacturing industry. Interestingly, previous studies have shown that there are considerable price rigidities in the manufacturing industry and they have a large impact on the economy; see, e.g., Goldberg and Hellerstein (2007) and Nakamura and Zerom (2010). As noted in Nakamura and Zerom (2010), almost all of the delay in pass-through of costs into prices in the coffee industry occurs at the manufacturing level, indicating that it is price rigidities at this level that matter the most.

The IVP data contain annual information on prices and quantities of products for all Swedish industrial plants with at least 10 (20) employees for the years 1990-1996 (1997-2002). The IS survey provides annual information on inputs and outputs for all Swedish industrial plants with 10 employees or more and a sample of smaller plants. In the analysis, only plants that are also firms have been considered since pricing decisions are made at the firm level. Also, the analysis is limited to firms that are in operation throughout the full sample period in order to exclude the potentially deviant pricing behavior of entering and exiting firms. In

the analysis, the data has been split into two sub-samples: one covering a period before inflation targeting (1990-1994) and one after (1998-2002). Focusing on the pre- and post-reform periods leaves 10,062 price-change observations across 1,493 unique product codes, 3,179 unique product/firm identities and 680 firms. The observations are fairly well-balanced between the pre- and post-reform period with 5,525 and 4,479 observations, respectively.

The main variables used in the analysis are measures of prices and costs. To compute prices on individual goods, data on sales revenues and quantities sold is used. Specifically, the unit price for each product code is calculated by dividing the firm's yearly reported value for the product code with the accompanying volume. The measure of prices is thus based on actual transaction prices and not list prices. Price changes are defined as changes in log prices, $\Delta P_{i,p,t} = logP_{i,p,t} - logP_{i,p,t-1}$, and hence give the price changes as a percentage.[11] Relying on a Cobb-Douglas production function where the marginal cost is proportional to unit labor costs, the measure used for marginal costs is calculated by dividing the firm's wage bill by its real output, which is obtained by deflating the firm's value of sales by a firm-specific producer price index. Hence, the measure of marginal cost is in line with most New Keynesian models assuming a log-linear production function.[12] The corresponding measure of changes in marginal costs is defined as the change in log unit costs, $\Delta MC_{i,t} = logMC_{i,t} - logMC_{i,t-1}$.

Central to the analysis is a measure of the idiosyncratic price-change dispersion, which is computed by running the following regression with the price change as the dependent variable

$$\Delta P_{i,p,t} = \alpha^P + \gamma^P_{s,t} + \Delta P^{ID}_{i,p,t}, \tag{1}$$

where $\gamma_{s,t}$ is a sector-year fixed effect constructed as time-interacted with two-digit NACE sector-code dummies. The estimated residual, $\Delta \hat{P}^{ID}_{i,p,t}$, captures the firm-specific idiosyncratic component. With the interest in this study being the steady state effects of idiosyncratic shocks, $\Delta \hat{P}^{ID}_{i,p,t}$ is the preferred measure of price changes since potential effects of trend infla-

[11] With $\Delta P_{i,p,t}$ being the price change of product p in firm i at year t.

[12] The marginal cost is there given by $\frac{\partial Cost}{\partial Production} = \frac{\partial Cost}{\partial Labor}\frac{\partial Labor}{\partial Production} = \frac{Wage}{A} = \frac{Labor\quad Cost}{Production}$, where the firm's production function is given by $Production = A \times Labor$, see Section 4.

tion and any sectoral or aggregate time-varying effects have been removed.[13] The standard deviation of $\Delta\hat{P}^{ID}_{i,p,t}$ is used as a measure of price-change dispersion.

To derive a corresponding measure for marginal costs, the same regression as above is used, but with marginal costs as dependent variable

$$\Delta MC_{i,t} = \alpha^{MC} + \gamma^{MC}_{s,t} + \Delta MC^{ID}_{i,t}. \tag{2}$$

Again, the estimated residual, $\Delta\hat{MC}^{ID}_{i,t}$, is the part of marginal-cost change that is of interest in this study, and the standard deviation of the residual is used as a measure of the idiosyncratic dispersion. Thus, what is used in the analysis is the distribution across firms within sectors and years.

A measure of idiosyncratic changes in markups is then given by subtracting changes in marginal costs from changes in prices

$$\Delta\mu_{i,t} = \log\Delta\hat{P}^{ID}_{i,p,t} - \log\Delta\hat{MC}^{ID}_{i,t} \tag{3}$$

with its standard deviation measuring the inefficient price-change dispersion, equivalent to the dispersion of markup changes.

3.2 Description of Time Period Covered

The data cover a period when monetary policy in Sweden went through significant changes. On November 19, 1992, the Swedish central bank (the Riksbank) abandoned a fixed exchange rate relative to the European Currency Unit (ECU) and moved to a floating exchange rate. Following this, in January 15, 1993, the Riksbank published a policy statement announcing that it had shifted to an inflation-targeting system where the inflation target was set at an annual rate of 2 percent. The Riksbank announced that the target would be in place from

[13] This is equivalent to removing the aggregate and within-industry average in each time period from each firm and serves to eliminate any aggregate or sectoral components.

1995 onward. For the empirical analysis, the data has been split into a pre-reform period covering the years before the policy change (1990-1994) and a post-reform period were the inflation target has had some time to settle (1998-2002).[14]

Since there may be a direct mechanical effect on the price-change distribution stemming from a change in inflation due to sticky prices, it is important to consider the aggregate price evolution across the sub-samples. Figure 1 shows the monthly evolution of the producer price index (PPI) for the years 1991-2002. As can be seen, the PPI is not drastically different between the pre- and post-reform period. Inflation had already come down from previously high levels in the 80s before the inflation target was implemented. With the relatively small change in inflation that occurred between the two periods, it is not plausible for the direct effects of the inflation rate to sufficiently explain the change in the distribution of price changes observed in the data. This will also be confirmed in the structural analysis, where the effect of the change in inflation rate turns out to be negligible.

The evolution of costs is also key for price setting. In the 90s, Sweden did not only experience a change in how monetary policy was conducted, but the labor market also underwent institutional changes that affected the wage-setting norms. The earlier period of the sample is characterized by decentralized wage negotiations and conflicts between labor market parties. The wage negotiations in 1995 became particularly turbulent and resulted in substantial increases in the wage level, which together with a depreciation of the Swedish krona resulted in a remarkable temporary increase in PPI followed by a sharp decrease as seen in Figure 1. The end of the sample is instead characterized by substantially calmer wage negotiations and coordinated wage setting. The stabilization of the negotiating environment followed the Agreement on Industrial Development and Wage Formation, signed in 1997 between the Swedish Employers' Confederation and the unions (Elvander (2002)).[15] As will

[14]This means that the specification of the pre-reform period is based on when the inflation target was adopted. Alternatively, it is possible to consider the date of the announcement, i.e. define the pre-reform period as 1990-1993. Using this specification instead does not significantly change the overall result and only has a marginal effect on the empirical estimates toward larger changes in the price-change distribution between the pre- and post-reform period.

[15]More specifically, the agreement was signed by all employers' associations belonging to the Swedish Employers' Confederation and all national unions within the industrial sector.

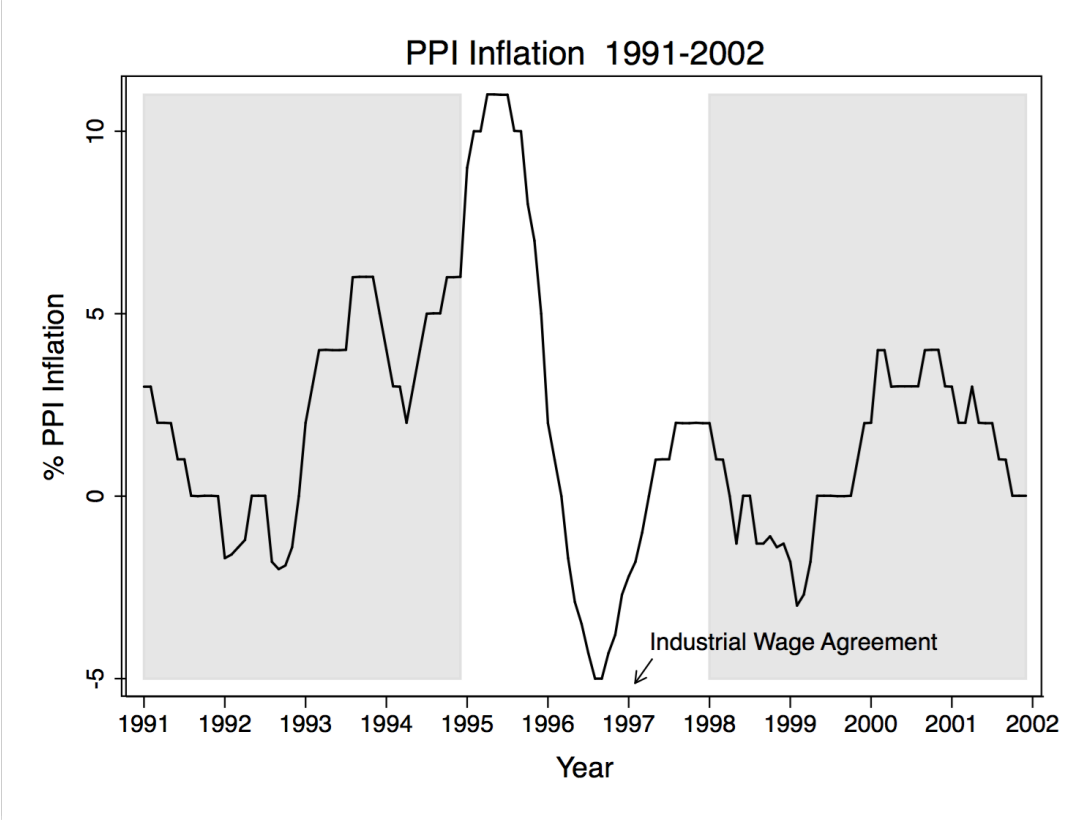


Figure 1: Monthly Producer Price Index (PPI) inflation, 1991-2002. Shaded regions represent the pre- and post-reform period used in the analysis.

be shown in the next section, the dispersion of unit labor cost changes is significantly lower in the post-inflation targeting sample. The change in the wage negotiating environment is a plausible explanation for this. There is of course no way to entirely separate the effect on the price-change distribution originating from the introduction of inflation targeting from a potential effect of the shift in the environment of wage formation. However, only considering the dispersion of price changes across firms within the sector and relevant years controls for the direct effect from the labor market reform. To the extent that there have been any effects at the firm level, this is addressed by looking at the price-change distribution conditional on changes in costs.[16]

[16] Although controlling for the direct concerns of the reforms on the labor market contributing the changes in the behavior of price changes, it is not possible to fully guarantee that changes in the labor market did not have any contribution to the changes the in the price-change dispersion. Because the Agreement on Industrial

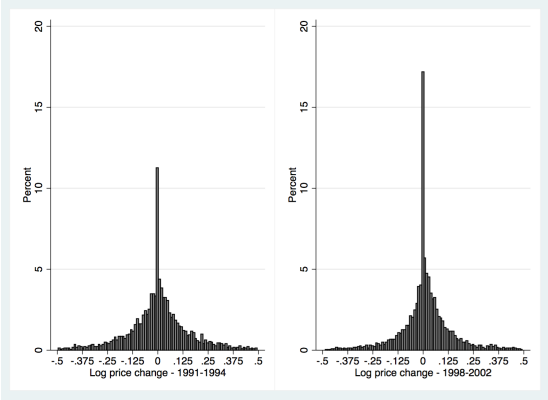
3.3 The Evolution of Price-Change Dispersion

Panel A in Figure 2 displays the distribution of (residualized) log price changes in the pre- and post-reform period. In the figure, observations exceeding a [-0.5, 0.5] log point interval have been excluded, and the bins represent a log difference of 0.01. It is possible to clearly see a compression of the whole distribution with thinner tails in the post-reform period. There is also a noticeable increase in the frequency of zero price changes between years. For the full sample period, 13.6 percent of the price-change observations are confined to a ±0.5 percent interval, indicating that a substantial fraction of price spells remain fixed across years.[17] This further motivates the need to consider prices as being rigid. As noted in Carlsson (2017), this magnitude of zero price changes in a year is in line with previous survey data on Swedish firms, but somewhat lower than estimates from U.S. data by, for example, Nakamura and Steinsson (2008).

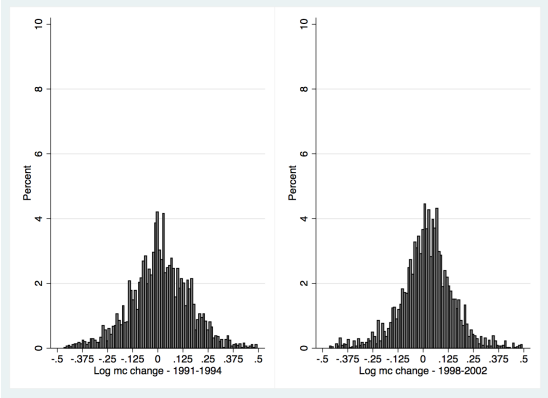
Comparing the two sub-samples, the fraction of price-change observations confined within the ±0.5 percent interval is 10.7 and 16.6 for the pre- and post-reform periods, respectively. Because the inflation rate did decrease somewhat in the post-reform period, the decrease in the frequency of price changes could potentially reflect lower incentives to change prices. The lower incentives are a result of other firms prices changing by less but also a result of smaller changes in marginal costs. However, previous studies on the relationship between inflation and the frequency of price changes have found the frequency to be unrelated or only weakly related to inflation for low levels of inflation; see, e.g., Gagnon (2009) and Alvarez et al. (2011) documenting this using CPI data. The relationship seems to be strong only for levels of inflation exceeding 10 percent, which is significantly higher than the inflation rate in the two sub-samples.

Development and Wage Formation was part of a structural labor market reform following the introduction of inflation targeting, it may have had an effect on the expectation formation process of firms that is hard to distinguish from the effect of the inflation target itself. Given the extent to which the labor market reform is controlled for in this paper, however, the results are interpreted as being driven by the inflation targeting reform.

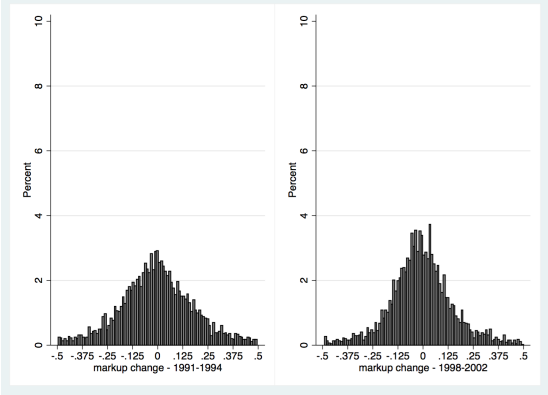
[17] The reason for the focus being on the zero bin rather than price changes of exactly zero is to take into consideration the possibility of rounding errors in the data since prices are given by reported values of revenues and volumes, which are subject to rounding adjustments. The maximum span of this rounding error is small (0.0164 percentage units at the median); see Carlsson (2017).



(a) Distribution of Changes in Log Prices



(b) Distribution of Changes in Log Marginal Costs



(c) Distribution of Changes in Markups

Figure 2: Distributions of changes in log prices, changes in log prices and markups in the period before ($1991 - 1994$) and after the implementation of an inflation target ($1998 - 2002$) focusing on the interval [-0.5, 0.5] log points. The figures show the distribution of raw data, i.e. before conditioning on sector-year fixed effects.

Returning to our main interest, dispersion, the compression of price changes reflects a decrease in the standard deviation of price changes from 0.2 in the pre-reform period to around 0.17 in the post-reform period. Looking at the ratio of the sample's interquartile range, it is substantially higher in the pre-reform period, 0.148 compared to 0.095.

However, as mentioned, what is of importance for welfare is not the distribution of price changes per se, but only the part that cannot be attributed to changes in costs. In panel B of Figure 2, we can see that the distribution of marginal-cost changes also seems to be more compressed in the post-reform period. Hence, the compression of the price-change distribution could potentially be a reflection of a compression in the distribution of marginal-cost changes. To see if this is the case, panel C of Figure 2 therefore shows the price-change distribution controlling for marginal-cost changes; that is, changes in inefficient price dispersion or equivalently changes in markups. As can be seen, the distribution of markup changes is also less dispersed in the post-reform period, supporting the hypothesis that a more compressed price-change distribution reflects more than just a change in relative cost. If the change in the price-change distribution would be a result of a lower spread in efficient price changes, motivated by the lower dispersion in marginal-cost changes,we would not expect to see any observable change in the distribution of markup changes.

The differences in the pre- and post-reform distributions discussed above are also confirmed by statistical tests, with the results shown in Table 1. The first column shows the result of testing the hypothesis of the standard deviations being equal between the pre- and post-reform sample. As can be seen, this can be rejected both in the case of price changes (first row), marginal-cost changes (second row) and price changes controlled for changes in marginal cost (last row). When looking at the price-change distribution conditioning on marginal-cost changes, the difference in standard deviation between the two sub-periods remains essentially the same as in the unconditional test with only a slight change in the ratio of standard deviations from 1.195 to 1.194. In the second column, we can see that this also holds if we look at the sum of the percentiles being equal between the two samples.[18] The same result

[18]Looking at tests of the percentiles is only appropriate for normalized distributions where corresponding percentiles of the two samples are of same sign, which is fulfilled in our case.

holds when separately looking at the the 10th, 25th, 75th and 90th percentiles. Standard errors, shown in parenthesis, are bootstrapped (re-sampled clustered on firms).

Table 1: Distribution Tests

	Relative Standard Dev.	**Sum of Percentiles Ratio**
	Unconditional Test	
$d\ln P^{ID}$	1.195	1.430
	(0.051)**	(0.276)**
$d\ln MC^{ID}$	1.077	0.553
	(0.035)**	(0.192)**
	Conditional Test	
$d\ln P^{ID}$	1.194	1.189
	(0.052)**	(0.244)**

Notes: The first two rows of the first column test the null hypothesis that the standard deviations of the residual change of prices and marginal costs, respectively, are equal (with the residual being defined as in Section 3.1). The null hypothesis in the first column is defined in terms of the ratios of the standard deviation, i.e. $H_0: \quad \frac{std(\Delta P)^{pre}}{std(\Delta P)^{post}} = 1$. The last row in the first column shows the result of the same test but on price changes controlled for marginal-cost changes. This test is performed on the residual price-change distribution when linearly removing the effect of marginal-cost changes on price changes. The second column shows the result of testing if the ratios of the percentiles are equal, i.e. $H_0: \quad \frac{P(10)^{pre}}{P(10)^{post}} + \frac{P(25)^{pre}}{P(25)^{post}} + \frac{P(75)^{pre}}{P(75)^{post}} + \frac{P(90)^{pre}}{P(90)^{post}} - 4 = 0$. Bootstrap standard errors clustered on firms are inside the parentheses. Superscripts ** and * denote significance at the 1 and 5 percent level, respectively.

Hence, it has been established that changes in prices and markups are less dispersed in the post-reform period. Thus, firms' price-setting seems to be affected by an idiosyncratic factor that has changed between the two sub-periods other than changes in costs. Following theory, it is natural to consider a change in expectations as a potential explanation for the empirical observations. Unfortunately, due to a lack of micro data on firms' expectations during the period, it is not possible to directly test this hypothesis empirically. Instead, in the following section, we rely on a structural model of firms' price setting. An idiosyncratic component is then introduced to capture a potential change in the distribution of expectations about the evolution of the aggregate price level across firms.

4 Economic Environment

The model outlined in this section has two purposes. First, it allows for a structural analysis of the change in the price-change distribution disentangling different contributing factors. More specifically, it allows for an analysis of the change in the price-change distribution that is due to changes in 1) marginal costs, 2) inflation, 3) nominal rigidities and 4) firms' beliefs about the aggregate price level. In so doing, it also allows for an indirect inference about the change in distribution of firms' expectations about the aggregate price level.[19] The second purpose is to provide a framework to analyze the welfare implications of the change in the price-change distribution in a general equilibrium setting. For the first purpose, a partial equilibrium model is sufficient since it is only the distribution across firms that is of interest and aggregate components are only relevant to the extent that they affect the idiosyncratic outcomes. However, to analyze welfare, a general-equilibrium framework is necessary. Since the focus here is to study idiosyncratic distributions, aggregate shocks are abstracted from and the focus is on a steady-state comparison.

The structure of the model closely follows some of the well-established models in the New Keynesian literature; in particular, see Nakamura and Steinsson (2010).[20] The main difference between the standard New Keynesian model and the model presented here is the introduction of heterogeneity in the form of idiosyncratic productivity shocks and idiosyncratic perceptions about the evolution of the aggregate price level. More specifically, firms are facing idiosyncratic productivity shocks, which allows the model able to match the distribution in marginal-cost changes observed in the data. In order to match the price-change distribution in data, firms are also facing idiosyncratic disturbances to their perception about the progression of the aggregate price level.

The model is in discrete time with each period, representing a month, divided into two

[19]The possibility of making this indirect inference hinges on the availability of micro data on both prices and costs.

[20]That is, price rigidities are in the form of random menu costs. For a set of different methods to model price rigidities, see Taylor (1980), Calvo (1983), Reis (2006), Golosov and Lucas (2007), or modified versions of these such as multi-product models à la Midrigan (2011) and Alvarez et al. (2014)

sub-periods. In the first sub-period, the firm-specific shocks (to productivity and beliefs) are realized. Firms then set their prices based on these shocks and perceptions about the price level.[21] In the second sub-period, goods are traded in the market and the aggregate consumption and price level are realized based on the prices set in the previous sub-period. Hence, when firms set their prices, they do not observe the actual aggregate price level, but rather base their decision on what they expect it to be, as will be described further below.

4.1 Households

The role of households in the model is to provide a framework for demand for the firms' products and supply of labor and allow for a welfare analysis in a general equilibrium. Following the standard New Keynesian model, there is a continuum of identical households with utility depending on aggregate consumption, C_t, and supply of labor, L_t. The representative household's discounted expected utility is given by

$$E_t \sum_{k=0}^{\infty} \beta^k \Big[\log C_{t+k} - \omega L_{t+k} \Big], \tag{4}$$

where β is the discount factor and E_t is the expectation operator conditional on information available to the household in period t.

Aggregate consumption, C_t, is composed of a bundle of individual products according to

$$C_t = \left[\int_0^1 C_t(i)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}}, \tag{5}$$

with θ being the elasticity of substitution between individual products, $C_t(i)$. In each period,

[21] The decision is also based on agents' perception about aggregate consumption, but as described below all firms share the same belief about aggregate consumption, which therefore does not affect the distribution of the prices set by the firms.

the household chooses the composition of goods that maximizes the aggregate consumption index, C_t, implying that the demand for individual products is given by

$$C_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\theta} C_t, \tag{6}$$

where $P_t(i)$ is the price of the good produced by firm i and P_t denotes the consumption-based aggregate price index given by

$$P_t = \left[\int_0^1 P_t(i)^{1-\theta}\right]^{\frac{1}{1-\theta}}. \tag{7}$$

The household maximizes its discounted expected utility subject to its budget constraint given by

$$P_t C_t + Q_t B_t \leq W_t L_t + D_t + Q_t B_{t-1}, \tag{8}$$

where W_t is the wage and Q_t, D_t and B_t are the price, dividend and quantity of assets, respectively. When maximizing its discounted expected utility under the constraint above, the price and wage levels are taken as given. When solving for optimal consumption, C_t, and labor supply, L_t, the resulting choice of labor-consumption combination, is given by

$$\frac{W_t}{P_t} = \frac{-U_L}{U_C} = \omega C_t. \tag{9}$$

Hence, the preferences imply that the nominal wage is proportional to nominal spending.

4.2 Firms

There is a continuum of firms of mass one producing a single individual product using labor as the only input. The production technology is given by:

$$Y_t(i) = A_t(i)L_t(i), \tag{10}$$

where $A_t(i)$ is the productivity at firm i. All firms face the same wage rate determined on a competitive labor market implying that their marginal cost is given by $MC_t(i) = \frac{W_t}{A_t(i)}$. Hence, the firms' marginal cost depends on the economy-wide wage rate and the firm-specific productivity. The firms' productivity follows an AR(1) process that evolves over time according to

$$\log A_t(i) = \rho_a \log A_{t-1}(i) + \epsilon_t(i). \tag{11}$$

As in Carlsson (2017), the shock $\epsilon_t(i)$ is assumed to follow a Laplace distribution with mean zero and variance $\frac{\sigma_a}{\sqrt{2}}$. A Laplace distribution of the shock is used in order to match the observed marginal costs in the data with fatter tails than the normal distribution.

Firms are assumed to always meet demand, $C_t(i) = Y_t(i)$, which is determined on a monopolistic market where the firms are price setters. Hence, a firm's production is determined by the demand for its products, as given by (6), and thus a function of its relative price and the aggregate consumption level. Moreover, the firms face rigidities in the price setting as a result of random menu costs. Specifically, the Calvo-Plus set-up à la Nakamura and Steinsson (2010) is used. In contrast to the standard menu-cost model, the cost of changing the price, here given by $\kappa_t(i)$, is time-dependent and high with probability α and low otherwise.[22] Allowing for different costs of changing the price generalizes the standard menu-cost model (where we have a constant single menu cost) and allows the model to generate small price changes aligned with what is observed in data. An appealing feature of the model is also that it nests the Calvo and menu-cost model as special cases. In the extreme case of $\kappa_{low} = 0$

[22] Following Nakamura and Steinsson (2010), κ can be interpreted as the additional labor needed to change the price and that cannot be used in production of the good.

and κ_{high} being very large, the model becomes the standard Calvo model, and in the case $\kappa_{low} = \kappa_{high}$ it becomes the standard menu cost model (Nakamura and Steinsson, 2010).

In each period, the firm maximizes the value of the expected discounted stream of profits discounted at the same rate as households, β, by choosing to adjust its price to its optimal level or leaving its price unchanged. If it decides to adjust, it pays the implementation cost, $\kappa_t(i)W_t$. If it does not adjust, its nominal price remains fixed and its relative price, $p_t(i) = P_t(i)/P_t$, is adjusted by the rate of inflation. When making its pricing decision, the firm needs to consider how its price will affect the demand for its good which in turn depends on how the price compares to the price of other goods. A relatively high price means a high real return per sold item but also lower demand as consumers will substitute the good with relatively cheaper substitutes. What matters for the firm's decision is therefore how its price compares to other firms' prices, represented by the aggregate price level.

As the aggregate price level is determined by the prices set by the individual firms, determining the aggregate price level requires that we keep track of the distribution of firms over their idiosyncratic prices and productivity levels. To simplify the computation, we assume that a monetary authority, represented by a central bank, in the absence of aggregate shocks is able to perfectly control the aggregate price level and make it follow a deterministic path given by

$$\log P_t = \mu_\pi + \log P_{t-1}. \tag{12}$$

To reduce the computational burden, aggregate dynamics are abstracted away, and focus is on the idiosyncratic distribution of firms' relative prices in equilibrium.

To allow for heterogeneity in beliefs, firms are assumed to not fully believe in the central bank's intention and/or ability to achieve the (deterministic) evolution of the price level given by (12). Instead, they believe that there is an underlying risk that equation (12) will not fulfilled. The perceived deviation from the deterministic path is assumed to be heterogeneous across firms and independent across time. It results in firms, instead of correctly anticipating the growth of the price level between period $t-1$ and t to be μ_π, expecting the price level

to grow by $\mu_\pi + \eta_t(i)$, where $\eta_t(i) \sim N(0, \sigma_\eta^2)$ reflects firm-specific beliefs.[23]

In this set-up, a higher confidence in the central bank's intention/ability to achieve the price path given by (12) is captured by a decrease in the variance of $\eta_t(i)$ across firms. There are several ways in which the implementation of an inflation target can play a role here. First, by officially declaring the central bank's intention for the inflation rate, the inflation target could help anchor expectations. Second, the introduction of an inflation target in Sweden was accompanied by an increase in the transparency and information about the inflation rate, potentially making the monetary policy more credible. And last, the ability of the central bank to actually achieve the target could be argued to be improved by the increase in its credibility and the better-anchored expectations. In the extreme case, when agents fully believe in the central bank, agents' expectations about the aggregate price level are identical and show no dispersion. In sum, the implementation of an inflation target could increase the confidence in the central bank to achieve the price path given by (12), resulting in a lower dispersion of expectations across firms.

The source of the heterogeneity is not explicitly modeled. A potential way to model expectations endogenously is to introduce an imperfect information framework, with the the main avenues being noisy signaling models (e.g. Woodford, 2003), sticky information (e.g. Mankiw and Reis, 2002) and rational inattention (e.g. Mackowiak and Wiederholt, 2009). A key problem with many of these models is that they often imply a compression in the dispersion of private information to dispersion of actions. In order to match the observed distribution of inflation expectations in this study, the variance in the idiosyncratic belief shock would need to be unreasonably large compared to the actual variability of inflation. Hence, in this

[23]The seemingly irrational behavior of expecting a deviation of a deterministic price path in equilibrium can be justified by thinking of it as a "peso-problem". A "peso-problem" refers to a situation where agents have rational expectations about a significant discrete shift in an economic variable of interest possibly taking place in the future. In the "peso problem" case, this event occurs with a low probability, and in a finite sample it might not occur at all, which makes expectations appear irrational. The concept is usually referenced to the Mexican peso market during the 1970's and was originally discussed in Rogoff (1980). For a thorough description, see Evans (1996). The motivation for such an approach can be found in studies showing that inflation expectations tend to consistently deviate from realized inflation rates; see, e.g., Andolfatto et al. (2008).

paper, $\eta_t(i)$ enters the model exogenously as an idiosyncratic belief shock.[24]

As the firms make their pricing decision in the first sub-period, before the current aggregate price level is revealed, they have to set their price based on the perceived price level. Following the structure above, when firms set their price, they perceive the log aggregate price to be $\log P_t + \eta_t(i)$ instead of just $\log P_t$, making firms over- or underestimate the true aggregate price level. In the second sub-period of each period, their mistake is revealed so that they have correct information about the last period's price level, $\log P_{t-1}$, to form their new estimation of $\log P_t$. Hence, firms expect inflation between $t-1$ and t to be $\mathrm{E}[\pi_t] = \mu_\pi + \eta_t(i)$ and future inflation to be $\mathrm{E}[\pi_{t+k}] = \mathrm{E}[\mu_\pi + \eta_{t+k}(i)] = \mu_\pi, \quad \forall k > 0$. This results in a level effect so that the expected path for the aggregate price level is common among firms from $t+1$ and onward and given by the deterministic drift term for inflation, μ_π. However, as the level of the aggregate price today differs between firms because of the $\eta_t(i)$ term, there is a firm-specific (perceived) level of the aggregate price path. As the aggregate price is revealed in each period, all firms share the same knowledge when forming their expectations. Hence, there is no role for more complicated formation of expectations, which include higher order beliefs, that result from average expectations differing from the expectations about other agents' expectations, such as in Nimark (2017). With the last period's inflation being revealed in each period and agents becoming fully aware of their mistake, it is natural to model the $\eta_t(i)$ process without any persistence.

A firm makes its decision to adjust its price or not by comparing its expected discounted stream of profits when keeping the current relative price, which is perceived to be $E_t(i)[\frac{P_{t-1}(i)}{P_t}]$, and changing to the new perceived optimal price $E_t(i)[\frac{P_t^*(i)}{P_t}]$, where $E_t(i)[\log P_t] = \mu_\pi + \log P_{t-1} + \eta_t(i)$. For a given adjustment cost, the further the non-adjusted price is from the perceived optimal price, the more likely it is to reset it. As we are only interested in the steady state, where real wages are determined by productivity rather than inflation, firms are assumed to believe the nominal wage will grow at the rate of perceived inflation. Hence, with constant aggregate productivity, firms expect nominal wages to grow by $E_t(i)[\log W_t] =$

[24] Modelling the formation of $\eta_t(i)$ explicitly would of course be an interesting exercise, but for the purpose of this study it is enough to look at the variance of the idiosyncratic belief shock.

$\mu_\pi + \log W_{t-1} + \eta_t(i)$. This implies that all firms share the same beliefs about the real wage and aggregate consumption level.

Denoting the value function when the firm keeps the previous period's price V^K and the value function when changing the price V^C, the firm's problem can be written recursively as:

$$V = \max\{V^K, V^C\}, \tag{13}$$

where

$$V^K\Big(P_{t-1}(i), P_{t-1}, W_{t-1}, \eta_t(i), A_t(i), \kappa_t(i)\Big) = \Pi_t^K(i) + \beta E_t\Big[V\Big(P_{t-1}(i), P_t, W_t, \eta_{t+1}(i), A_{t+1}(i), \kappa_{t+1}(i)\Big)\Big] \tag{14}$$

$$V^C\Big(P_{t-1}, W_{t-1}, \eta_t(i), A_t(i), \kappa_t(i)\Big) = \max_{p_t(i)}\Big\{\Pi_t^C(i) + \beta E_t\Big[V\Big(P_t(i), P_t, W_t, \eta_{t+1}(i), A_{t+1}(i), \kappa_{t+1}(i)\Big)\Big]\Big\}, \tag{15}$$

where $\Pi_t^K(i)$ is the firm's profit if keeping its price, given by

$$\Pi_t^K(i) = E_t(i)\Big[Y_t^K(i)\Big(\frac{P_{t-1}(i)}{P_t} - mc_t(i)\Big)\Big], \tag{16}$$

and $\Pi_t^C(i)$ is the firm's profit if changing its price, given by

$$\Pi_t^C(i) = E_t(i)\Big[Y_t^C(i)\Big(\frac{P_t(i)}{P_t} - mc_t(i)\Big) - \kappa\frac{W_t}{P_t}I_t(i)\Big], \tag{17}$$

where $Y_t^K(i) = Y_t\big(\frac{P_{t-1}(i)}{P_t}\big)^{-\theta}$ is the firm's demand if keeping its price unchanged, $Y_t^C(i) = Y_t\big(\frac{P_t(i)}{P_t}\big)^{-\theta}$ is the firm's demand if it changes its price, $mc_t(i) = \frac{W_t}{P_t A_t(i)}$ is the real marginal cost, and $I_t(i)$ is an indicator variable that equals one if the firm changes its price in period t and zero otherwise, and $\kappa_t(i)\frac{W_t}{P_t}$ is the real menu cost where $\kappa_t(i)$ is given by

$$\kappa_t(i) = \begin{cases} \kappa^{high} & \text{with prob.} \quad \alpha \\ \kappa^{low} & \text{with prob.} \quad 1-\alpha. \end{cases} \tag{18}$$

Hence, a firm decides on its nominal price, $P_t(i)$, to maximize its value function (13) given its current perceived relative price, $E_t(i)[\frac{P_{t-1}(i)}{P_t}]$, real marginal cost, $mc_t(i) = \frac{W_t}{P_t A_t(i)}$, adjustment

cost, $\kappa_t(i)$, and expected future values of the same.[25] As the perceived price and wage levels are given by $E_t(i)[\log P_t] = \mu_\pi + \log P_{t-1} + \eta_t(i)$ and $E_t(i)[\log W_t] = \mu_\pi + \log W_{t-1} + \eta_t(i)$, respectively, the firms' perception of price and wage inflation coincide.

4.3 Welfare

In the New Keynesian model, there are in general two sources of welfare costs; see, e.g., Galí (2008). One comes from the fact that the market is characterized by monopolistic competition with firms setting their prices with a markup over marginal costs. This markup gives rise to a distortion on the goods and labor market with an inefficiently low level of output and employment. This distortion is present even in a case where firms can flexibly change their prices and have perfect knowledge about current and future states of the world. The second source of welfare cost is caused by unwarranted differences in relative prices across firms, here resulting from distortions in the firms' price setting. Considering the model described in the previous section, there are three potential sources of price dispersion. The first two sources of price dispersion give rise not only to dispersion of prices but also to dispersion of markups. These are caused by 1) firms being unable to flexibly change their prices and 2) belief shocks distorting the prices being reset. As dispersion of markups gives rise to misallocation, which has negative effects on welfare. The third source of price dispersion is idiosyncratic productivity shocks that despite causing dispersion of prices do not have a direct effect on the dispersion of markups and do not affect welfare negatively.

As described, inefficient dispersion of prices and the resulting markup dispersion leads to welfare losses through allocative distortions, with households consuming and firms producing an inefficient composition of the consumption basket. The aggregate welfare effect can, however, be decomposed into two effects. Besides the negative effect on welfare from allocative distortions, an increase in markup dispersion also has a potentially positive effect on welfare. To

[25] The profit function is expressed in terms of expectations operator, E, as the profit depends on the unknown realizations of aggregate consumption, the wage level and the aggregate price level that is not yet revealed when the firm makes its decision.

see this, one needs to consider the fact that a higher dispersion of markups allows consumers to shift consumption towards products with lower markups. As a consequence, the aggregate markup in the economy goes down, reducing the distorting effect that markups have on the labor market.[26] Hence, there are two effects at play here. An increase in markup dispersion leads first to a less efficient allocation of labor across firms. Second, it leads to a decrease in the aggregate markup, and thereby to an increase in the total number of labor hours. To gain an understanding of the different effects that markup dispersion has on welfare, two cases are considered here. First, we compare the social planner's solution for the relative allocation of labor and the market outcome by only focusing on misallocation. Second, we compare the social planner's solution and the market solution when also considering the effect on the aggregate markup.

4.3.1 Misallocation

Social Planner

A social planner would like to allocate resources so that the value of marginal products of each type of good produced is equalized across firms. Considering a simple case where all firms have the same productivity, the optimal allocation is to allocate labor equally across all firms. At the other extreme, when we allow firms to have different productivities but assume that all firms produce products that are perfect substitutes, allocating all labor to the most productive firm would maximize welfare. In all cases in-between these two extremes, the social planner's problem is more complex. On one hand, the social planner wants a large variety of products to be produced in order to achieve a large aggregate consumption basket. On the other hand, the planner wants to allocate labor to more productive firms to achieve a high level of output. To solve the social planner's problem, we set up an optimization problem over the allocation of labor, where the social planner aims to maximize the utility of the representative agent. That is, the social planner wants to maximize the utility of the

[26]The aggregate markup here refers to the cost-weighted average of firm-level markups.

representative agent given by equation (4) subject to the $C_t = \left[\int_0^1 \left(A_t(i)L_t(i)\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}}$ and the resource constraint $\int_0^1 L_t(i)di = L$. The solution to the maximization problem can be described by the ratio of the first order conditions with respect to any two units of labor

$$\frac{A_t(i)^{\frac{\theta-1}{\theta}} L_t(i)^{\frac{\theta-1}{\theta}-1}}{A_t(j)^{\frac{\theta-1}{\theta}} L_t(j)^{\frac{\theta-1}{\theta}-1}} = \frac{A_t(i)^{\frac{\theta-1}{\theta}} L_t(i)^{\frac{-1}{\theta}}}{A_t(j)^{\frac{\theta-1}{\theta}} L_t(j)^{\frac{-1}{\theta}}} = 1 \leftrightarrow \frac{A_t(i)^{\frac{\theta-1}{\theta}}}{A_t(j)^{\frac{\theta-1}{\theta}}} = \frac{L_t(i)^{\frac{1}{\theta}}}{L_t(j)^{\frac{1}{\theta}}}, \tag{19}$$

with the left-hand side representing the ratio of marginal values (in terms of welfare) of employing one more unit of labor in firm i to firm j. As an optimality condition, this should evidently be equalized across firms. This implies that the relative labor use is given by

$$\frac{L_t(i)}{L_t(j)} = \left(\frac{A_t(i)}{A_t(j)}\right)^{(\theta-1)}. \tag{20}$$

Market Solution

To derive the corresponding relative allocation given by the market, we use the demand function for individual goods, $C_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\theta} C_t$, giving the relative demand for products

$$\frac{C_t(i)}{C_t(j)} = \left(\frac{P_t(i)}{P_t(j)}\right)^{-\theta}. \tag{21}$$

Using that market clearing implies $C_t(i) = Y_t(i)$, and combining this with the firm's production function, $Y_t(i) = A_t(i)L_t(i)$, and the price set as a firm-specific markup over marginal costs[27], $P_t(i) = \mu_t(i)\frac{W_t}{A_t(i)}$, we can express relative consumption of two different goods as

$$\frac{P_t(i)}{P_t(j)} = \left(\frac{\mu_t(i)/A_t(i)}{\mu_t(j)/A_t(j)}\right) = \left(\frac{Y_t(j)}{Y_t(i)}\right)^{1/\theta} = \left(\frac{L_t(j)A_t(j)}{L_t(i)A_t(i)}\right)^{1/\theta}. \tag{22}$$

[27]This result follows from the firms maximizing profits under monopolistic competition.

Rearranging, we arrive at an expression that is easily compared to the social planner solution given in (20)

$$\frac{L_t(i)}{L_t(j)} = \left[\frac{\mu_t(i)}{\mu_t(j)}\left(\frac{A_t(i)}{A_t(j)}\right)^{\frac{(1-\theta)}{\theta}}\right]^{-\theta} = \left(\frac{\mu_t(j)}{\mu_t(i)}\right)^{\theta}\left(\frac{A_t(i)}{A_t(j)}\right)^{(\theta-1)}. \tag{23}$$

For the solutions above to coincide with the social planner solution in (20), we must have $\frac{\mu_t(i)}{\mu_t(j)} = 1$, which only happens if the firms charge the same markups (i.e. $\mu_t(i) = \mu_t(j)\ \forall(i,j)$). Hence, by comparing the outcomes we can see that the optimal social solution requires markups to be identical across firms. Following this reasoning, markup dispersion inevitably results in welfare losses. As can be seen in (23), there will be too much labor employed in firms with relatively low markups and too little labor in firms with high markups. This welfare effect of markup dispersion, comparing the allocation of labor across firms, is exclusively due to distributional factors and only gives the complete picture if assuming a constant level of employment. If allowing the aggregate employment to respond to changes in markups, the level of the aggregate markup is also of importance, with potentially discouraging effects on employment as described in the next section.[28]

4.3.2 Aggregate Consumption

To better understand the complete effect of the dispersion of markups, we have to look at its effect on aggregate consumption. This can be analyzed by again comparing the distorted market solution to an undistorted case illustrated by what a social planner would do.[29]

[28]The level of the aggregate markup does not cause any distortions in the allocation of inputs across firms, but affects welfare by reducing employment unless the distortion of the aggregate markup is perfectly offset by a subsidy to employment.

[29]The term undistorted refers to the case where the social planner chooses the outcome and is not affected by nominal rigidities or heterogeneous beliefs.

Social Planner

In an undistorted case, profit maximization by firms implies that the optimal relative price for each firm i is given by $p_t(i)^* = \frac{\theta}{\theta-1}\frac{W_t}{P_t A_t(i)}$, i.e. the optimal price is set with a markup, $\frac{\theta}{\theta-1}$, over marginal cost. From the Dixit-Stiglitz aggregator, the aggregate price index expressed in terms of relative prices is given by $1 = \left[\int_0^1 p_t(i)^{1-\theta}\right]^{\frac{1}{1-\theta}}$. Combining these we get

$$1 = \frac{\theta}{\theta-1}\frac{W_t}{P_t}\left(\int_0^1 (\frac{1}{A_t(i)})^{1-\theta} di\right)^{1/(1-\theta)} \tag{24}$$

and hence that aggregate consumption, C_t, is given by

$$C_t = \frac{W_t}{P_t} = \frac{\theta-1}{\theta}\left(\int_0^1 \big(A_t(i)\big)^{\theta-1} di\right)^{1/(\theta-1)}, \tag{25}$$

where $\frac{\theta-1}{\theta}$ captures the aggregate markup and $\left(\int_0^1 \big(A_t(i)\big)^{\theta-1} di\right)^{1/(\theta-1)}$ can be interpreted as aggregate productivity, A_t.[30] Worth noting here is that this implies that a higher dispersion of productivity across firms results in a higher level of aggregate productivity, which we will return to when looking at the results. As aggregate consumption equals production, i.e. $C_t = Y_t = A_t L_t$, we have from (25) that aggregate labor is given by the inverse of the aggregate markup, $\frac{\theta-1}{\theta}$.

Market Solution

The aggregate consumption in the economy would be given by (25) if the marginal value of products were equalized across plants. However, since prices are not flexible and the belief shocks disturb the price setting, the optimal price will not be achieved in general, i.e. $p_t(i) \neq p_t(i)^* = \frac{\theta}{\theta-1}\frac{W_t}{P_t A_t(i)}$. Defining the firm's distortion to its markup $\hat{\mu}_t(i)$, a firm the

[30] Note that it is different from average productivity since production is weighted by the share of contribution to the aggregate consumption bundle.

re-optimize its price sets the price as $p_t(i) = \hat{\mu}_t(i)p_t(i)^* = \hat{\mu}_t(i)\frac{\theta}{\theta-1}\frac{W_t}{P_t A_t(i)}$.[31] This gives us the new aggregate price index expressed in terms of relative prices

$$1 = \frac{\theta}{\theta-1}\frac{W_t}{P_t}\left(\int_0^1 \left(\frac{\hat{\mu}_t(i)}{A_t(i)}\right)^{1-\theta} di\right)^{1/(1-\theta)} \rightarrow \frac{W_t}{P_t} = \frac{\theta-1}{\theta}\left(\int_0^1 \left(\frac{A_t(i)}{\hat{\mu}_t(i)}\right)^{\theta-1} di\right)^{1/(\theta-1)}, \quad (26)$$

and hence that aggregate consumption is

$$C_t = \frac{W_t}{P_t} = \frac{\theta-1}{\theta}\left(\int_0^1 \left(\frac{A_t(i)}{\hat{\mu}_t(i)}\right)^{\theta-1} di\right)^{1/(\theta-1)}. \quad (27)$$

This expression can be compared to the social planner solution given in equation (25). Compared to the expression in equation (25), the market solution, equation (27), depends on the distribution of firm productivity as well as the distribution of markups. For any given level of the aggregate markup, aggregate consumption decreases with markup dispersion. However, in general, the aggregate markup will not be constant but depends on both the average firm level markup and the dispersion of markups across firms. If we increase the average firm level markup, but hold the distribution of markups constant, the aggregate markup will be higher and aggregate consumption lower. The lower consumption level is the result the increase in the markup lowering the level of employment, in the model given by the inverse of the aggregate markup. If we instead hold the average markup across firms constant but increase the dispersion of markups, production will shift toward firms with relatively lower markups, resulting in a lower aggregate markup and hence higher employment. However, a higher markup dispersion also results in misallocation, as described above, with negative effects on aggregate consumption through the reduction of the allocative efficiency of production.

To sum up, welfare in the economy can be described as a function of the distribution of productivities and markups across firms. While a more dispersed productivity distribution has welfare-enhancing effects as agents shift consumption toward more productive producers, a dispersion of markups has an overall negative effect on welfare.

[31] For firms that are not changing their price in the current period $\hat{\mu}_t(i)$ also captures the distortion from price rigidities.

4.3.3 Welfare Comparison

To compare welfare in the pre- and post-reform period, a consumption equivalent welfare measure is used. Specifically, the welfare change is measured by solving

$$E\big[\log((1+\Delta)C^{pre}) - \omega L^{pre}\big] = E\big[\log(C^{post}) - \omega L^{post}\big], \tag{28}$$

for Δ. This gives a measure of the percentage change in consumption that the households in the pre-reform period would need to achieve the same level of utility as the one induced by the reform.

4.4 Solving the Model

The model is solved using an iterative fixed point procedure. In a first step, the firms' optimization problem is solved by value function iteration on grids for the state variables using an initial guess for aggregate consumption.[32] The transition probability matrices for the stochastic variables have been approximated using the method of Tauchen (1986). Given the resulting policy functions, a distribution of relative prices and productivities is simulated. Using the initial guess for aggregate consumption together with the resulting distributions of prices and productivities, a new estimate of aggregate consumption is computed. If the new estimate is not consistent with the initial guess, we return to step one but now use the new estimate as the initial guess. The same iterative fixed point procedure is carried out until the initial guess of the aggregate consumption and the resulting estimate are close enough.

[32]The initial guess for aggregate consumption is based on solving for the real wage analytically in a symmetric steady state with average productivity normalized to unity resulting in $\frac{W}{P} = \frac{\theta}{\theta-1}$ and using that $\frac{W}{P} = \omega C$.

5 Calibration

Before solving the model, we need to pin down the parameter values of the model. This is done by calibrating the parameters, which are divided into two groups: 1) parameters obtained directly from data or the literature (β,θ,μ_π, ω and κ), and 2) parameters calibrated to match moments simulated from the model with moments from the data (ρ_a, σ_a, α and σ_η). Because a period in the model represents a month while the data are on annual frequency, the simulated data are aggregated to annual frequency in order to be matched to the real data. The aggregation is based on Carlsson (2017) using monthly output weights; for details, see Appendix A.

For the first category of variables, we have the drift parameter of inflation, μ_π, set to 0.0014 and 0.0007 for the pre- and post-reform period, respectively, in order to be in line with estimates of the average monthly Swedish industrial producer price data.[33] Consistent with Carlsson (2017) and Carlsson et al. (2014), the elasticity of substitution, θ, is set to 3 in line with Swedish manufacturing sector firm-level estimates. The discount factor is set to match a real interest rate of about 4 percent, $\beta = 0.96^{1/12}$, and we set $\omega = 1$ following Nakamura and Steinsson (2010). Based on the results in Carlsson (2017), the menu costs are set to reflect a pure Calvo model. In other words, the value of κ^{low} is set to zero and κ^{high} is set to a very large number (9999).[34]

For the second category of parameters, the values are pinned down by requiring that the model matches selected features of the data in the two sub-periods. The model-based moments are based on simulations of 31,800 firms (10 times the number in data) over five years (to allow for a burn-in, these are picked from the last 60 periods of a simulation period of

[33] This implies a yearly average inflation rate of 1.7 and 0.8 percent, respectively.

[34] Originally the model was estimated for calibrated values of κ. However, when matching to moments in the data, given by different moments of the price-change distribution, it resulted in, essentially, a Calvo model with κ^{low} close to zero and κ^{high} being very high. As an exercise the model has also been solved for using values of κ taken from Carlsson (2017) with $\kappa^{high} = 4.7330$ and $\kappa^{low} = 0.0015$. Carlsson (2017) uses the same data as in this study but his model differs from the one here as it does not include belief shocks. However, the parameter values taken from Carlsson (2017) are used as a lower bound on the "degree of Calvo" in the model and the overall result and welfare implications are not affected by using these values instead.

2,060 months). Hence, the simulated sample has the same length as each sub-period in the data. The calibrated parameters are found by using the MATLAB built-in genetic algorithm and fminsearch to minimize the distance between the moments of the model and the chosen moments in the data.[35] The moments are chosen so they are informative about the parameters to be calibrated. Specifically, the estimated auto-correlation and variance of the marginal-cost process in the data should be informative about the parameters governing the same process in the model, i.e. about the auto-correlation parameter, ρ_a, and standard deviation of the productivity shock, σ_a. The parameter values for the probability of a high menu cost, α, in the two periods is chosen to match the spike capturing the frequency of unchanged prices. Allowing α to change between the periods is not standard practice in the literature but important in order to be able to match the frequency of zero price changes in data. It is also questionable whether it is realistic to consider the probability of a high menu cost to be fixed over a longer time period. As α should be seen as a proxy for rigidities to nominal prices rather than a completely exogenous force, such as a Calvo-fairy, giving firms the opportunity to randomly be able to adjust their prices, it is reasonable to at least consider a change of these rigidities over an extended period of time, e.g. as a result of changes in contract lengths.[36] When it comes to the standard deviation of the idiosyncratic belief shock conditional on the marginal-cost process, the standard deviation of price changes across firms should be informative and hence used as a moment to match. To be clear, the actual values of the parameters have been calibrated by simultaneously matching all four moments as described above.

The resulting parameter values and moments are shown in Table 2 on page 38. Because the same estimated $\hat{\rho}_a$ is used as the targeting moment in both periods, our parameter value of ρ_a is also the same in the pre- and post-reform period, 0.981.[37] When it comes to the standard deviation of the productivity shock, σ_a, the calibrated parameters are 0.049 and 0.045 for the

[35] Initially the genetic algorithm has been used since it is better at finding the global optimum and the resulting values have then been used as initial values for the local optimizer fminsearch.

[36] It should be clarified that α is still exogenous in the model considered in this paper, but it is allowed to differ between the pre- and post-reform period.

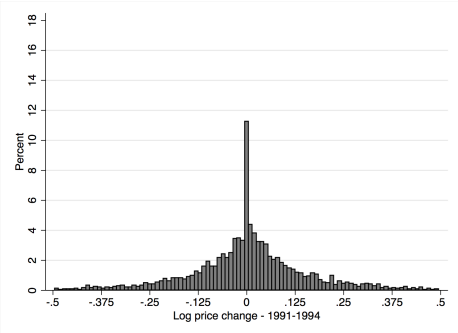
[37] The estimated ρ_a from the data did not differ substantially between the two periods, so to reduce the number of parameters that change between the pre- and post-reform period ρ_a is assumed to be the same in the two periods.

pre- respectively post-reform period, capturing a decrease in the variance of marginal-cost changes in the post-reform period.

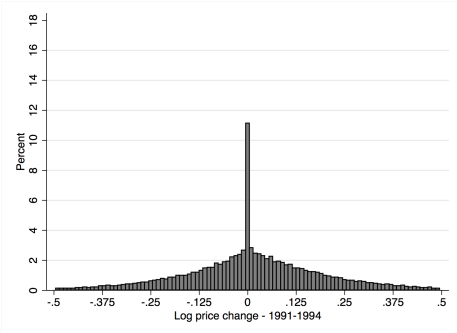
For the remaining parameters, the resulting values for the pre- and post-reform period of the frequency of zero price changes are $\alpha = 0.897$ and $\alpha = 0.917$, respectively, capturing a lower share of price changes in a year in the post-reform period. The resulting values for the standard deviation of the belief shock in the pre- and post-reform period are $\sigma_\eta = 0.184$ and $\sigma_\eta = 0.154$. The lower standard deviation in the post-reform period allows the model to match the lower dispersion of price changes in that period. The estimated parameters give the model a good fit as seen in the comparison between the simulated moments and the corresponding moments in the data, as shown in Table 2, and in terms of the distribution of price changes as shown in Table 3. Looking at the size of the standard deviation of the belief shock, it takes on a high value. The high value is necessary in order to match the price-change dispersion not explained by cost differences. Although a large dispersion of expectations has been documented before, in e.g. Kumar et al. (2015), the high values value does raise a concern about the risk of σ_η capturing things other than heterogeneous expectations, but that are not observed in the data. However, the important thing to capture here is the change in σ_η between the pre- and post-reform period, where the value seems more reasonable. When it comes to the distribution of price changes, the model performs very well in matching the standard deviation and percentiles but fails to match the higher moments with a substantially higher kurtosis and different skewness in the data. Both these moments are, however, very sensitive to outliers in the data.[38] Figures 3 and 4 present histograms of the real and model-simulated data for changes in prices, costs and markups in the pre- and post-reform period, respectively.[39]

[38] Excluding the top and bottom one percent of the price change distribution results in lower kurtosis and skewness, although not enough to be in line with the model estimates. Further, if excluding the top and bottom one percent of the price change distribution the skewness is higher in the post-reform period which is also what is predicted by the model.

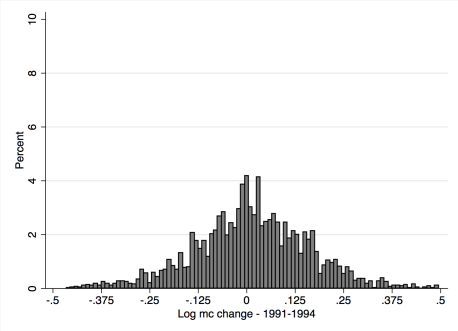
[39] As can be seen the model performs very well in terms of replicating the two targeted distributions, changes in log prices and log marginal costs. When it come to the non-targeted distribution of markup changes the model, in both periods, gives a somewhat flatter distribution with fatter tail than what is observed in the data.



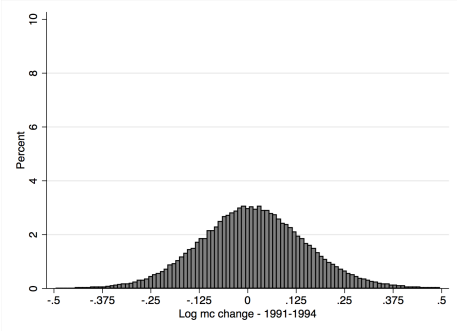
(a) Log price changes



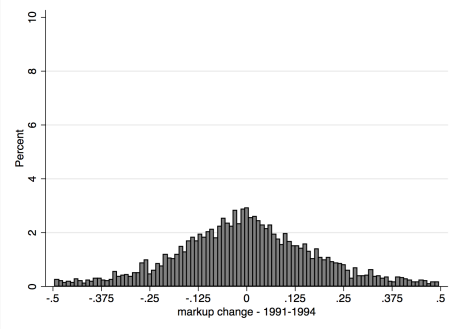
(b) Log price changes (simulated)



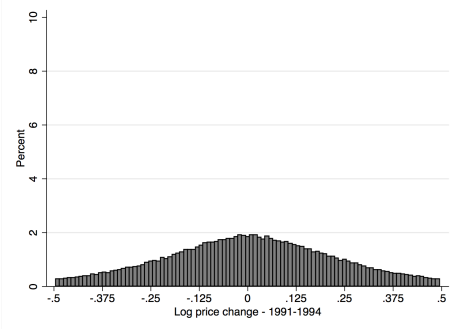
(c) Log mc changes



(d) Log mc changes (simulated)

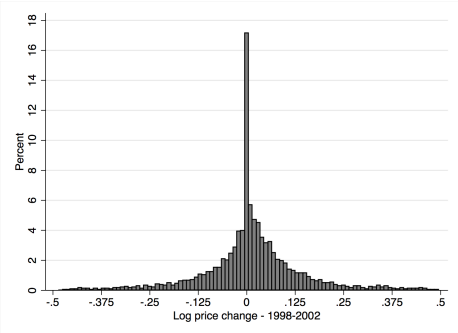


(e) Log markup changes

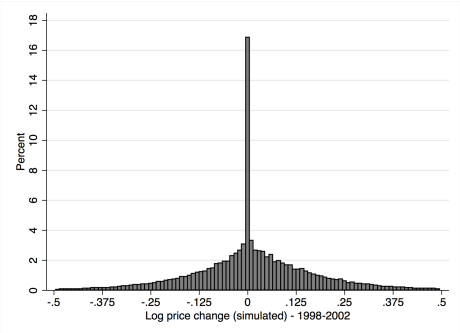


(f) Log markup changes (simulated)

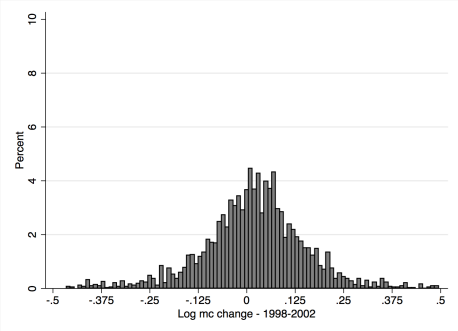
Figure 3: Real and Simulated Data in the Pre-Reform Period



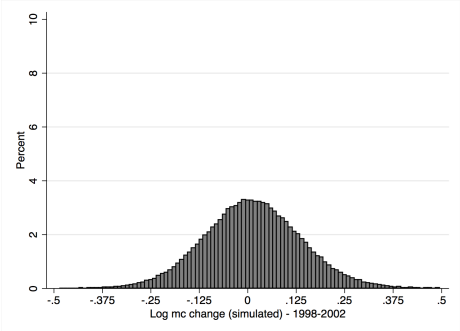
(a) Log price changes



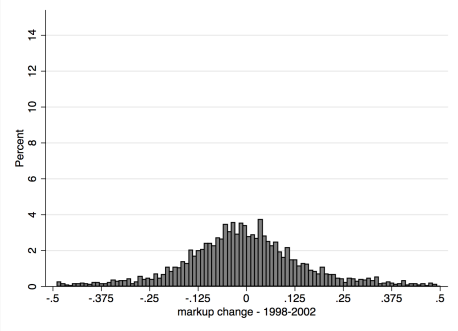
(b) Log price changes (simulated)



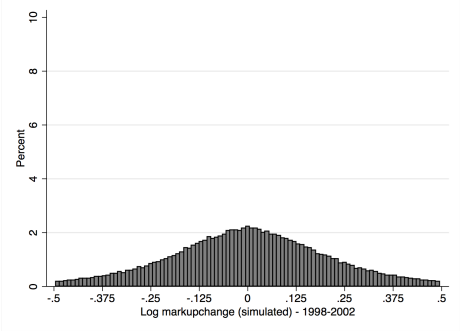
(c) Log mc changes



(d) Log mc changes (simulated)



(e) Log markup changes



(f) Log markup changes (simulated)

Figure 4: Real and Simulated Data in the Post-Reform Period

Table 2: Calibration

Assigned Parameters

Description	Parameter	Value
Discount rate	β	$0.96^{1/12}$
Elasticity of substitution	θ	3
High menu cost	κ^H	9999
Low menu cost	κ^L	0
Inflation pre-reform	μ_π^{pre}	0.0014
Inflation post-reform	μ_π^{post}	0.0007
Disutility of labor	ω	1

Calibrated Parameters

Description	Parameter	Value
Pre-reform		
Autoregressive coefficient in productivity process	ρ_a	0.981
Standard deviation of productivity shock	σ_a	0.049
Probability high menu cost	α_{calvo}	0.897
Standard deviation of idiosyncratic belief shock	σ_η	0.184
Post-reform		
Autoregressive coefficient in productivity process	ρ_a	0.981
Standard deviation of productivity shock	σ_a	0.045
Probability high menu cost	α_{calvo}	0.917
Standard deviation of idiosyncratic belief shock	σ_η	0.154

Matched Moments

Moment	Model	Data	Standard Error
Pre-reform			
Autoregressive coefficient in MC process	0.8702	0.8714	0.0066
Standard deviation of marginal-cost change	0.1376	0.1385	0.0035
Frequency of zero price changes	0.1081	0.1070	0.0041
Standard deviation of price change	0.2008	0.2023	0.0056
Post-reform			
Autoregressive coefficient in MC process	0.8709	0.8714	0.0066
Standard deviation of marginal-cost change	0.1259	0.1285	0.0035
Frequency of zero price changes	0.1662	0.1664	0.0049
Standard deviation of price change	0.1657	0.1693	0.0059

Notes: The calibrated parameter values are for the model that is on a monthly basis, while the moments matched are based on annual data and aggregated monthly simulations.

Table 3: Price-Change Distribution Moments

Moment	Data	Model
	Pre-reform	
Standard deviation	0.202	0.2008
Mean	0	0.0153
5th percentile	-0.312	-0.3168
25th percentile	-0.076	-0.0834
50th percentile	0.001	0
75th percentile	0.067	0.1173
95th percentile	0.316	0.3557
Skewness	0.413	0.0506
Kurtosis	8.22	4.9162
	Post-reform	
Standard deviation	0.168	0.1657
Mean	0	0.007
5th percentile	-0.235	-0.2600
25th percentile	-0.056	-0.0594
50th percentile	0.005	0
75th percentile	0.052	0.0903
95th percentile	0.256	0.2978
Skewness	0.403	0.1025
Kurtosis	11.105	5.4384

Notes: The moments from the data are computed controlling for sector-time dummies but are unconditional on marginal costs.

6 Results

While the previous section showed the performance of the model in matching features of the data, this section compares the outcome in the two sub-periods with the focus on inefficient price-change dispersion and its effect on welfare. To shed light on the relative importance of the changes in the two periods, we start by looking at the change in the price-change distribution disentangled by the contribution of changes in each parameters. Following this, the second part of the section looks at the welfare implications of the changes.

6.1 Price Dispersion

Although the main interest lies in the distribution of inefficient price changes, in what follows, results for both regular price-change dispersion and price-change dispersion controlling for changes in marginal costs are presented. The purpose of this is to show how they differ since only regular price changes are commonly observed and used in the literature.

Before analyzing the outcome of the model, we start by using the calibrated parameters for the two sub-periods to look at the model when only allowing for idiosyncratic shocks that affect productivity. This analysis is interesting because it is the most commonly included idiosyncratic shock in the literature and gives motivation for adding an additional idiosyncratic shock. When calibrating the standard deviation of the productivity shocks to match the price-change dispersion, the standard deviation of the shock needs to be substantially larger than when it is matched to moments from the cost data and results in the moments of marginal cost being far off from what is observed in data (with the standard deviation of marginal-cost changes more than double the size of what is observed in data, 0.29 compared to the observed standard deviation of 0.13).[40] As noted in Nakamura and Steinsson (2010), where the idiosyncratic productivity shock is matched to the size and frequency of price changes in U.S. data, the standard deviation of the shock is larger than required for being in line with observed variation in firm productivity. The result here confirms their reasoning that the inclusion of an idiosyncratic productivity shock, with the aim of better matching the price data, should rather be viewed as representing a broader class of causes of variation in firms' prices and not as a pure productivity shock. However, lumping together different idiosyncratic components into a single shock is not appropriate in a welfare analysis. As will be discussed below, although a change in the variance of a productivity and belief shock affects the distribution of desired prices in a similar way, it has different effects on welfare. Hence, the possibility of disentangling the productivity shock from the belief shock is important for a proper welfare analysis.

[40]The calibrated value for σ_{mc} is 0.094, compared to 0.052 when matched to the cost data (using the full sample moments).

Using the full model, the idiosyncratic belief shock captures the excess dispersion of price changes that the productivity shock is not able to capture and at the same time matches the moments in the cost data. Table 4a presents a decomposition of the different contributing factors to the price change dispersion. More specifically, it shows how much of the total change in the standard deviation of price-changes between the pre- and post-reform period can be explained by the change in a single parameter.[41] That is, the percentage share of the change in the standard deviation of price changes explained by a single parameter is given by

$$\text{Explained share} = \frac{\sigma_{\Delta p}^{partial} - \sigma_{\Delta p}^{pre}}{\sigma_{\Delta p}^{post} - \sigma_{\Delta p}^{pre}}, \tag{29}$$

where $\sigma_{\Delta p}^{partial}$ is the standard deviation of price changes when only changing one of the parameters, σ_η, σ_a, μ or α, to its calibrated post-reform value while keeping all other parameters at their pre-reform values. Moreover, $\sigma_{\Delta p}^{pre}$ and $\sigma_{\Delta p}^{post}$ are the standard deviations of price changes using the full calibration for the pre- and post-reform period, respectively.

Comparing the effects of the two idiosyncratic shocks using this measure, the belief shock is a more important factor than the productivity shock in explaining the change in price-change dispersion, see Table 4a. In fact, the change in the variance of the belief shock alone explains about 63 percent of the total explained change in the standard deviation of price changes. The change in the cost process only explains about 16 percent. The remainder is explained by a change in the probability of a high menu cost while the change in inflation rate has a negligible effect. The belief shock's contribution to the decline in inefficient price dispersion is even more important. As shown in Table 4b, when looking at the inefficient price-change dispersion, the belief shock now explains about 74 percent of the total explained change in the standard deviation of price changes and the cost process only about 13 percent.[42]

[41] The total change in price dispersion here refers to the total change captured by the model. Since the model almost perfectly matches the price-change dispersion in the data, the result do not differ much when using the data moments of $\sigma_{\Delta p}^{pre}$ and $\sigma_{\Delta p}^{post}$.

[42] The standard deviation of cost changes does not give rise to any distortion in prices themselves but affects the dispersion of inefficient price changes in the presence of price rigidities as firms then are constrained to

When it comes to the effect on the price-change dispersion of a change in the probability of a high menu cost, the increase in the probability of a high menu cost contributes to the reduction in price-change dispersion. This is also true for inefficient price-change dispersion. It is worth pointing out here that, in contrast to the effect of the productivity and belief shock, the decrease in inefficient price-change dispersion does not imply a lower level of markup dispersion in this case.[43] In the next section, we will further explore the effects of inefficient price-changes dispersion on markups when looking at the welfare implications of the reform.

Table 4: Decomposition of the Change in Price-Change Dispersion

(a) Actual Price-Change Dispersion

Contributing Factor		**Explained Share**
Parameter	*Description*	
$\Delta\sigma_\eta$	Standard deviation of belief shock	63%
$\Delta\sigma_a$	Standard deviation of marginal-cost change	16%
$\Delta\alpha$	Probability high menu cost	22%
$\Delta\pi$	Inflation rate	-0.86%

(b) Inefficient Price-Change Dispersion

Contributing Factor		**Explained Share**
Parameter	*Description*	
$\Delta\sigma_\eta$	Standard deviation of belief shock	73.5%
$\Delta\sigma_a$	Standard deviation of marginal-cost change	12.5%
$\Delta\alpha$	Probability high menu cost	15%
$\Delta\pi$	Inflation rate	0%

Notes: Table 4a and Table 4b give the percentage share of the change in the standard deviation of price changes between the pre- and post-reform period, explained by the change in a single parameter from its pre-reform to post-reform calibrated value. Table 4a shows the results for unconditional price changes and Table 4b shows the results for price changes conditional on changes in marginal costs. The shares do not necessarily sum to 100% because of the presence of interaction effects in the fully calibrated versions.

change prices following cost shocks.

[43]Higher price rigidity means that firms are more restrictive in their price changes in response to shocks. This leads to a lower dispersion of inefficient price changes, but in this case also to a reduction in the dispersion of prices changes that is efficient and motivated by differences in costs.

6.2 Welfare

The welfare effects are driven by three main factors: 1) changes in the aggregate markup, affecting employment, 2) changes in markup dispersion, with effects on misallocation of factors of production, and 3) changes in the productivity distribution, mainly affecting the potential (undistorted) productivity in the economy. This section focuses on one channel at a time to give some intuition into the different roles they play, with the caveat that the three channels are not perfectly additively separable. First, we look at the total effect on welfare with an extra focus on the role of the aggregate markup. This is followed by a section that focuses on the role of misallocation. Finally, we look at the role played by the change in the productivity process. The welfare effects are evaluated using a consumption equivalent variation measure comparing the pre- and post-reform period as described in Section 4.3.

6.2.1 Full effect

Recalling from Section 4.3.2, the aggregate markup and dispersion in markups play important roles for welfare. To understand the effect on markups from the introduction of the inflation target, we start out by looking at the effects from changes in specific parameters. Table 5 gives the change in markup dispersion and the aggregate markup from a change in a single parameter from its pre- to post-reform value. As can be seen, the change in both idiosyncratic shocks results in a decrease in markup dispersion, with the effect of the belief shock being larger. Further, both shocks result in an increase in the aggregate markup (again, with the effect of the belief shock being larger). As a decrease in markup dispersion increases welfare while an increase in the aggregate markup decreases it, it is not possible to draw any conclusion about welfare from Table 5. However, the figures are indicative of welfare effects and a takeaway from Table 5 is that changes in parameters can have counteracting effects on welfare by both affecting the dispersion of markups and the aggregate markup. This observation is interesting in light of recent discussions about a rise in markups; see, e.g., De Loecker and Eeckhout (2017). The results here indicate that there can be a trade-

off between a low aggregate markup and an improved allocation of inputs. A concurrent decrease in misallocation and rise in the aggregate markup is also discussed in e.g. Edmond et al. (2018).

Table 5: The Effect on Markups from Changes in Single Parameters

Contributing Factor	**ΔStandard deviation**	**ΔAggregate markup**
Parameter		
$\Delta\sigma_\eta$	-11.1%	2.65%
$\Delta\sigma_a$	-3.15%	0.43%
$\Delta\alpha$	4%	-0%
$\Delta\pi$	0.14%	0.04%

Notes: The table gives the effect on markup dispersion, the aggregate markup from a change in a single parameter from its pre-reform to post-reform calibrated value.

To see the effect on welfare we instead need to look at what effects the changes in markup dispersion and aggregate markup have on consumption. Tables 7 and 6 show the welfare effect between the pre- and post-reform periods given by changes in specific parameters. More specifically, the tables show the consumption equivalent changes in welfare, both decomposed to changes in single parameters (row 1–4) and the total effect between the pre- and post-reform period (row 6). The difference between the two tables is that Table 7 shows the total effect on welfare while Table 6 shows the effect with a constant aggregate markup, which could be achieved by an employment subsidy that offsets the negative effects on labor demand. To better understand the mechanisms affecting welfare, it is informative to disregard the effect of the aggregate markup for a moment and focus on Table 6. Here, it is clear that, besides the effect of the aggregate markup, there are two counteracting forces affecting welfare. The first three rows of the table show the welfare effect between the pre- and post-reform periods given by changes in specific parameters. Hence, it gives us the consumption equivalent variation measure of the change in welfare disentangled by each parameter's contribution.[44] As can be seen, there are both positive and negative welfare changes between the two periods. The positive effect on welfare comes from a decrease in misallocation mainly driven by the decrease in the variance of the belief shock. Loosely, we could translate the 11.1 percent decrease in markup dispersion attributed to the decrease in the variance of the belief shock

[44]This is not fully correct as the total effect on welfare going from the pre- to post-reform period also depends on interacting effects making the figures in the table not perfectly additively separable.

(from Table 5) into a 1.6 percent increase in consumption (last column of the first row in Table 6). Also in line with Table 5, the higher degree of price rigidities (increasing markup dispersion) reduces welfare and the effect of inflation is negligible. When it comes to the change in the process determining the evolution of productivities, we saw in Table 5 that it resulted in a lower dispersion of markups. The effect on welfare from the change in the productivity process do, however, also depend on its effect on aggregate productivity. The effect on welfare is here dominated by its effect on aggregate productivity where a lower dispersion of productivity shocks results in a lower undistorted productivity level (through the aggregation of firm productivities given in section 4.3.1 and discussed further below), and hence the effect on welfare is negative, as shown in Table 6 (row 2).

The last row of Table 6 gives the total welfare effect disregarding the effect of the change in aggregate markup. It shows that the representative consumer in the pre-reform period needs to be compensated with a 0.23 percent increase in consumption in order for her to be indifferent between the pre- and post-reform period. The increase in welfare reflects lower distortions to the economy, with an inflation target in place, and resulting in higher level of output.

However, the numbers in Table 6 do not tell the full story as the table disregards the effect from changes in the aggregate markup.[45] To see the effects on welfare when also taking the aggregate markup into account we turn to Table 7. If looking at the effect of the decrease in the variance of the belief shock (row 1) the effect is in this case smaller than before. The reason for this is that the lower dispersion of beliefs resulting in lower dispersion of markups also results in a higher aggregate markup as shown in Table 5 and discussed in section 4.3.2. The total effect of the decrease in the variance of the belief shock, when taking all mechanisms at work into consideration, is now a required increase in consumption in the pre-reform period by 0.79 percent (compared to 1.6 percent with an employment subsidy in place). If looking at the effect of the change in the productivity process and price rigidity these effects are instead

[45]The aggregate markup increases from about 1.37 to 1.4. This change is entirely due to a lower dispersion of markups and not caused by an increase in firm-level markups. Note that in an undistorted case, with no markup dispersion, the aggregate markup is equal to 1.5 (given by $\frac{\theta}{\theta-1}$).

stronger when taking the effect of the aggregate markup into consideration. By comparing the first three rows in Table 7 and Table 6, we see that the negative welfare effect of a lower variance in productivity shocks seems to be exacerbated while the positive effects of a lower variance of the belief shock seems to be dampened by the change in the aggregate markup.

It turns out that when taking all mechanisms into account the negative effects on welfare exceed the positive effects resulting in a lower consumption level and welfare in the post-reform period. Hence, despite the increased efficiency in the allocation of inputs, following the decrease in markup dispersion, the negative effect on employment of a higher aggregate markup and the lower aggregate productivity level dominates. Specifically, in this case, households require a 0.18 percent *decrease* in consumption in the pre-reform period in order to achieve the same utility as in the post-reform period, see the last row (6) of Table 7. The negative effect is, to a large extent, a result of changes in the productivity process and not a result of changes in the markup. Although the increase in aggregate markup reduces welfare, this negative effect is still off-set by the improved allocation of inputs resulting from the decrease in markup dispersion. Hence, without the change in the productivity process the effect on welfare would be positive also when taking the aggregate markup into consideration (row 5). The role of the decrease in the variance of the productivity shock is discussed further below.

Table 6: Parameter-Specific Consumption Equivalent Results (with Employment Subsidy)

Parameter	**Description**	**Change**	**EV**
$\Delta\sigma_\eta$	Standard deviation of belief shock	-0.03	1.6%
$\Delta\sigma_a$	Standard deviation of marginal-cost change	-0.004	-0.26%
$\Delta\alpha$	Probability high menu cost	0.02	-0.56%
$\Delta\mu_\pi$	Inflation rate	0.0007	0%
$\Delta\sigma_\eta, \Delta\alpha, \Delta\mu_\pi$	Total effect (exl. s.d. marginal-cost change)	–	1.15%
$\Delta\sigma_\eta, \Delta\sigma_a, \Delta\alpha, \Delta\mu_\pi$	**Total effect**	–	**0.23**%

Notes: The table gives the EV measure of a change in a specific parameter, with EV being the change in consumption that the representative household in the pre-reform period needs to be at the same level of utility as with an inflation target. The change, given in the middle column, is the difference between the calibrated parameter value between the pre- and post-reform periods.

Table 7: Parameter-Specific Consumption Equivalent Results (without Employment Subsidy)

Parameter	**Description**	**Change**	**EV**
$\Delta\sigma_\eta$	Standard deviation of belief shock	-0.03	0.79%
$\Delta\sigma_a$	Standard deviation of marginal-cost change	-0.004	-0.8%
$\Delta\alpha$	Probability high menu cost	0.02	-0.57%
$\Delta\mu_\pi$	Inflation rate	0.0007	0%
$\Delta\sigma_\eta, \Delta\alpha, \Delta\mu_\pi$	Total effect (exl. s.d. marginal-cost change)	–	0.28%
$\Delta\sigma_\eta, \Delta\sigma_a, \Delta\alpha, \Delta\mu_\pi$	**Total effect**	–	**-0.18**%

Notes: The table gives the EV measure of a change in a specific parameter, with EV being the change in consumption that the representative household in the pre-reform period needs to be at the same level of utility as with an inflation target. The change, given in the middle column, is the difference between the calibrated parameter value between the pre- and post-reform periods.

6.2.2 Misallocation

As described in Section 6.1, the most important factor behind the decrease in inefficient price-change dispersion is the lower dispersion of beliefs. By looking at the effect on welfare when only allowing for a change in the standard deviation of the belief shock, keeping all others parameters at their pre-reform values, we saw in the previous section that the decrease in inefficient price-change dispersion translated into a decrease in markup dispersion. The mechanism behind the positive effect on welfare is that relative prices are more accurate in the post-reform period, implying a lower dispersion of markups with lower output distortions and a more efficient allocation of labor.

Another factor with direct effects on misallocation is the degree of price rigidities. In general, the expectation is that a higher degree of price rigidity results in higher price dispersion and lower welfare. However, as discussed above, in this case the higher probability of a high menu cost in the post-reform period results in a lower standard deviation of price changes, see Tables 4a and 4b. Still, the effect on welfare is negative as expected. As seen in the third row of 7 (6), the increase in the probability of a high menu cost in the post-reform period requires a 0.57 (0.56) percent decrease in consumption in the pre-reform period to be at the

same level of utility as after the reform.[46]

6.2.3 Productivity

To shed light on the role of the productivity process, we compare the results in the last row of Table 7 (6) to a case where the effect of a change in the productivity process is ignored (by only focusing on the belief shock, price rigidities and inflation). Total welfare is then higher in the post-reform period, see the fifth row of Table 7 (6). In this case, the representative household needs to be compensated with a 0.28 (1.15) percent *increase* in consumption to be as well off in the pre-reform period as after the inflation target was implemented. This result is interesting as these changes are most likely to be a result of the inflation-targeting reform.

To understand the effect of the productivity process better it is also informative to look at how aggregate productivity differs between the two periods when comparing the undistorted case to the actual one.[47] Comparing the ratio of the actual and the undistorted aggregate productivity it is 0.92 in the pre-reform period and 0.94 in the post-reform period. Hence, the post-reform aggregate productivity is closer to the undistorted level. Despite this, the actual productivity is only marginally higher in the post-reform period. This is because the level of undistorted productivity is higher in the pre-reform period, which is a result of a larger variance of productivity shocks in that period. In the model, a higher productivity dispersion affects aggregate productivity positively. The explanation behind this result is a combination of substitutability between goods and that a higher productivity dispersion means that there are some firms with, in absolute terms, a higher productivity level. Because agents can shift consumption toward these more productive firms, resulting in these firms producing a relatively larger share of total production, this results in a higher level of aggregate productivity. As shown in the second row of Table 7 and 6, considering the lower

[46] To see how the effect of lowering price dispersion and reducing welfare can coincide, recall that some price-change dispersion is warranted by heterogeneous changes in marginal costs. If firms, due to nominal rigidities, are not able to optimally adjust to these, the effect on welfare is negative.

[47] The term undistorted refers to the case without nominal rigidities and belief shocks.

variance of productivity shocks in isolation results in a negative effect on welfare.

The discussion above shows the value of being able to distinguish between idiosyncratic productivity and belief shocks. As mentioned, if only allowing for idiosyncratic productivity shocks, a decrease in price-change dispersion in the post-reform period requires a sizeable decrease in the variance of the productivity shock with negative effects on aggregate productivity and welfare. It is therefore of importance to separate the idiosyncratic belief shock, which has distortionary effects, from the productivity shock, which in itself does not create any distortions to the economy but does so when coupled with price distortions. Hence, without being able to identify the distortionary effect of the idiosyncratic belief shock and, instead, attribute the decrease in price-change dispersion mainly to a change in the standard deviation of a productivity shock, it would be hard to correctly capture the welfare effect from the inflation-targeting reform.

6.2.4 Elasticity of Substitution

The welfare effects described above are sensitive to the elasticity of substitution. In general, the role of substitutability between products, in the model determined by θ, affects aggregate production in two directions. First, it has the positive effect of a higher substitutability between goods, allowing agents to more easily shift consumption toward more productive firms. In addition, a higher θ reduces firms' optimal markup resulting in higher demand for labor. Second, it has a negative effect by amplifying distortions since relative price distortions will have a larger effect on misallocation, making firms with higher than optimal prices underproduce even more, and vice versa.[48] Hence, a lower θ results in a lower undistorted aggregate productivity but also in a smaller gap between the undistorted and actual productivity. Consider the case were $\theta = 2$. This results in a lower level of undistorted productivity but also in less misallocation. With $\theta = 2$, actual productivity in the pre- and post-reform period is about 5 and 4 percent lower, respectively, than the potential level compared to the case

[48]This is because consumers find it easier to substitute a specific good if the price increases.

with $\theta = 3$, where the corresponding numbers were about 8 and 6 percent, respectively. Hence, the value of θ is of importance for the results of the welfare analysis. However, it does not affect the parameter-specific mechanisms described above, but only to which extent one effect dominated the other. As mentioned, in this study the choice of $\theta = 3$ is made in order to be in line with Swedish manufacturing sector firm-level estimates.

7 Concluding Remarks

To sum up, the empirical analysis shows a decrease in the dispersion of price changes and changes in prices controlling for changes in marginal costs following the introduction of an official inflation target. The decrease in price-change dispersion supports the hypothesis that inflation targeting can anchor inflation expectations and thus stands in contrast to the results in Kumar et al. (2015). Using a structural model to disentangle the effect of better-anchored inflation expectations from parallel changes in the economic environment, 73.5 percent of the decrease in inefficient price-change dispersion can be attributed to a lower dispersion of inflation expectations. Looking at the effect of the decrease in inefficient price-change dispersion on the markup dispersion suggests that decreasing the dispersion of inflation expectations gives rise to significant welfare gains. Another interesting finding is that the role of the level of inflation seems to be minor for welfare in comparison to the effect of dispersion of inflation expectations (at least for the relatively low levels of inflation considered in this study). Further, it is shown that the possibility to distinguish between different kinds of shocks is critical when analyzing welfare. When disentangling the effect of a change in dispersion of inflation expectations, we conclude that the change in welfare is equivalent to a 0.79 percent increase in consumption necessary for a representative household in the pre-reform period to be at the same level of utility as after the inflation target is introduced.

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A Time Aggregation

To match annual statistics, the simulated monthly data is time-aggregated using monthly output weights. The annual unit price of firm j is constructed as

$$\begin{aligned} P_{jt} = & \frac{Annual\ Sales_{jt}}{Annual\ Volume_{jt}} = \frac{\sum_m P_{jt}^m Y_{jt}^m}{\sum_m Y_{jt}^m} = \\ = & \quad P_{jt}^1 \frac{Y_{jt}^1}{\sum_m Y_{jt}^m} + ... + P_{jt}^{12} \frac{Y_{jt}^{12}}{\sum_m Y_{jt}^m}, \end{aligned} \tag{A.1}$$

where m denotes month. Similarly we can write

$$\begin{aligned} ULC_{jt} &= \frac{Annual\ Wage\ Bill_{jt}}{Annual\ Volume_{jt}} = \frac{\sum_m W_{jt}^m L_{jt}^m}{\sum_m Y_{jt}^m} = \\ &= \frac{W_{jt}^1 L_{jt}^1}{Y_{jt}^1} \frac{Y_{jt}^1}{\sum_m Y_{jt}^m} + ... + \frac{W_{jt}^{12} L_{jt}^{12}}{Y_{jt}^{12}} \frac{Y_{jt}^{12}}{\sum_m Y_{jt}^m} = \\ &= ULC_t^1 \frac{Y_t^1}{\sum_m Y_t^m} + ... + ULC_t^{12} \frac{Y_t^{12}}{\sum_m Y_t^m}, \end{aligned} \tag{A.2}$$

as the unit labor cost of firm j.

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