Price Rigidity at Near-Zero Inflation Rates: Evidence from Japan

Kota Watanabe* Tsutomu Watanabe†

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Abstract

A notable characteristic of Japan's deflation since the mid-1990s is the mild pace of price decline, with the CPI falling at an annual rate of only around 1 percent. Moreover, even though unemployment increased, prices hardly reacted, giving rise to a flattening of the Phillips curve. In this paper, we address why deflation was so mild and why the Phillips curve flattened, focusing on changes in price stickiness. Our first finding is that, for the majority of the 588 items constituting the CPI, making up about 50 percent of the CPI in terms of weight, the year-on-year rate of price change was near-zero, indicating the presence of very high price stickiness. This situation started during the onset of deflation in the second half of the 1990s and continued even after the CPI inflation rate turned positive in spring 2013. Second, we find that there is a negative correlation between trend inflation and the share of items whose rate of price change is near zero, which is consistent with Ball and Mankiw's (1994) argument based on the menu cost model that the opportunity cost of leaving prices unchanged decreases as trend inflation approaches zero. This result suggests that the price stickiness observed over the last two decades arose endogenously as a result of the decline in inflation. Third and finally, a cross-country comparison of the price change distribution reveals that Japan differs significantly from other countries in that the mode of the distribution is very close to zero for Japan, while it is near 2 percent for other countries including the United States. Japan continues to be an "outlier" even if we look at the mode of the distribution conditional on the rate of inflation. This suggests that whereas in the United States and other countries the "default" is for firms to raise prices by about 2 percent each year, in Japan the default is that, as a result of prolonged deflation, firms keep prices unchanged.

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*Canon Institute for Global Studies (CIGS) and University of Tokyo. E-mail: watanabe.kota@canon-igs.org. We would like to thank Kosuke Aoki, Christian Broda, Hideo Hayakawa, Kazuo Monma, Roberto Rigobon, Shigenori Shiratsuka, Kazuo Ueda, Hirohide Yamaguchi, Hiroshi Yoshikawa, and David Weinstein for valuable comments on earlier versions of this paper, and Takuto Murase for preparing part of the dataset used in the paper. This research forms part of the project on "Understanding Persistent Deflation in Japan" funded by a JSPS Grant-in-Aid for Scientific Research (No. 24223003).

†Graduate School of Economics, University of Tokyo. E-mail: watanabe@e.u-tokyo.ac.jp, Website: https://sites.google.com/site/twatanabelab/.

1 Introduction

From the second half of the 1990s onward, Japan suffered a period of prolonged deflation, in which the consumer price index (CPI) declined as a trend. During this period, both the government and the Bank of Japan (BOJ) tried various policies to escape from deflation. For instance, from 1999 to 2000, the BOJ adopted a "zero interest rate policy" in which it lowered the policy interest rate to zero. This was followed by "quantitative easing" from 2001 until 2006. More recently, in January 2013, the BOJ adopted a "price stability target" with the aim of raising the annual rate of increase in the CPI to 2 percent. In April 2013, it announced that it was aiming to achieve the 2 percent inflation target within two years and, in order to achieve this, introduced Quantitative and Qualitative Easing (QQE), which seeks to double the amount of base money within two years. Further, in February 2016, the BOJ introduced a "negative interest rate policy," in which the BOJ applies a negative interest rate of minus 0.1 percent to current accounts held by private banks at the BOJ, followed, in September 2016, by the introduction of "yield curve control," in which the BOJ conducts JGB operations so as to keep the 10-year JGB yield at zero percent. See Table 1 for an overview of recent policy decisions made by the BOJ.

Looking at the year-on-year (y-o-y) rate of change in the CPI excluding fresh food, after leaving negative territory and returning to zero in May 2013, it turned positive in June that year and rose to 1.5 percent by April 2014 (excluding the direct effects of the consumption tax hike in April 2014). However, since then, inflation has gradually slowed as consumption demand declined and, if the effect of the consumption tax hike is excluded, has fallen to under 1 percent since October 2014.

Against this background, uncertainty over the future course of prices strengthened, and questions have been raised as to whether the 2 percent inflation target can be achieved and whether a target of 2 percent was not too ambitious. The aim of this paper is to investigate why it is proving this difficult to achieve the 2 percent inflation target and, in doing so, assess whether the 2 percent inflation target can realistically be achieved. There is already a considerable body of literature on Japan's prolonged deflation since the mid-1990s.[1] Moreover, there are also already a considerable number of studies on the effects of QQE and other measures taken by the BOJ on the economy. Yet, although these studies in one way or another

[1]For example, the Asian Economic Policy Review published a special issue in January 2014 focusing on "Persistent Deflation and Monetary Policy" comprising articles on various aspects such macro- and microeconomic analyses of deflation, wage deflation, and the foreign exchange market. For details, see: `http://onlinelibrary.wiley.com/doi/10.1111/aepr.2014.9.issue-1/issuetoc`.

Table 1: Monetary Policy Decisions Made by the Bank of Japan in 2013-2016

Jan 22, 2013	Joint statement of the Government and BOJ on overcoming deflation and achieving sustainable economic growth was released. BOJ set an inflation target of 2 percent.
Apr 4, 2013	BOJ introduced Quantitative and Qualitative Monetary Easing (QQE). BOJ decided to double the monetary base to achieve the 2 percent target with a time horizon of about two years.
Oct 31, 2014	BOJ expanded QQE by increasing its annual net purchases of JGBs from 50 trillion yen to 80 trillion yen.
Jan 29, 2016	BOJ decided to apply a negative interest rate of minus 0.1 percent to part of BOJ current account balances.
Sep 21, 2016	BOJ decided to employ yield curve control with the target level of 10-year JGB yields set to zero.

consider Japan's experience with deflation and possible mechanisms of escaping from it, they have discussed the two issues separately. In contrast, the present paper seeks to understand in a unified manner the process of deflation and the process of overcoming deflation.

To do so, this paper focuses on the fact that Japan's deflation since the mid-1990s consisted of an extremely mild decline in prices. The largest monthly rate of y-o-y decline in the CPI during this period was only around 2 percent, and for the period as a whole the average was slightly less than 1 percent. Therefore, even though it was deflation, it was very mild and did not turn into the kind of severe deflation one might associate with the term; it certainly also did not turn into the kind of deflationary spiral many had feared. Of course, the fact that it was possible to avoid severe deflation itself is a good thing. However, from the perspective of escaping from deflation, it is possible that because the decline in prices was "neither here nor there," the market forces to turn the price decline into an increase were weak.

The analysis in this paper makes extensive use of sectoral price data. Japan's CPI is constructed from items such as margarine and shampoo, and the total number of items is 588. For each of these items, about 570 prices are collected by price collectors of the Statistics Bureau of Japan every month. Therefore, the total number of prices collected each month reaches about 250,000. Roughly speaking, the general CPI announced each month is the average of this large number of prices, and averages such as this certainly are an important statistical indicator that shows the characteristics of a large number of prices. However, the average is not the only useful indicator. Other statistical indicators - for example, higher-order moments of the distribution of price changes for individual items - also provide a wealth of information on developments in prices. This paper seeks to take advantage of such information by looking at what kind of shape the distribution of price changes takes and how this distribution evolves over time, in order to examine the mechanism underlying changes in the average of the distribution.

The rest of the paper is organized as follows. Section 2 provides a description of the salient features of Japan's deflation, in particular the mildness of the price decline and the flattening of the Phillips curve. Section 3 then examines the shape of the distribution of price changes of individual items in the consumer price statistics and how this shape changed over time. Next, in order to investigate the reasons for price stickiness, Section 4 examines the relationship between the share of items for which the rate of change is close to zero and the rate of change in the CPI. Section 5 then conducts a cross-country comparison of the price change distribution in order to identify causes behind the prolonged deflation in Japan, while Section 6 concludes. Finally, there are two appendixes. Appendix A provides details on the methodology used to estimate the mode of the price change distribution, while Appendix B describes the characterization of multiple modes in the *Ss* model on sectoral price inflation that we employ.

2 Characteristics of Japan's Deflation since the Mid-1990s

2.1 Mild but persistent price declines

Let us start by reminding ourselves of the nature of price developments in Japan since the mid-1990s. Note that rates of change in this paper always refer to the y-o-y rate of change. Figure 1, which presents monthly values of the rate of change in the CPI, shows that inflation decelerated in the wake of the collapse of the bubble economy and turned negative in the middle of the 1990s. Subsequently, inflation temporarily turned positive again as a result of rising natural resource and grain prices, but as a trend CPI inflation continued to fall, turning into a sustained decline in prices, i.e., deflation. However, the situation has changed since spring 2013, with the rate of change first returning to zero in May 2013 and then turning positive in June, rising to 1.5 percent in April 2014 (excluding the direct effects of the consumption tax hike). Yet, since then, inflation has gradually slowed again with the decline in consumption demand and, if the effect of the consumption tax hike is excluded, has been below 1 percent since October 2014. In fact, in 2016, inflation briefly fell back into negative territory, reflecting the substantial decline in oil prices, although with the rebound in oil prices inflation has turned positive again.

As noted, Japan's deflation has two important characteristics. First, deflation has lasted for a long time. Prices declined for two decades from the mid-1990s, so that it has clearly been prolonged. Second, however, in terms of the pace of deflation, even when prices were falling relatively fast, they never fell at a rate beyond 2 percent, and the average for the period is only 1 percent. In this sense, deflation was mild.

These two characteristics become even clearer when comparing Japan's experience with the deflation in the United States during the Great Depression. The deflation during this period was severe, with prices falling at an annual rate of more than 8 percent. This is a stark difference from the average rate of deflation of less than 1 percent in Japan. On the other hand, the deflation during the Great Depression ended in about three years, so the duration was short. In this respect, too, it differs from Japan's deflation. The reasons for these differences in the deflation rate and the duration are not easy to identify because the two deflationary episodes concern not only different countries but also different eras. That being said, these differences may stem, at least partially, from different price setting behaviour of producers and distributors in the two countries.

As pointed out by Gordon (1981), during the Great Depression in the United States, firms quickly adjusted prices in response to changes in demand and supply.[2] That is, prices were flexible. On the other hand, in Japan price flexibility has fallen in recent years, so that even when demand and supply conditions change, there has been a strong tendency for firms not to change prices immediately. For example, Abe et al. (2008), based on a survey of Japanese manufacturers, report that more than 90 percent of firms responded that they "do not immediately change prices even if demand and supply conditions change." Moreover, in a survey published in the Annual Report on the Japanese Economy and Public Finance 2013, only 21 percent of firms answered that they fully passed on increases in marginal costs to consumers, while the majority indicated that they could not fully pass on such cost increases.[3]

[2]Gordon (1981) measures how much the quantity of output (real GDP) and prices (GDP deflator) changed in response to a change in nominal GDP. He finds that in the 1920s it was mainly prices that changed in response to a change in nominal GDP, and that the extent to which prices changed was higher than during other periods. In other words, on the eve of the Great Depression, the sensitivity of prices to changes in demand (=nominal GDP) increased, and in this sense, price stickiness may have declined.

[3]According to the survey in the Annual Report on the Japanese Economy and Public Finance 2013, 23 percent of firms answered they passed on about half, 12 percent answered that they passed on less than half, and 26 percent answered that they could not pass on any cost increases at all.

2.2 Flattening of the Phillips curve

A possible reason that Japan's deflation since the mid-1990s was mild is that firms did not see a need to lower prices at a quick pace. For example, it is possible that firms did not experience any change in marginal costs, so that they did not have to change prices. However, it is very likely that firms *did* experience a substantial change in marginal costs and therefore should have lowered prices quickly.

This can be seen by looking at the evolution of the Phillips curve for Japan. The Phillips curve is shown in Figure 2, which depicts the unemployment rate on the horizontal axis and the rate of change in the CPI on the vertical axis, and plots the values for each year. As can be seen from the figure, in the 1970s and 1980s, there existed a relationship such that when unemployment decreased, inflation increased. That is, an increase in demand would lead to an increase in production and a fall in unemployment; this, in turn, increased marginal production costs, pushing up inflation.

However, from the 1990s onward, this relationship rapidly weakened. The slope of the Phillips curve became much shallower and for the period since 2000 has been close to zero. Looking at the period since 2000 in more detail, even though the unemployment rate fluctuated within the range of 3.9 percent to 5.4 percent, the rate of change in the CPI hovered in a narrow range between -1.4 percent (in 2009) and 1.4 percent (in 2008), and in many years remained close to zero. Even during the global financial crisis, which resulted in a sharp rise in the unemployment rate, the CPI did not fall much. In this sense, it is possible to say that firms at times when they should essentially have lowered prices did not do so.

While Milton Friedman pointed out that the Phillips curve becomes steeper in times of high inflation, the exact opposite of this - a flattening - has occurred in Japan since 2000. Note that while the horizontal axis in Figure 2 measures the unemployment rate, the same thing could be observed if instead we used the output gap, which measures the percentage deviation of actual GDP from potential GDP.

The flattening of the Phillips curve has important implications with regard to overcoming deflation. Spurring demand through QQE and fiscal stimulus measures should help to reduce unemployment and lead to an improvement in the output gap. Yet, if the Phillips curve is more or less flat, a reduction in the unemployment rate or improvement in the output gap is less likely to result in price increases, making it more difficult to overcome deflation. Watanabe (2013) shows, through a numerical exercise based on the estimated slope of the

Phillips curve, that the output gap would have to increase by 5.3 percentage points each year in order to achieve the 2 percent inflation target in two years. Assuming that Japan's potential GDP growth rate is 1 percent, raising the output gap by 5.3 percent points in one year would require real GDP to grow at a rate of 6.3 percent per year, which is clearly unrealistic. In other words, overcoming deflation only by stimulating demand is impossible; instead, it is vital to return the Phillips curve to its original slope or to shift the Phillips curve upward.[4] However, looking at the dots for recent years in Figure 2, it appears that so far no notable change in the Phillips curve has taken place.

2.3 Slope of the Phillips curve for goods and services

Next, Figure 3 looks at the slope of the Phillips curve for goods and services separately. As shown by previous studies based on micro price data, such as Higo and Saita (2007), service prices tend to be sticky, while goods prices tend to be less sticky. This difference is often explained by the fact that the marginal cost of services is entirely determined by wages and that wages tend to be very sticky. However, what is of interest here is not differences in the price stickiness of goods and services, but which one - goods or services - is responsible for the change in the slope of the Phillips curve since 2000.

The blue line in the figure shows the slope obtained when conducting a rolling regression, with a window size of 36 months, of the annual CPI inflation rate on the unemployment rate. For instance, the value shown for March 2000 is from the regression over the period April 1997 to March 2000. The slope represented by the blue line is -6 in March 1987, meaning that a 1 percentage point decline in the unemployment rate was associated with a 6 percentage point increase in the CPI inflation rate. However, in the second half of the 1990s, the slope rapidly approached zero, and in March 2000 it was more or less zero. Subsequently, the slope moved in the rage of -1 to -2. Further, it appears that since 2013, the slope, if anything, has become smaller, shrinking from about -2 to about -1.

The red line in the figure depicts the result when conducting the same regression but looking only at goods in the CPI, while the green line is for services. As in the case of the estimation for the headline CPI, the explanatory variable used for estimating the slopes is the unemployment rate in the economy as a whole (not the unemployment rates in the goods and service sectors). As can be seen from the figure, the red line is below the green line,

[4]That stimulating demand is insufficient to achieve the 2 percent inflation target and that it is also necessary to change the slope of the Phillips curve and/or shift the position of the curve is also frequently pointed out by members of the BOJ policy board.

indicating that goods prices are more sensitive to changes in the unemployment rate than services prices. Of greater interest here, though, is that the slopes for both goods and services declined. While the slope for goods was -8 in 1993, it rapidly shrank thereafter and became more or less zero in 2000. Furthermore, the slope for services also gradually diminished and in 2002 became around zero. These results show that the slope not of one or the other – goods or services – changed, but that both contributed to the flattening of the Phillips curve.

3 The Distribution of Item-Level Price Changes

Recent literature on the Phillips curve shows that the frequency with which firms adjust prices is an important parameter determining the slope of the Phillips curve. For example, the Phillips curve derived in a Calvo (1983) setting, in which the adjustment of prices by firms follows a Poisson process, the slope is positively related with the probability of price adjustment. If the price adjustment probability is low, changes in economic conditions (as represented by changes in the unemployment rate) will not be factored into prices quickly, so that the slope of the Phillips curve will be shallow.

This suggests that the change in the slope of the Phillips curve in Japan may have been caused by a decline in the frequency of price adjustment. This raises a host of questions such as: Did the frequency of price adjustment actually decline? And if it did decline, for which items is this the case? What are the causes of such a decline in the frequency of price adjustment? And has the adjustment frequency started to increase again since April 2013, when QQE began? In order to find answers to these questions, this section looks at price developments in the individual items making up the CPI. Specifically, the shape of the distribution of price changes of individual items and the evolution of that distribution over time are examined.

3.1 The shape of and changes in the item-level price change distribution

Figure 4 shows the distribution of price changes (monthly y-o-y changes) for each of the 588 items making up the CPI. The vertical axis shows the sum of the CPI weights of the items included in each bin on the horizontal axis. The blue line shows the distribution for March 2014, when the inflation rate was relatively high due to monetary easing, while the black line shows the distribution just before the start of the BOJ's policies to overcome deflation (December 2012). Looking at the blue line, the density is highest in the bins from -0.75 percent to -0.25 percent and from -0.25 percent to $+0.25$ percent, and these two bins alone make up about 50 percent of the total CPI weight. The rate of change of the CPI excluding fresh food for March 2014 was +1.3 percent, and the figure clearly shows that this increase does not reflect a uniform increase in prices of 1.3 percent; rather, there is substantial heterogeneity across items in the rate of price change.

Comparing the distribution for March 2014 with that for December 2012 shows that the former has a fatter upper tail (for items whose prices increased) and a thinner lower tail (for items whose prices decreased) than the latter, and it is this that is responsible for the rise in the CPI inflation rate from −0.2 percent in December 2012 to +1.3 percent in March 2014. On the other hand, the shape of the central part of the distribution (representing items whose prices remained unchanged) is almost the same, meaning that in both 2012 and 2014 observations are concentrated in the vicinity of zero.

In order to examine when the distribution started to take this shape with the peak in the vicinity of zero, Figure 5 plots the share over time of items for which the rate of price change was close to zero. Specifically, four different definitions for "close to zero" are used: ±0.5 percent, ±0.3 percent, ±0.1 percent, and 0 percent. Then, for each year, items for which the rate of change was close to zero are identified and the CPI weights of those items are summed up, and it is this value which is shown on the vertical axis in the figure. Starting with the purple line, which defines "close to zero" as ±0.5 percent, the share of items whose rate of price change was close to zero was only 10-20 percent during the period of high inflation in the 1970s. This indicates that during this inflationary period, almost all items registered price changes every year and only for a limited number of items was the rate of change close to zero, presumably due to circumstances specific to those items. During the 1980s, as overall CPI inflation decelerated, the share of such items increased to a level of about 20-25 percent. Note that the sharp drop in 1989 seen in the figure reflects the effect of the introduction of the consumption tax, as a result of which prices inclusive of tax increased. Similarly, in 1997, the increase in the consumption tax rate resulted in another sharp drop in the share.

However, it is from 1995 that the most conspicuous change in the share of such items can be observed: with the exception of 1997, the share rose rapidly until 1999. In that year, the share of items whose rate of price change was close to zero reached 55 percent, and it has remained at that high level, with some fluctuations, ever since. Looking at the change in the distribution during this period in more detail (Figure 6), while the peak of the distribution for March 1993 is in the bin from +2.25 percent to +2.75 percent, it gradually moves over time, so that in March 1999 the peak is in the vicinity of zero and the distribution starts to take on the shape observed today.

It is important to note that in Figures 4 and 6 the peak of the distribution is not exactly zero but in the vicinity of zero. There are two possible explanations why the peak is in the vicinity of, but not exactly, zero. The first is that there are small but frequent price changes. The other is that for the large majority of the different products that make up the price index of an item the price change was exactly zero, but for a small number of products it differed from zero, so that when the price changes of different products in a particular item category are aggregated, the rate of price change for that item diverges slightly from zero. In order to find out which of these explanations is correct, it is necessary to look at the price changes for individual products published in the Retail Price Survey by the Statistics Bureau of Japan, which provides the source data for the consumer price index.[5] Doing so shows that it is not the case that the prices of individual products changed frequently but in small steps and that, if anything, small price changes are less frequent than large price changes. It can therefore be concluded that the increase in the share of items with a close-to-zero price change is due to the fact that the prices for many products were left unchanged.

To examine this issue further, Figure 7 presents a scatterplot of the share of individual products making up an item index for which the price changed from the previous month for 1995 and 2013. For the construction of the figure, data from the Retail Price Survey were used. Each dot in the figure represents an item, and the figure shows for each of the items the share of products for which prices were adjusted in 1995 on the vertical axis and the share for 2013 on the horizontal axis. We see that for items for which the price adjustment share in 1995 was above 10 percent (that is, items with flexible prices), this share was even higher in 2013. On the other hand, for many items for which the price adjustment share in 1995 was less than 10 percent (i.e., items with sticky prices), the price adjustment share had fallen considerably by 2013. That is, the price stickiness of items whose prices were sticky to start with (such as taxi fares or haircuts) has tended to increase. And it is this increase in price stickiness that is responsible for the peak of the item-level distribution close to zero.

3.2 Item-level price change distributions before and after QQE

Next, let us examine if and how items whose price remained unchanged contributed to inflation under the BOJ's monetary easing since spring 2013. Figure 8 depicts the joint distribution

[5]The indexes of items in the consumer price index are the average of prices gathered in 167 municipalities and the Retail Price Survey provides prices at the level of these municipalities. Saita and Higo (2007) use these data to calculate the frequency of price adjustment.

Table 2: Transition Probability Matrix from December 2012 to March 2014

		Item Level Inflation in Mar. 2014		
		Positive	Zero	Negative
Item Level Inflation in Dec. 2012	Negative	23%	30%	48%
	Zero	4%	79%	16%
	Positive	16%	20%	64%
Unconditional Probability		11%	57%	32%

Note: "Zero" here is defined as a price change between ± 0.75 percent.

of item-level price changes at two points in time: December 2012 and March 2014. Note that the two distributions in Figure 4, that for December 2012 and that for March 2014, are the marginal distributions of this joint distribution. As already seen, the peaks of the marginal distributions for March 2014 and December 2012 were close to zero, but as Figure 8 indicates, the peak of the joint distribution is close to zero on a two-dimensional surface. This means that the price of items whose price remained unchanged in 2012 also remained unchanged in 2014, suggesting that heterogeneity in price stickiness across items is highly persistent.

In order to examine this heterogeneity in detail, Table 2 shows the transition probabilities from 2012 to 2014. Items are divided into those whose price in March 2012 had risen on a y-o-y basis, those whose price had remained unchanged, and those whose price had fallen, and the table shows for each of these groups how prices subsequently developed. Specifically, taking the topmost row as an example, the table is read as follows: among items whose price had fallen in 2012, 23 percent also registered a price decline in 2014, while for 30 percent of these items, prices in 2014 remained unchanged, and 48 percent of items that had registered a fall in 2012 actually saw a price increase in 2014. Note that for the construction of this transition matrix, price changes between -0.75 percent and $+0.75$ percent are defined as "zero" price changes, while anything below is defined as a decrease and anything above as an increase.

The results in Table 2 show that an extremely high percentage of 79 percent of items that registered no price change in 2012 remained in that category in 2014. On the other hand, the percentage of items that transitioned from no price change in 2012 to an increase in 2014 is only 16 percent. In other words, items that registered no price change in 2012 made hardly any contribution to the increase in CPI inflation, suggesting that the BOJ's inflation targeting policy and QQE had very little effect on these items. On the other hand, among items that registered a price increase in 2012, 64 percent also registered an increase in 2014 and contributed to raising the inflation rate. Moreover, among items that registered a price decrease in 2012, 48 percent saw a price increase instead, and this also contributed to pushing up inflation. Thus, items with flexible prices contributed to raising the inflation rate, while items with sticky prices tended to register no price change and were the major obstacle to increases in the CPI inflation rate.

3.3 Is the flattening of the Phillips curve due to higher price rigidity?

The analysis so far has shown that price stickiness increased during the deflationary period. The next task is to examine whether the increase in price stickiness has been responsible for the flattening of the Phillips curve. In order to do so, this subsection presents a simulation analysis in which it is assumed that the prices of unchanged items did not remain unchanged but instead were adjusted. Based on this assumption, the CPI is then recalculated and the slope of the Phillips curve estimated.

We denote the inflation rate of item i in month t by π_{it} and denote the CPI weight of item i by ω_i. We define the average rate of increase of items whose price goes up, π_t^U, by

$$\pi_t^U \equiv \frac{\sum_{\{i|\pi_{it}>\theta\}} \omega_i \pi_{it}}{\sum_{\{i|\pi_{it}>\theta\}} \omega_i} \tag{1}$$

where θ is the parameter determining the threshold for price increases. For example, if $\theta = 0.005$, then when the price of a particular item rises by more than 0.5 percent, this will be regarded as a price increase. Similarly, we define the average rate of decline of items whose price goes down, π_t^D, by

$$\pi_t^D \equiv \frac{\sum_{\{i|\pi_{it}<-\theta\}} \omega_i \pi_{it}}{\sum_{\{i|\pi_{it}<-\theta\}} \omega_i} \tag{2}$$

The set of items whose price remains unchanged is $\{i \mid -\theta \leq \pi_{it} \leq \theta\}$. The aim here is to calculate how the CPI inflation rate would have changed if the prices of these items had not remained unchanged. We employ the following two approaches to calculating the counterfactual inflation rate. In the first approach, the inflation rate, $\hat{\pi}_t$, is the weighted average of π_t^U and π_t^D and is given by the following equation:

$$\hat{\pi}_t \equiv \frac{\pi_t^U \sum_{\{i|\pi_{it}>\theta\}} \omega_i + \pi_t^D \sum_{\{i|\pi_{it}<-\theta\}} \omega_i}{\sum_{\{i|\pi_{it}>\theta \text{ or } \pi_{it}<-\theta\}} \omega_i} \tag{3}$$

Eq. (3) means that part of the unchanged items are converted into items whose price increased and part are converted into items whose price decreased. The shares of items whose prices increased or decreased are set on the basis of the actual share of increasing items ($\sum_{\{i|\pi_{it}>\theta\}} \omega_i$) and the actual share of decreasing items ($\sum_{\{i|\pi_{it}<-\theta\}} \omega_i$) in that month. In other words, the impact of increases or decreases in the share of unchanged items on the inflation rate is completely removed, but no strong assumptions as to whether the prices of unchanged items should have increased or decreased are imposed.

In the second approach to calculating the counterfactual inflation rate, $\hat{\hat{\pi}}_t$, it is assumed that the prices of unchanged items should have fallen but did not do so because of downward price rigidity, so that all unchanged items are converted to items whose prices fell. The second counterfactual inflation rate is defined as follows:

$$\hat{\hat{\pi}}_t \equiv \pi_t^U \sum_{\{i|\pi_{it}>\theta\}} \omega_i + \pi_t^D \sum_{\{i|\pi_{it}<-\theta \text{ or } -\theta\leq\pi_{it}\leq\theta\}} \omega_i \tag{4}$$

Figure 9 shows the Phillips curve when the inflation rate is calculated as in eqs. (3) and (4) using monthly data from 1995. Starting with the Phillips curve obtained using the inflation rate defined by eq. (3), which is represented by the blue squares in the figure, the figure shows that even though the inflation rate becomes slightly lower than actually observed, the difference is very small. Moreover, as was actually observed, the slope of the Phillips curve is extremely small. In contrast, in the Phillips curve obtained using eq. (4), which is represented by the red circles in the figure, the inflation rate is considerably lower than actually observed. For example, the actual inflation rate in 2009, immediately after the outbreak of the global financial crisis, was -1.6 percent, but in this simulation it is -4.3 percent. Reflecting this, the slope of the Phillips curve is also much steeper than the actual slope. These results suggest that prices of items whose prices should have fallen did not fall due to downward price rigidity, and this caused the flattening of the Phillips curve.

4 Why Have Prices Become Stickier?

4.1 Exogenous vs. endogenous changes in price stickiness

There are two possible reasons as to why prices in Japan have become stickier since the mid-1990s. The first is a structural change in the economy, such as a change in the competitive environment that firms operate in, leading firms to change their price setting behaviour and resulting in the increase in price stickiness. Previous studies point to a variety of factors that may have resulted in structural changes in the competitive environment. For instance, the second half of the 1990s is a period when the rise of new firms in emerging economies such as China gathered pace, intensifying global competition. This may have created a situation in which firms were unable to pass on any increases in marginal costs to customers.[6]

An alternative to this is that the increase in price stickiness since the mid-1990s may have been caused endogenously rather than exogenously. Ball and Mankiw (1994) argue based on a menu cost model that price stickiness can change endogenously depending on the level of trend inflation. That is, when trend inflation is high, the profits forgone for a firm by not adjusting prices will be considerable. Such a firm would fall behind if it alone does not raise prices while its rivals do. Because the profits forgone due to not adjusting prices are large, firms will choose to adjust prices despite incurring menu costs. As a result, prices are flexible and the Phillips curve is steeper. In contrast, when trend inflation is close to zero, as has been the case in Japan since the mid-1990s, the profit forgone due to not adjusting prices is smaller than the menu costs, so that firms will put off adjusting prices. Prices are stickier and the slope of the Phillips is curve smaller. In this way, changes in trend inflation lead to endogenous changes in price stickiness. See Levin and Yun (2007), Bakhshi et al. (2007), and Ascari and Sbordone (2014) for more on this issue.

It is important to note that whether the increase in price stickiness arose exogenously or endogenously has quite different implications. If the increase in price stickiness is due to exogenous structural changes, prices should continue to be stickier and it seems unlikely that the slope of the Phillips curve will return to its previous level. In contrast, if the increase in price stickiness is the result of the endogenous mechanism shown by Ball and Mankiw (1994), then price stickiness should decline and the slope of the Phillips curve should return to where it was once trend inflation picks up.

4.2 Relationship between the fraction of price changes and the rate of inflation

To determine whether the observed increase in price stickiness is caused exogenously by structural changes or whether it is caused endogenously, this subsection examines the relationship between price stickiness and trend inflation. Specifically, we will check whether the share of

[6] Studies making this point include those by Rogoff (2003) and Sbordone (2007), while Ball (2006) presents a critical view of the argument that firms' price setting behaviour changed as a result of globalization. Mizuno et al. (2010), taking the intensification of price competition in online markets as an example, point out that greater price transparency due to the internet has given rise to a situation where firms cannot raise prices since each firm fears that rival firms might not raise prices even if marginal costs increase, and that if it alone were to raise prices it would lose customers.

items whose prices are not adjusted is inversely correlated to the rate of inflation, as argued by the previous studies including Ball and Mankiw (1994).

To examine whether this is the case, the shares of items whose prices increased, fell, or remained unchanged are calculated for each month from January 1971 to March 2014. In the panels of Figure 10, these shares are depicted on the vertical axis and monthly observations are plotted against the inflation rate, which is shown on the horizontal axis. It should be noted that "unchanged prices" here are defined as price changes that are strictly zero, while any positive price change is defined as an increase and any negative price change as a decrease. Also, note that observations for April 1989-March 1990 and April 1997-March 1998, when the inflation rate was respectively affected by the introduction of and hike in the consumption tax, are excluded from the sample.

Starting with the panel depicting the relationship between the share of items whose prices rose and the inflation rate, this indicates that in the period 1971-1994, which is represented by the blue circles, a higher inflation rate was associated with a higher share of items whose prices increased. The same relation can be seen for the period 1995-2014, represented by the red squares, but the blue circles and the red squares display a break somewhere around 3 percent inflation. From 1995 onward, the share of increasing price items declines more quickly with the rate of inflation.

Turning to the share of items whose prices fell, the figure indicates that in the period 1971-1994 this tends to fall when inflation rises. However, similar to the share of increasing price items, the share of decreasing price items displays a break in the neighbourhood of 3 percent and rapidly increases when inflation falls to zero.

A simple linear regression shows that in the period 1971-1994, a 1 percentage point fall in the inflation rate led to a 1.3 percentage point decline in the share of items whose price increased and a 0.9 percentage point rise in the share of items whose price fell, indicating that the decline in the former was greater than the increase in the latter. Consequently, a 1 percentage point decline in the inflation rate raised the share of items whose price remained unchanged by 0.4 percentage points. The fact that the blue circles in Figure 10(c) are downward sloping provides a graphic representation of this relationship. In other words, price stickiness as measured by the share of unchanged items increases as the inflation rate declines from a positive value to zero. This finding suggests that the observed increase in price stickiness is, at least partially, due to the endogenous mechanism described by Ball and

Mankiw (1994).[7]

Figure 10(c) also shows that price stickiness decreases as the inflation rate falls from zero into negative territory.[8] A simple regression shows that the share of items whose price remained unchanged increases by 0.008 percentage points for a 1 percentage point deviation in the rate of inflation from zero in a negative direction. Interestingly, the corresponding figure is greater when the rate of inflation deviates in a positive direction (0.003), suggesting that the extent to which prices become less sticky is greater when the inflation rate moves from zero into negative territory than when it moves into positive territory. Note that this is the opposite of downward price rigidity.[9]

4.3 Relationship between the average size of price changes and the rate of inflation

Next, Figure 11 examines the relationship between the average size of price adjustments for individual items and the rate of inflation. The figure shows the average size of price adjustments (in percentage terms vis-à-vis the same month a year earlier) for items for which prices in a particular month increased (panel (a)) or decreased (panel (b)) on the vertical axis and the inflation rate on the horizontal axis.

Looking at the period 1971-1994 represented by the blue circles, the figure shows that the average size of price increases for items whose price increased is larger the higher the inflation rate. On the other hand, for items whose price decreased, the average size of price reductions

[7]Evidence of endogenous changes in price stickiness can be found for other countries as well. Using Mexican data, Gagnon (2009) shows that during the transition from the period of high inflation in 1994-1995 to lower inflation in the second half of the 1990s the frequency of price adjustment declined. Specifically, he finds that in the low inflation period, an increase in the inflation rate by 1 percentage point was associated with a 0.35 percentage point increase in the share of products whose price increased and a 0.22 percentage point decrease in the share of products whose price fell. As a result, the share of products whose prices remained unchanged declined by 0.13 percentage points. He further finds that the negative correlation between the inflation rate and price stickiness was stronger during the high inflation period. Similarly, Nakamura and Steinsson (2008), using micro price data for the United States, find evidence of a negative correlation between price stickiness and the inflation rate.

[8]Note that all of the studies to date using micro price data deal with periods of positive inflation and there are no examples of studies on the relationship between the inflation rate when this is zero and price rigidity. Gagnon (2009) also mainly focuses on a period of positive inflation, although in 2001 and 2002 the prices of fresh vegetables and fruits in Mexico fell due to weather factors and the y-o-y rate of change in the CPI for goods turned negative. It appears that during this period, symmetry held in that price stickiness tended to decrease the more the inflation rate in terms of the CPI for goods fell below zero (see Figure 4 in Gagnon (2009)). However, this bout of deflation lasted only for a few months, so that it is not possible to tell whether this is a robust tendency.

[9]Menu cost models assume that a firm does not change its price as long as the deviation of the current price from the optimal price, which would be achieved if prices were perfectly flexible, is within a certain range. If this "inaction" range is symmetric around zero, we should observe that a change in the share of items whose prices remain unchanged is symmetric when inflation moves from zero to positive and from zero to negative.

is more or less fixed regardless of the level of inflation. These two results are similar to the findings of previous studies using micro price data. The fact that the average size of price increases is positively correlated with the inflation rate can be interpreted as reflecting that the higher the inflation rate the higher is the number of individual products making up each item category whose price goes up.

Turning to the period 1995-2014 represented by the red squares, the figure shows that the larger the rate of deflation, the smaller is the size of price increases and the larger is the size of price decreases.[10] The finding that during the deflationary period the average size of price increases became smaller and the average size of price decreases larger itself is not particular surprising, but what is of note here is the relative sizes of the two. Linear regression shows that a 1 percentage point decrease in the inflation rate (or increase in the deflation rate) is associated with a 0.53 percentage point reduction in the average size of price increases and a 0.28 percentage point increase in the average size of price decreases. This result may be interpreted as reflecting the presence of downward rigidity of prices during the deflationary period.

5 Cross-country Comparison of Price Change Distributions

Over the last two decades, inflation has been falling in most industrial countries. However, no country except Japan has experienced persistent deflation. Why did Japan fall into deflation, while other countries did not? To address this question, we conduct a cross-country comparison in this section. Specifically, we compare major industrial countries including Japan and the United States in terms of the item-level price change distribution, with a particular focus on price stickiness in those countries.

5.1 Cross-country comparison as of March 2014

Let us start by comparing the item-level price change distribution for Japan as of March 2014 with those for the United States, Canada, and the United Kingdom (Figure 12). Starting with the United States, the peak of the distribution lies between 2 and 3 percent. Although there is also a small peak around zero, the peak around 2-3 percent is much higher, and the shape of the distribution is quite different from that for Japan. It could be said that in the United

[10] The decline in the size of price increases of items whose price increases can be interpreted as reflecting that the number of individual products making up an item whose price goes up decreases. The increase in the size of price declines for items whose price declines can be explained in a similar way.

States price increases of around 2-3 percent are the default, meaning that unless there are special circumstances, US firms raise their prices every year in the range of 2-3 percent. On the other hand, in Japan the default is to leave prices unchanged, and this likely gives rise to the difference in the distributions. Meanwhile, it is interesting to note that in March 2014, the overall CPI inflation rate in the United States was 1.5 percent, which is not very different from the corresponding rate in Japan. Thus, differences in the shape of the distribution cannot be explained by differences in the rate of CPI inflation.

Looking at the results for the other two countries, the peaks of the distributions for both Canada and the United Kingdom are in the range of 1-2 percent. In other words, for all three countries – the United States, Canada, and the United Kingdom – the peak of the distribution is in the vicinity of 2 percent. These countries have an inflation target of 2 percent and the peak of the distribution and the level of the inflation target more or less coincide with each other. While Figure 12 alone does not allow us to judge whether this is the outcome of inflation targeting, what can be said is that it is likely that, in these three countries, firms' inflation expectations, which are a key determinant of firms' price setting behaviour, are firmly anchored at around 2 percent.

Neither the United States nor Canada or the United Kingdom have experienced deflation in the recent past, so that their circumstances differ from Japan's. Therefore, Figure 13 shows the price change distribution for Switzerland, which recently has experienced deflation. Following the first bout of deflation in summer 2009 in the wake of the global financial crisis, Switzerland again experienced deflation in summer 2012. Although the shapes of the distributions differ somewhat, they have in common that the peak of the distribution is in positive territory not far from 2 percent. In both cases, the lower tail of the distribution is thick, and because this pulls down the mean of the distribution, the overall CPI inflation rate is negative. It is likely that the thick lower tail reflects the decline in import prices as a result of the appreciation of the Swiss franc. However, despite the price decline through currency appreciation, many firms raised prices by 1-3 percent, suggesting that even though there was deflation, firms' inflation expectations were well anchored.

5.2 The fraction of items with a near-zero price change conditional on the mean of the item-level price change distribution

As we saw in the previous section, the shape of the item-level price change distribution differs depending on the level of trend inflation. Therefore, a simple comparison of price change distributions in different countries at a particular point in time may be misleading, since the rate of inflation in different countries differs at any particular point in time. In what follows, we instead focus on the distribution of item-level price changes in period t conditional on the mean of the distribution in the same period (i.e., the rate of inflation in period t). We compare such "conditional" distributions for eight countries, namely, Japan, the United States, Canada, Germany, France, Switzerland, Italy, and the United Kingdom.[11]

The first thing we do is to calculate, for each country, the fraction of items with a near-zero price change for a given overall inflation rate. The results are shown in Figure 14, which is read as follows. The value on the vertical axis corresponding to, say, 2 percent on the horizontal axis represents the fraction of items with a near-zero price change in those months in which the mean of the distribution – i.e., the inflation rate – is in the vicinity of 2 percent. As can be seen, a common feature across countries is that the fraction of items with near-zero inflation tends to decrease with the rate of inflation. In other words, prices tend to be stickier the closer the rate of inflation is to zero. As mentioned in the previous section, this is extensively discussed by Ball and Mankiw (1994) among others in the context of state dependent pricing. However, a number of important differences across countries can be observed. First, the fraction of items with near-zero inflation is significantly higher in Japan than the other countries, irrespective of the rate of inflation shown on the horizontal axis. This suggests that prices are sticker in Japan than the other countries. Note that this may be due to differences in terms of the data granularity. The number of items in the Japanese item-level price data is 588, which is comparable to the number of items for Germany and that for the United Kingdom but much larger than those in the other countries (see footnote 11 for the number of items in the other countries). The granularity of the Japanese data is finer in this sense, so that it is possible that there are more zeros in the Japanese data. To check whether this is the reason for the higher fraction of items with near-zero inflation, we construct a new dataset in which we reduce the number of items from 588 to about

[11]The data on monthly item-level price indexes are obtained from the websites of the statistical offices of these countries. The number of items and the observation period for each country are as follows: for Japan, the number of items is 588 and the observation period is 1970 to 2016; for the United States, the number of items is 182 and the observation period is 1970 to 2016; for Canada, the number of items is 170 and the observation period is 1985 to 2016; for Germany, the number of items is 577 and the observation period is 1991 to 2016; for France, the number of items is 262 and the observation period is 1990 to 2016; for Switzerland, the number of items is 268 and the observation period is 1982 to 2016; for Italy, the number of items is 215 and the observation period is 1996 to 2010, and finally, for the United Kingdom, the number of items is 687 and the observation period is 1997-2016. The number of items for each country may not be the same throughout the observation period. Note that the analysis in this and later subsections is based on unweighted data (e.g., unweighted rather than weighted mean of the item-level price change distribution.

300 through aggregation and repeat the same exercise as in Figure 14. However, we find no significant difference in the result.

Second, the fraction of items with near-zero inflation for Japan takes the highest value when the inflation rate is somewhere around -2 percent and tends to become smaller as the rate of inflation goes deeper into negative territory. This is again consistent with the prediction by Ball and Mankiw (1994) that prices become less sticky as the rate of deflation increases. The same tendency can be seen for the other countries, but the location of the peak is different from that of Japan. For the United States and the United Kingdom, the peak is negative but not that far away from zero. For Canada and Switzerland, the peak is located in positive territory.[12] Note that if the mode of the conditional distribution is located somewhere around zero irrespective of the rate of inflation, we would expect the fraction of items with zero inflation to monotonically increase with the rate of inflation, reaching its maximum when the inflation rate is zero. However, given that this does not happen in some of the countries here, it may be the case that the mode of the conditional distribution in those countries is different from zero. In the next subsection, we will investigate this issue in more detail.

5.3 The mode of the item-level price change distribution conditional on the mean of the distribution

As we saw in Figure 12, the mode of the item-level price change distribution as of March 2014 was in the vicinity of zero for Japan, while it was above zero for the United States, Canada, and the United Kingdom. In the upper panel of Figure 15, we now look at the mode of the conditional distribution (i.e., the item-level price change distribution conditional on its mean) for each of the eight countries already considered in Figure 14. We see that for Japan the mode is much lower than for the other countries irrespective of the rate of inflation. For example, when the inflation rate, which is shown on the horizontal axis, is 3 percent, the mode is about 1 percent for Japan, while it is slightly higher than 3 percent for the United States.

A feature that is common to all countries is that the mode and the mean of the item-level price change distribution do not coincide with each other. Specifically, as the upper panel of Figure 15 shows, the mean is greater than the mode when the mean is high, indicating

[12] Meanwhile, for the other three countries (Germany, France, and Italy), no peak is observed, since there are not many observations with a negative inflation rate. However, looking at the curves for these countries, it appears that any peak likely would *not* be located in positive territory - at least in the case of Germany and France.

that the distribution is skewed to the right. In contrast, when the mean is low, the mean is smaller than the mode, indicating that the distribution is skewed to the left.[13] To see how the asymmetry of the conditional distribution changes depending on the rate of inflation, in the lower panel of Figure 15 we replace the vertical axis with the difference between the mean and the mode. As can be seen, in Japan's case, the mean and the mode coincide when the inflation rate is exactly zero, suggesting that the conditional distribution is symmetric. The conditional distribution is skewed to the right when the inflation rate is above zero, while it is skewed to the left when the inflation rate is below zero. In this sense, the threshold associated with symmetry/asymmetry is zero for Japan. However, for the United States, the threshold is slightly above 3 percent, much higher than for Japan. In fact, the threshold is higher than for Japan for all the other countries in our sample.[14]

What determines the mode of a price change distribution? Why does the mode of the conditional distribution differ across countries? In the rest of this section, we construct a state dependent pricing model to address these questions.

Suppose there are multiple sectors in the economy, each of which consists of multiple firms producing different products. For example, shampoo manufacturing represents one sector, and there are many firms producing shampoos within this sector, each of which produces different shampoo products. We introduce various types of heterogeneity across sectors, but to simplify the analysis, we assume that firms (and products) within a sector are all identical.

Following Caballero and Engel (2007), we assume that each firm knows the optimal price for its product; however, because adjusting prices is costly and incurs menu costs, firms do not always achieve that optimal price. Denote the log of the optimal price of a product in

[13]Details on the estimation method of the mode of the item-level price change distribution are provided in Appendix A.

[14]The presence of a positive correlation between the mean and the skewness of the cross sectional price change distribution was first pointed out by Vining and Elwertowski (1976) and discussed more extensively by Ball and Mankiw (1995) and Balke and Wynne (2000). Our result presented in Figure 15 is basically the same as the results obtained in these studies. As for the mechanism generating the positive correlation between the mean and skewness, these papers all point to heterogeneity in shocks to different sectors. For example, Ball and Mankiw (1994) argue that if the distribution of sector-specific shocks, such as oil price hikes, is skewed to the right, firms in a particular sector that experiences a large shock have an incentive to raise their prices, while firms in a sector that experiences only a very small shock do not want to change their prices, since this would incur menu costs. Therefore, even if the mean of the sector shock distribution is zero, the mean of the inflation rates in individual sectors could be positive, creating a positive correlation between the mean and skewness. On the other hand, Balke and Wynne (2000) argue that the positive correlation between the mean and the skewness has nothing to do with menu costs, but simply reflects skewness in the underlying shocks that cause relative prices to change. More recently, Choi (2010) and Choi and O'Sullivan (2013) have argued that the degree of price stickiness differs across sectors, so that even common shocks (i.e., shocks common to all sectors) may have different impacts on prices across sectors, thereby creating skewness in sectoral price change distributions.

sector i by p^*_{it} and the log difference from the previous period by Δp^*_{it}. It is assumed that Δp^*_{it} is determined as follows:

$$\Delta p^*_{it} = \Delta m_t + v_{it}, \tag{5}$$

where Δm_t is a common shock affecting all products in all sectors (therefore, there is no subscript i). We specify Δm_t as $\Delta m_t = \mu + \epsilon_t$, where μ is a drift in the common shock or trend inflation, and ϵ_t is a mean zero iid disturbance. The common shock includes monetary policy shocks such as a change in base money. On the other hand, v_{it} represents sector-specific shocks. It is assumed that the mean of v_{it} is zero, but its skewness may be different from zero, as discussed by Ball and Mankiw (1995) and Balke and Wynne (2000).

The log of the actual price of a product in sector i at time t is denoted by p_{it}. The price at the start of period t is p_{it-1}, and firms decide whether to change p_{it} to p^*_{it} or not. If the firm decides not to adjust its price to p^*_{it}, the price in period t becomes $p_{it-1} + \bar{\pi}$, where $\bar{\pi}$ is the rate of price change associated with price indexation. If there is no price indexation in the economy, $\bar{\pi} = 0$, which is what Caballero and Engel (2007) assume in their original model, but we allow $\bar{\pi}$ to take a non-zero value.[15] Firms decide whether to change p_{it-1} to p^*_{it} as follows. Firms calculate how much the sum of p_{it-1}, which is carried over from period t, and $\bar{\pi}$ deviates from p^*_{it}. Denote the percentage by which $p_{it-1} + \bar{\pi}$ deviates from p^*_{it} by x_{it}; that is,

$$x_{it} \equiv p_{it-1} + \bar{\pi} - p^*_{it} \tag{6}$$

If a firm has not adjusted its price for a long time, x_{it} should take a large value, which could be either positive or negative. Conversely, if a firm adjusted its price very recently, x_{it} should be close to zero. Thus, x_{it} contains information on the history of firms' price adjustment.

Whether a firm adjusts its price in period t depends on x_{it}. If x_{it} considerably diverges from zero, the firm will choose to adjust its price. Conversely, if x_{it} does not greatly diverge from zero, it will choose not to adjust. This decision-making is represented by function $\Lambda(x_{it})$, which is the probability that a firm chooses to adjust its price when the deviation from the

[15]See Yun (1996) for an example of a Calvo-type model with price indexation. In the standard Calvo model, it is assumed that only a fraction of randomly chosen firms are allowed to change their prices in each period. All other firms apply the same prices as in the previous period. In contrast, Yun (1996) assumes that these other firms are also allowed to change their prices, but not at a rate they decide but a rate that is mechanically fixed at a prespecified level.

optimal price in period t is x_{it}. We specify $\Lambda(x_{it})$ as follows:

$$\Lambda(x_{it}) = \begin{cases} 0 & \text{if} \quad L \leq x_{it} \leq U \\ \\ 1 & \text{otherwise} \end{cases} \tag{7}$$

where L and U are negative and positive parameters. Eq. (7) states that when x_{it} falls between L and U and hence the divergence from zero is sufficiently small, no price adjustment takes place, but when x_{it} diverges by more (that is, when x_{it} takes a larger negative value than L or a larger positive value than U) a price adjustment takes place with probability one.

Note that the new price set by a price-adjusting firm ("adjuster") is $p_{it-1} + \bar{\pi} - x_{it}$, while the price charged by a non-adjusting firm ("non-adjuster") is mechanically and uniformly updated to $p_{it-1} + \bar{\pi}$. Price changes in individual sectors, i.e., changes in p_{it}, can be aggregated to calculate the rate of inflation, π_t:

$$\pi_t = \int \pi_{it} di = \bar{\pi} - \int x\Lambda(x)h(x)dx \tag{8}$$

where π_{it} is the price change in sector i, and $h(x)$ is the steady state distribution of x across sectors.

We use this model to numerically show the shape of the item-level price change distribution conditional on its mean. The parameters of the model are set as follows: $\mu = 0.02$; $\sigma_m = 0.30$; $L = -0.05$; $U = 0.05$; $\bar{\pi} = 0.02$. The idiosyncratic shock v_{it} is assumed to follow a skew normal distribution with $v_{it} \sim SN(0, 0.05^2, 7.00)$. We continue to use the same parameter values throughout the rest of the analysis unless stated otherwise.

Figure 16 shows the shape of the conditional distribution and clearly indicates that it is multimodal. One of the modes is generated by non-adjusters. As they uniformly change prices by $\bar{\pi}$, the conditional distribution has a peak at $\bar{\pi}$. The other modes are generated by adjusters. As x_{it} differs across sectors, the size of the price change chosen by an adjuster differs depending on which sector that adjuster belongs to. However, we can still identify the major mode (i.e., the most frequent value) of the conditional distribution of price changes made by adjusters. That is, for a given level of Δm_t, the major mode is given by[16]

$$\text{mode } (\pi_{it}) = \begin{cases} \bar{\pi} - \tilde{x}(\Delta m_t) & \text{if} \quad \tilde{x}(\Delta m_t) < L \\ \bar{\pi} - L & \text{if} \quad L \leq \tilde{x}(\Delta m_t) \leq \tilde{x}(c) \\ \bar{\pi} - U & \text{if} \quad \tilde{x}(c) < \tilde{x}(\Delta m_t) \leq U \\ \bar{\pi} - \tilde{x}(\Delta m_t) & \text{if} \quad U < \tilde{x}(\Delta m_t) \end{cases} \tag{9}$$

[16]Details on this derivation are provided in Appendix B.

where $\tilde{x}(\Delta m_t)$ is defined by

$$\tilde{x}(\Delta m_t) = \arg\max_x \int_v \Lambda(x - \Delta m_t - v)h(x)f(v)dv \tag{10}$$

and $f(v)$ is the distribution of v across sectors, and the parameter c in eq. (9) is defined by

$$\int_v \Lambda(L - c - v)h(L)f(v)dv = \int_v \Lambda(U - c - v)h(U)f(v)dv. \tag{11}$$

Figure 17 shows the value of Δm_t on the horizontal axis and the major mode (i.e., mode (π_{it}) in eq. (9)) on the vertical axis. The upper and lower panels correspond to the case of positive and negative skewness in sector-specific shocks. Looking at the upper panel, we see that the mode changes depending on the level of Δm_t. If Δm_t takes a large positive value, the mode is given by $\bar{\pi} - \tilde{x}(\Delta m_t)$ and monotonically increases with Δm_t. When Δm_t is smaller than this but still positive, the mode is given by $\bar{\pi} - L$, which is greater than $\bar{\pi}$ as L is negative. When Δm_t is even smaller, the mode is given by $\bar{\pi} - U$, which is smaller than $\bar{\pi}$ as U is positive. Finally, if Δm_t takes a negative value, the mode is given by $\bar{\pi} - \tilde{x}(\Delta m_t)$ and monotonically decreases with Δm_t.

An important implication of the result presented in Figure 17 is that the mode of the price change distribution does not necessarily coincide with the common shock Δm_t. For example, if the skewness of the distribution of sector-specific shocks is positive and Δm_t takes a large positive value, then the mode is always smaller than Δm_t. If, instead, the distribution of sector-specific shocks were symmetric around the mean, then the mode of the price change distribution would coincide with Δm_t. If this is the case, we can obtain useful information about the common shock by observing the value of the mode. However, in practice, the distribution of sector-specific shocks is not symmetric but skewed, and therefore the mode is not an accurate estimator of the common shock. One implication of this is that, as we saw in Figure 15, Japan and the other countries have different modes, but we cannot say whether this stems from differences in the common shock across countries (e.g., differences in the drift term of the common shock, which is represented by μ).

However, Figure 17 allows us to make some inferences about the common shock from the value of the mode. That is, the mode and the common shock coincide with each other when the mode and the mean coincide with each other. This is represented by points A, B, and C in the figure. As the mode and the mean are both observable, we can identify observations for which the mode and the mean are identical, allowing us to make inferences on the common shock. More importantly, the mode and the mean coincide only in a limited number of cases such as points A, B, and C in the figure, so that we can obtain useful information on the values of $\bar{\pi}$, $\bar{\pi} - L$, and $\bar{\pi} - U$ from the observed value of the mode when it coincides with the mean.

This provides useful information when trying to understand why the threshold in Figure 15 at which the mode and the mean coincide differs between Japan and the other countries. It is unlikely that Japan and the other countries are located somewhere like point C, since even in Japan the rate of deflation is not very large. It therefore seems safe to rule out this possibility. However, there still remain two other possibilities. The first is that, for Japan, Δm_t is very close to zero, so that the fraction of non-adjusters is very large, making point B the major mode. In other words, the major mode for Japan is generated by non-adjusters rather than adjusters. In contrast, for the other countries, Δm_t is positive and far away from zero, so that the fraction of adjusters is large. Thus, the major mode is generated by adjusters, which is given by point A. In this case, the threshold is $\bar{\pi}$ for Japan, but $\bar{\pi} - L$ for the other countries. Since L takes a negative value, $\bar{\pi} - L$ is positive even if $\bar{\pi}$ is zero. Note that if it is for this reason that the threshold differs between Japan and the other countries, the difference would disappear sooner or later by raising Δm_t in Japan through policy measures such as monetary easing.

The second possibility is that all countries including Japan are located at point B, but the value of $\bar{\pi}$ differs between Japan and the other countries. For example, it is very close to zero for Japan, while it is slightly higher than 3 percent for the United States. It is this difference in $\bar{\pi}$ that creates the difference in the threshold observed in Figure 15. Note that the literal definition of $\bar{\pi}$ in our model is the rate of price change associated with price indexation. However, it may not be appropriate to interpret such price indexation as automatic annual price increases at a rate of $\bar{\pi}$ explicitly stated in contracts. Instead, a more realistic interpretation is that there is an implicit understanding among sellers and buyers that prices will be revised each year around a fixed rate. In this sense, $\bar{\pi}$ in our model may be interpreted as what Schultze (1981) and Okun (1981), among others, have referred to as the "inflation norm." Note that if the reason for the different thresholds in Japan and the other countries is different inflation norms, it will take time to eliminate such differences.

5.4 The dispersion of the item-level price change distribution conditional on the mean of the distribution

Thus far we have examined how the mean of the item-level price change distribution is related to the mode and skewness of the distribution. We now examine the relationship with the dispersion of the distribution. Previous studies on relative price variability (RPV), including Vining and Elwertowski (1976), Parks (1978), and Fischer (1981), show that the variance of the item-level price change distribution tends to increase with the rate of inflation.

Sheshinski and Weiss (1977) and Weiss (1993) provide an explanation of these empirical results based on menu cost models.[17] Specifically, Weiss (1993) argues that, at moderate inflation rates, an increase in inflation raises the relative size of each price increase; in addition, the degree of synchronization in firms' price adjustments is rather low, so that RPV rises with inflation. However, Weiss (1993) also argues that, at very high rates of inflation, most firms raise prices within the same period (so that price adjustments are synchronized) and at more similar rates, so that RPV *declines* as the rate of inflation increases.

Using the *Ss* model introduced in the previous subsection, we can calculate the cross-sectional variance of π_{it}. To simplify the analysis, we assume that $\Lambda(x)$ is symmetric around $x = 0$ and that the distribution of v_{it} is not skewed so that $f(v)$ is symmetric around $v = 0$. The cross-sectional mean and variance of π_{it} are given by

$$\begin{aligned} E(\pi_{it}) &= -\int_x \left[\int_v (x-\bar{\pi}-v)\Lambda(x-\bar{\pi}-v)f(v)dv\right] h(x-\bar{\pi})dx + \bar{\pi} = \bar{\pi} && (12) \\ Var(\pi_{it}) &= \int_x \left[\int_v (x-\bar{\pi}-v)^2 \Lambda(x-\bar{\pi}-v) f(v)dv\right] h(x-\bar{\pi})dx - \bar{\pi}^2 && (13) \end{aligned}$$

A change in the cross-sectional variance in response to a common shock $\Delta m - \bar{\pi}$ is given by

$$\Delta Var(\pi_{it}) = \int_x \left[\int_v (x-\Delta m-v)^2 \Lambda(x-\Delta m-v) f(v)dv\right] h(x-\bar{\pi})dx \quad (14)$$

We differentiate eq. (14) with respect to $\Delta m - \bar{\pi}$ and evaluate the derivative at $\Delta m - \bar{\pi} = 0$ to obtain:

$$-\int_x \left[\int_v \Big(2(x-\bar{\pi}-v)\Lambda(x-\bar{\pi}-v) + (x-\bar{\pi}-v)^2\Lambda'(x-\bar{\pi}-v)\Big) f(v)dv\right] h(x-\bar{\pi})dx \quad (15)$$

Note that, since $\Lambda(x)$ is symmetric around $x = 0$, $h(x)$ is also symmetric around $x = 0$, which implies

$$\int_x \left[\int_v (x-\bar{\pi}-v)\Lambda(x-\bar{\pi}-v)f(v)dv\right] h(x-\bar{\pi})dx = 0$$

[17] See Choi (2010) and Hajzler and Fielding (2014) for explanations not based on menu cost models.

and

$$\int_x \left[\int_v (x - \bar{\pi} - v)^2 \Lambda'(x - \bar{\pi} - v) f(v) dv \right] h(x - \bar{\pi}) dx = 0$$

Combining these two equations, we obtain that the marginal change in the cross-sectional variance of π_{it} in response to the common shock is zero when evaluated at $\Delta m_t = \bar{\pi}$, implying that the cross-sectional variance of π_{it} takes its minimum when $\Delta m_t = \bar{\pi}$.

Figure 18 presents a numerical result based on the Ss model introduced in the previous subsection. The figure depicts the standard deviation of the item-level price change distribution conditional on Δm_t. Here we assume v_{it} is not skewed so that it follows a normal distribution with mean zero and a standard deviation of 0.05. The figure shows that starting from 2 percent, the standard deviation tends to rise as inflation goes up. This is similar to the empirical findings reported in previous studies. However, the figure also shows that starting from 2 percent, the standard deviation tends to rise as inflation falls below that value and turns negative. In other words, the relationship between RPV and inflation is symmetric around 2 percent, which is the value of $\bar{\pi}$. This is consistent with the above result that the variance of π_{it} takes a minimum value at $\Delta m_t = \bar{\pi}$. Also, the figure shows that the cross-sectional standard deviation tends to decrease as Δm_t increases when Δm_t is greater than 10 percent, and that it tends to decrease as Δm_t decreases when Δm_t is smaller than -10 percent. This is consistent with the explanation by Weiss (1993) based on menu cost models that, at high rates of inflation, RPV is reduced as the rate of inflation increases.

Turning to the empirical analysis, Figure 19 shows the relationship between RPV, which is measured as the difference between the 10th and 90th percentiles of a distribution, and the inflation rate for the eight countries. We find the presence of a U-shaped relationship in all countries except Italy and Germany, for which the number of observations with negative inflation rates is quite limited.[18] More interestingly, the bottom of the U-shape differs across countries. It is slightly below zero for Japan, but positive for the other countries. For example, the bottom is located at 1 percent for the United States, 1.5 percent for Canada, 0.5 percent for Switzerland, 1.5 percent for France, and 1.5 percent for the United Kingdom. The result based on our model that the bottom of the U-shape is determined by $\bar{\pi}$ suggests that the observed difference in the bottom of the U-shape between Japan and the other countries stems from the difference in $\bar{\pi}$ across countries. If we interpret $\bar{\pi}$ as the inflation norm, this is somewhere around 1 percent for all countries in the figure other than Japan, while it is in

[18] Choi (2010) finds similar a U-shaped relationship between inflation and RPV for the United States and Japan.

the vicinity of zero for Japan. Why is the inflation norm so low in Japan? While addressing this question is beyond the scope of this paper, it seems likely that it is the result of the prolonged deflation Japan has experienced, which has led firms to gradually change their pricing behaviour and eventually keep prices unchanged.

6 Conclusion

The main findings of the paper are as follows. First, for the majority of the 588 items constituting the CPI, making up about 50 percent of the CPI in terms of weight, the y-o-y rate of price change was close to zero. In this sense, price stickiness was high. This situation started during the onset of deflation in the second half of the 1990s and continued even after the y-o-y rate of change in the CPI turned positive in spring 2013.

Second, using monthly data from 1970 onward, this paper examined the relationship between the share of items with a y-o-y rate of price change close to zero and the y-o-y rate of change in the CPI. The analysis showed that the share of items whose rate of price change is close to zero decreases with the rate of increase in the CPI. This result can be explained by a simple menu cost model; that is, as the trend inflation rate approaches zero, the opportunity cost of leaving prices unchanged decreases (see, for example, Ball and Mankiw (1994), Levin and Yun (2007), and Bakhshi et al. (2007)). It also suggests that the price stickiness observed from the second half of the 1990s arose endogenously as a result of the decline in inflation, and more importantly, that if prices start increasing again, prices will gradually become more flexible again.

Third, the cross-country comparison of price change distributions revealed that Japan differs significantly from other countries in that the mode of the distribution is very close to zero for Japan, while it is near 2 percent for the other countries examined, including the United States. This feature remains unchanged even if we look at the mode of the distribution conditional on the rate of inflation. This suggests that whereas in the United States and other countries the “default” is for firms to raise prices by about 2 percent each year, in Japan the default is that, as a result of prolonged deflation, firms keep prices unchanged.

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A Methodology to Estimate the Mode of the Cross-Sectional Price Change Distribution

This section explains our methodology to estimate the mode of the item-level price change distribution. Following Silverman (1981, 1983), we test the null hypothesis (H_0) that a probability distribution has at most M modes against the alternative hypothesis (H_1) that it has more than $M+1$ modes. Specifically, we first compute the kernel density estimate for observations $\{x_i\}_{i=1,2,\cdots,n}$ as follows:

$$\hat{f}_h(x) = (nh)^{-1} \sum_{i=1}^{n} K\left(\frac{x - x_i}{h}\right), \tag{A.1}$$

where K is a kernel function. As shown by Silverman (1981, 1983), the number of modes for bandwidth h is a right-continuous decreasing function of h when K is a Gaussian kernel function. Then, we define the critical bandwidths $h_{M,c}$ as follows:

$$h_{M,c} := \inf\{h | N(\hat{f}_h) \leq M\} \quad \text{for} \quad M = 1, 2, \ldots \tag{A.2}$$

where $N(\hat{f}_h)$ is the number of modes for bandwidth h, and $\hat{f}_h$ is defined by $\hat{f}_h = \{x | \hat{f}_h{}'(x) = 0, \hat{f}_h{}''(x) < 0\}$. If the number of modes is greater than $M+1$, $h_{M,c}$ takes a large value, so that the null is rejected.

Note that $N(\hat{f}_h) > M$ if $h < h_{M,c}$. We employ a bootstrap method to evaluate the statistical significance of $h_{M,c}$. Specifically, we randomly draw n times from observation $\{x_i\}_{i=1,2,\cdots,n}$ to obtain a bootstrap sample $\{x_i^*\}_{i=1,2,\cdots,n}$ and then compute a smoothed bootstrap sample $\{y_i^*\}_{i=1,2,\cdots,n}$, which is given by

$$y_i^* = \frac{1}{\sqrt{1 + h_{M,c}^2/\sigma^2}}(x_i^* + h_{M,c}\epsilon_i), \tag{A.3}$$

where σ^2 is the sample variance of observations and ϵ_i is an i.i.d standard Gaussian. By apply the smoothed bootstrap resampling procedure, we obtain the kernel density estimate for y_{it}^* and estimate the critical bandwidth $h'_{M,c}$ that has at most M modes. The test statistic is the bootstrap distribution of $h'_{M,c}/h_{M,c}$ and α-level test of H_0 against H_1 is to reject H_0 if $P(h'_{M,c}/h_{M,c} > 1) < \alpha$. In the analysis conducted in Section 5, we repeat the above bootstrapping procedure 1000 times to calculate the fraction of simulations where $h'_{M,c} > h_{M,c}$.

This test applies the kernel density estimator where the bandwidth is fixed in both of dense and sparse areas of the distribution. Hence, it is easily affected by tiny bumps or small samples in the tails. Also, note that the kernel estimate with a Gaussian kernel is usually a smooth curve and it will crush the peaks like spikes. For the former weakness, Izenman and Sommer (1988) proposes to use the adaptive kernel density estimate for this test. The adaptive kernel density estimate by Abramson (1982), Silverman (1984, 1986), and Fox and Long (1990) is given by

$$\tilde{f}_h(x) = n^{-1} \sum_{i=1}^{n} (h\lambda_i)^{-1} K\left(\frac{x - x_i}{h\lambda_i}\right), \tag{A.4}$$

In this equation, λ_i is a local band factor at each x_i defined by

$$\lambda_i = \left\{\bar{f}/\hat{f}(x_i)\right\}^{1/2}, \tag{A.5}$$

where $\bar{f}$ is the geometric mean of $\hat{f}(x_i)$. In the analysis conducted in Section 5, we start this test for $M = 1$ and continues until the test fails to reject H_0 at $\alpha = 0.05$. We adopt the minimum M which cannot reject H_0.

B The Mode of the Item-Level Price Change Distribution in the Caballero-Engel Model

Figure 1: Consumer price inflation

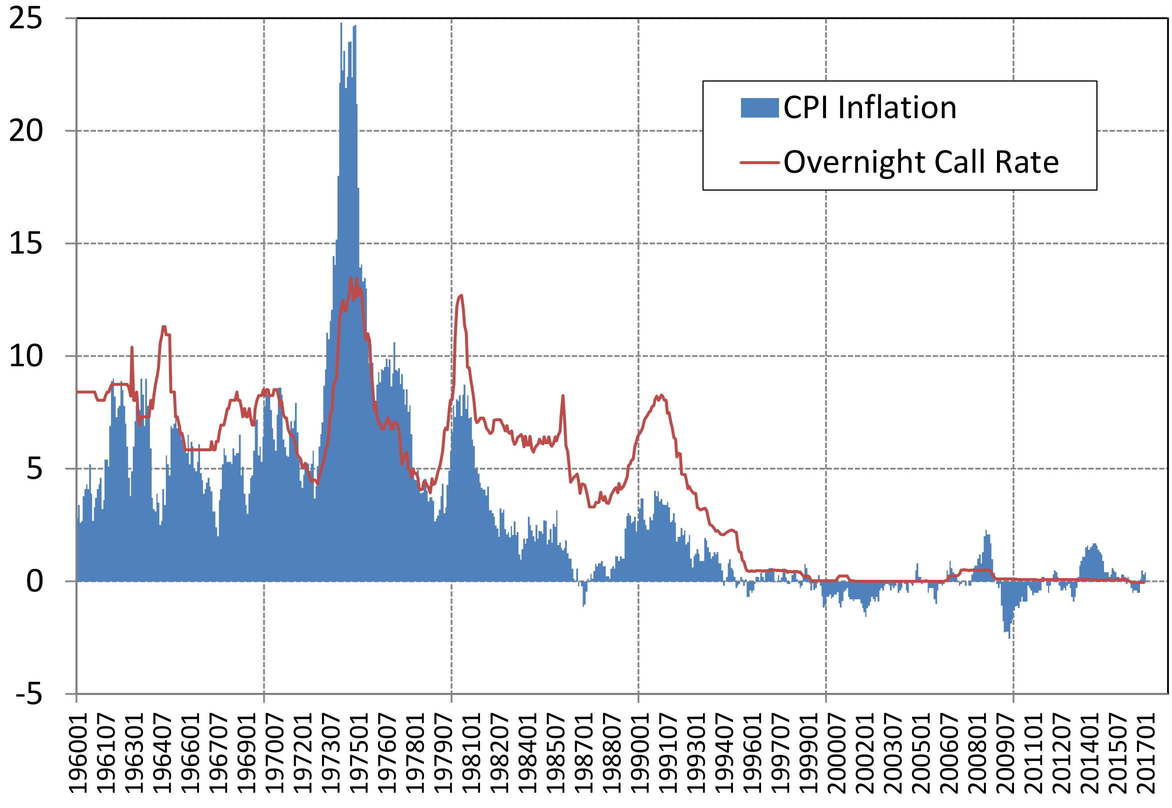


Figure 2: Phillips curve, 1971-2016

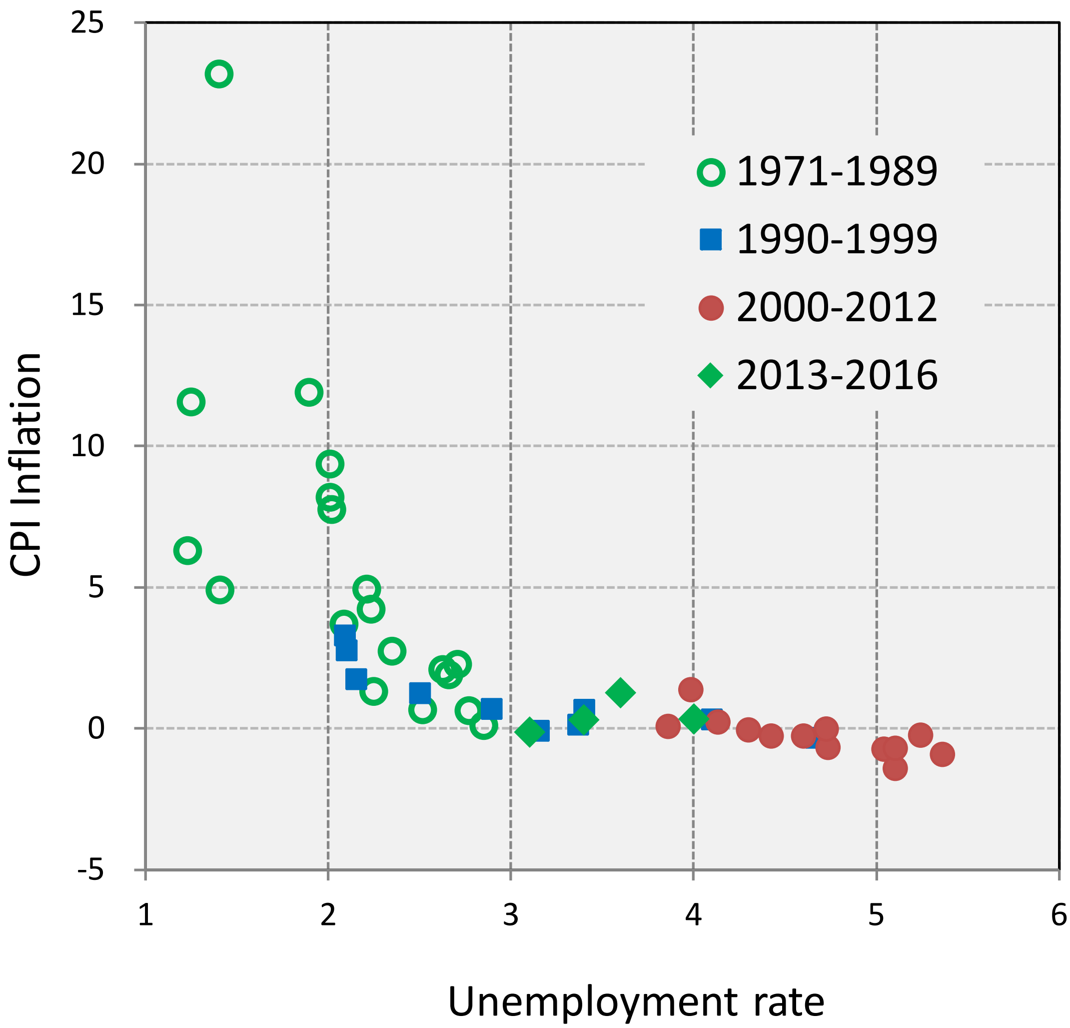


Figure 3: Slope of the Phillips curve

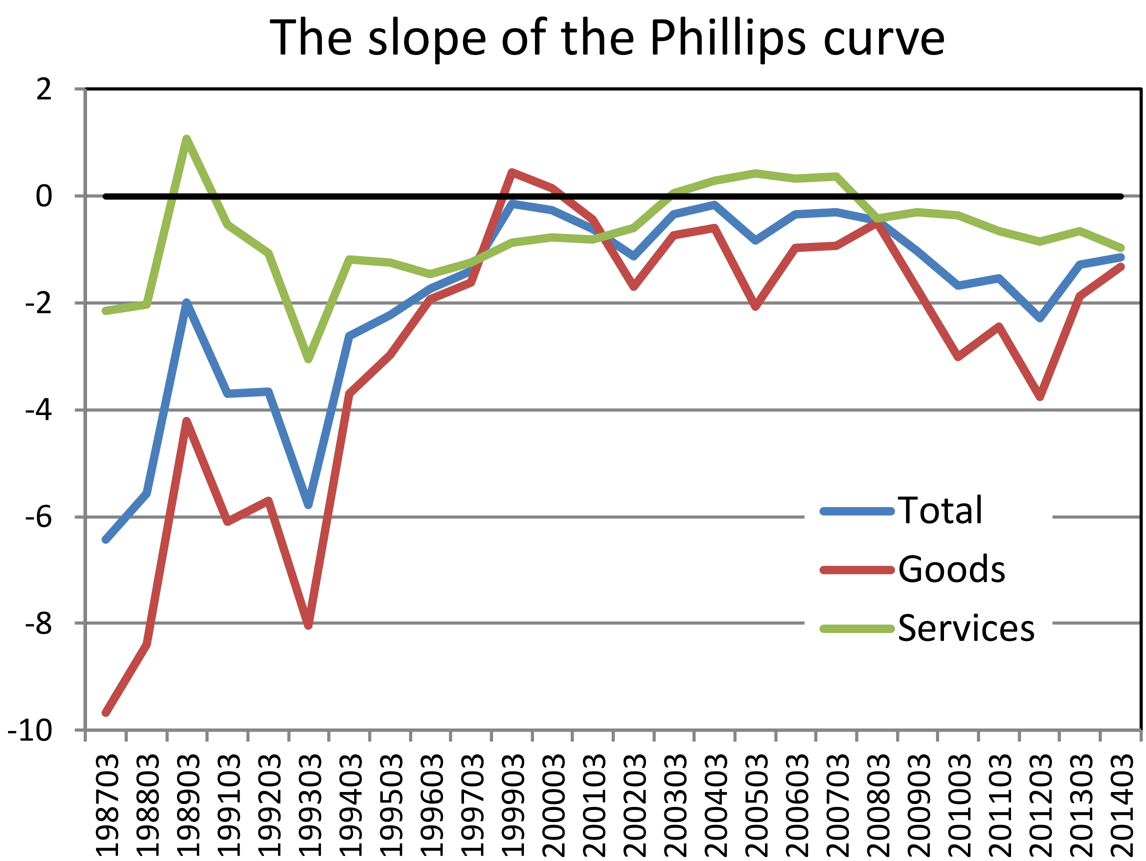


Figure 4: Distribution of price changes across items

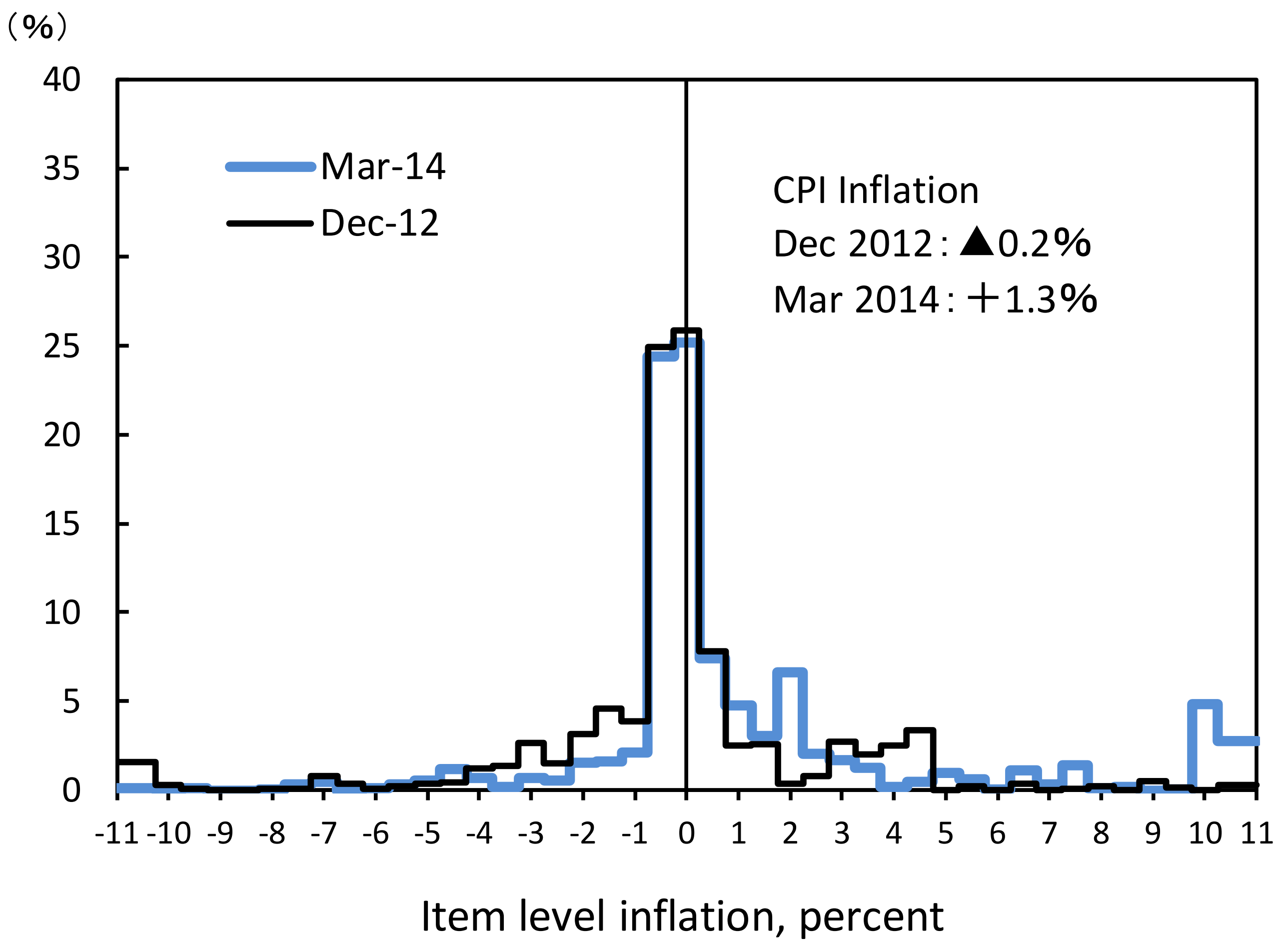


Figure 5: Fraction of items with a near-zero inflation rate

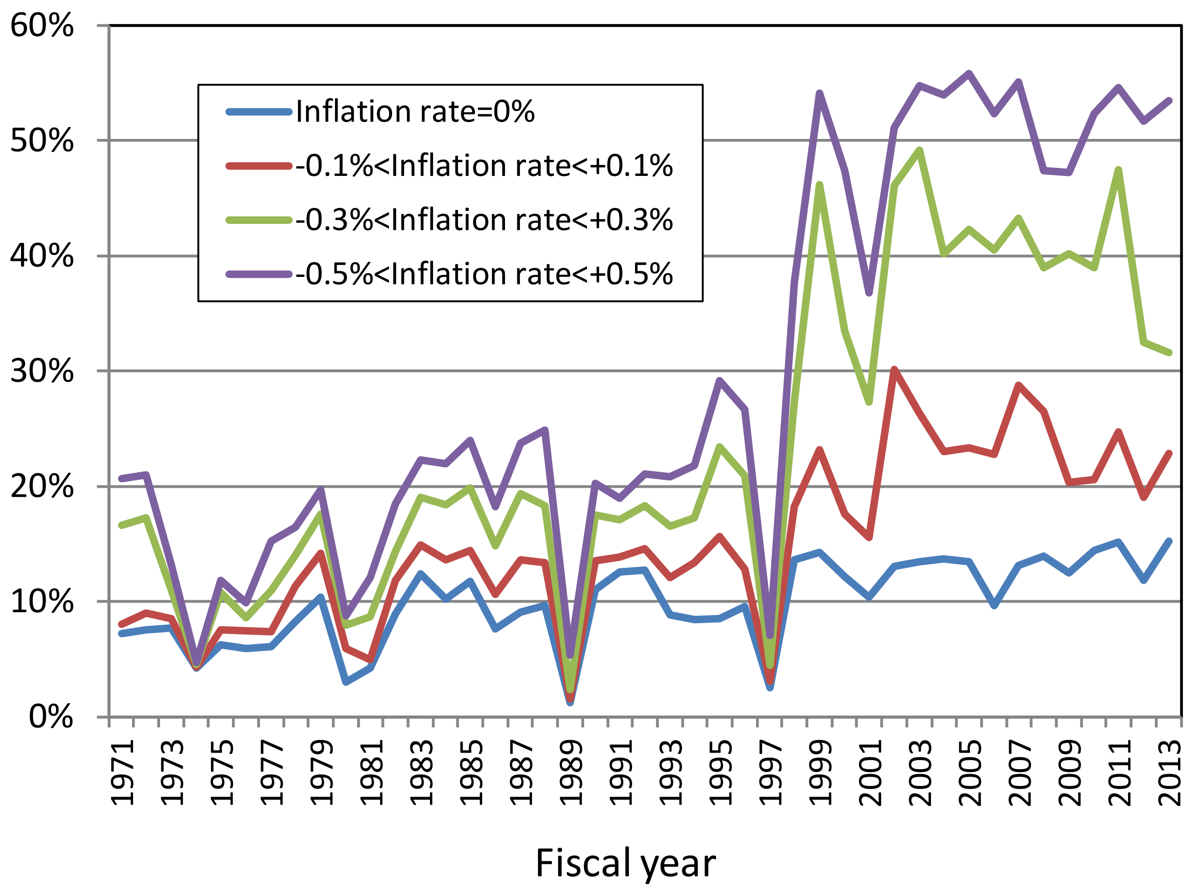


Figure 6: Evolution of the price change distribution in the 1990s

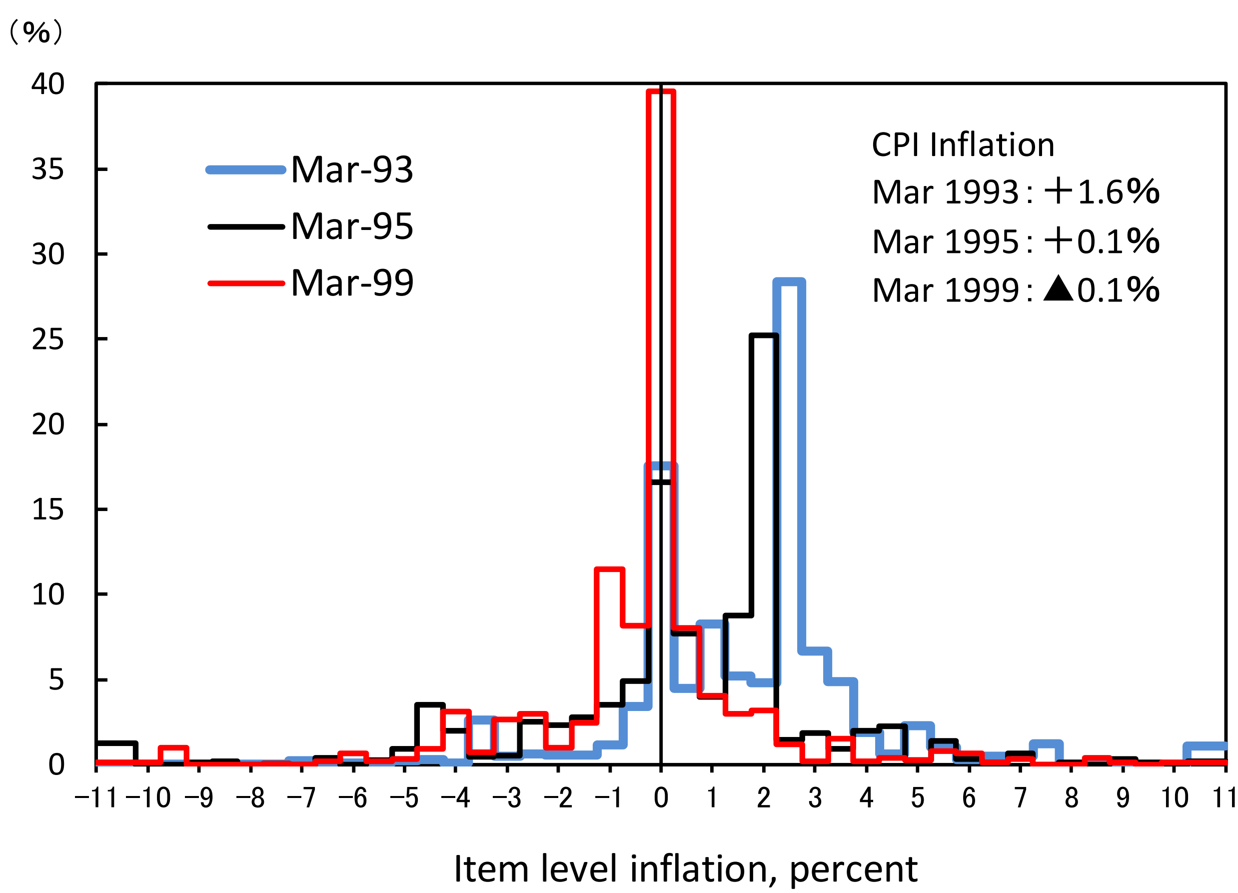


Figure 7: Fraction of products with price changes in 1995 and 2013

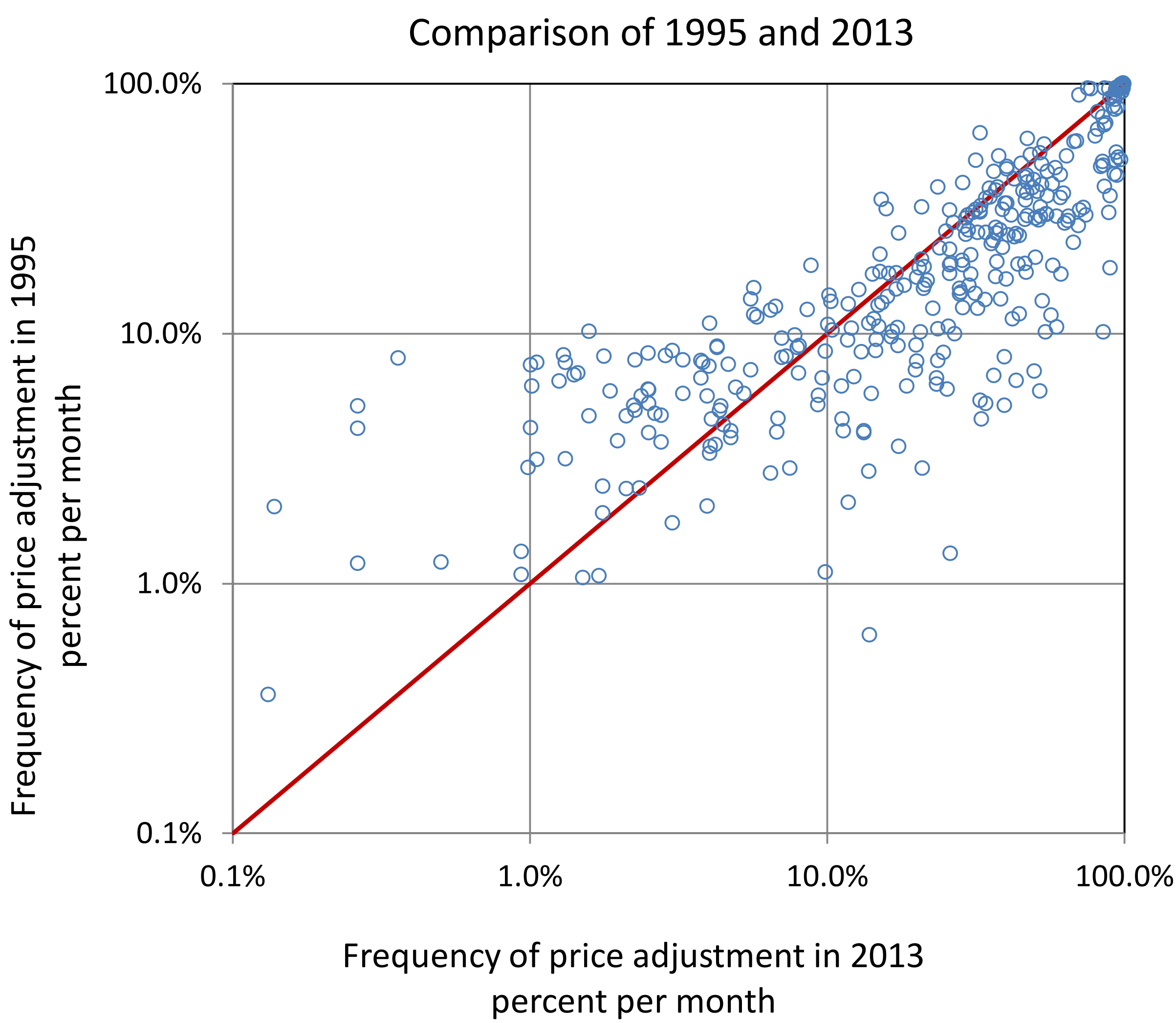


Figure 8: Joint distribution of price changes, 2012 and 2014

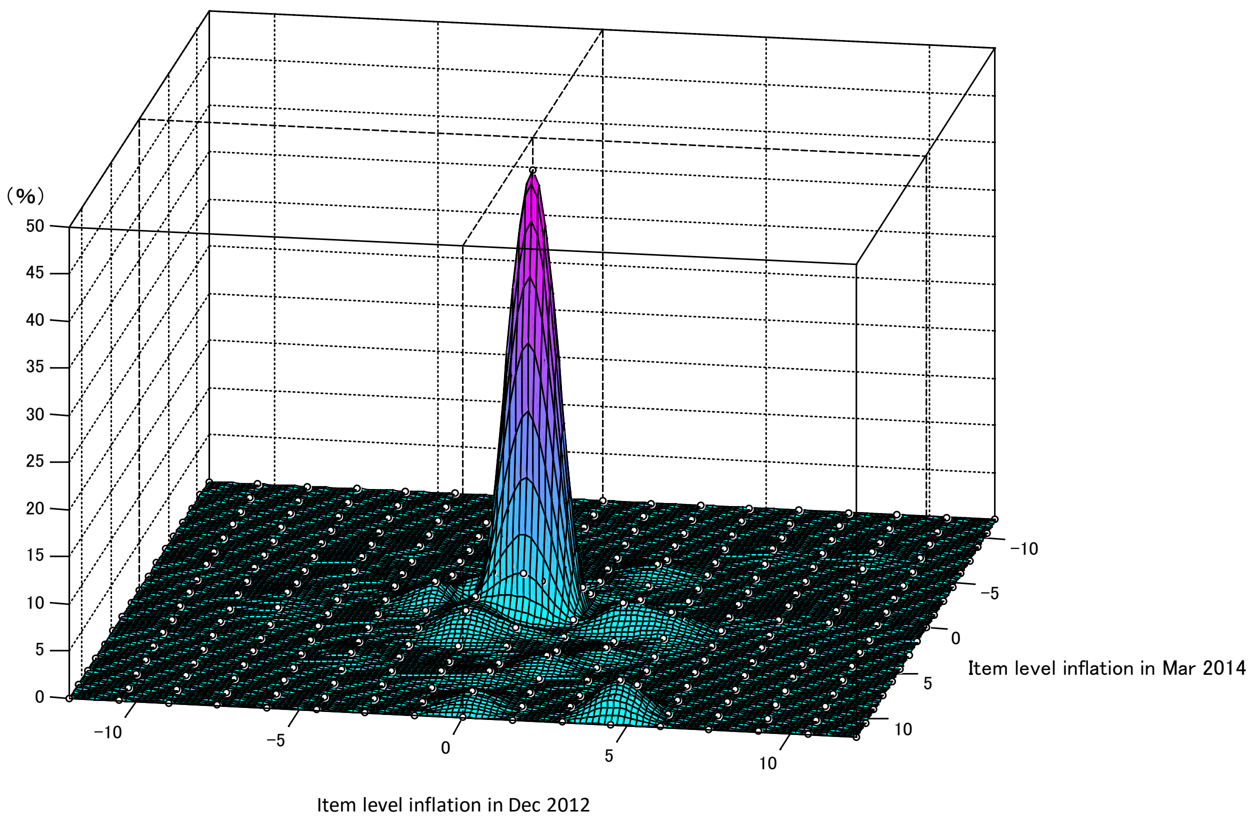


Figure 9: Flattening of the Phillips curve due to an increase in price stickiness

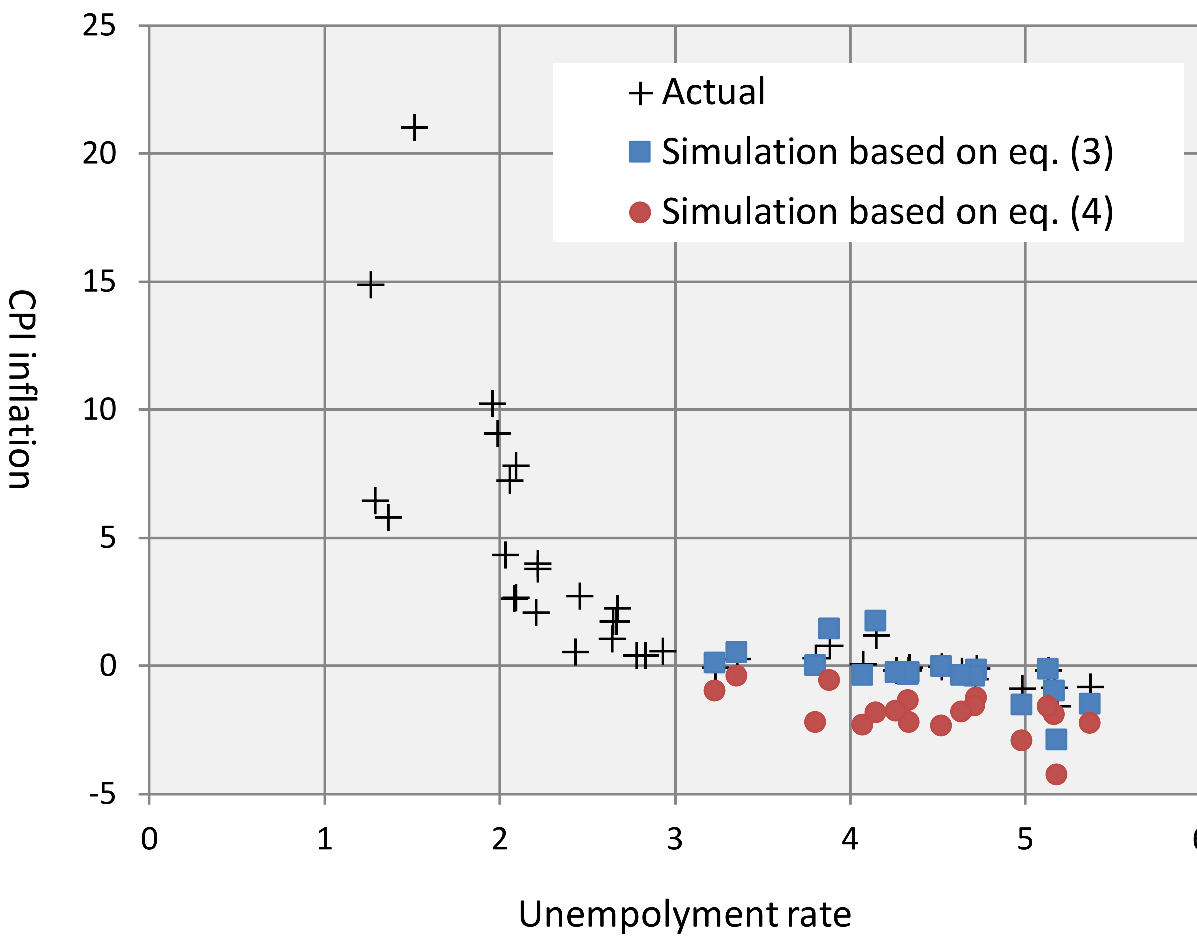


Figure 10: Fraction of items with price increase, price decrease, and no price change

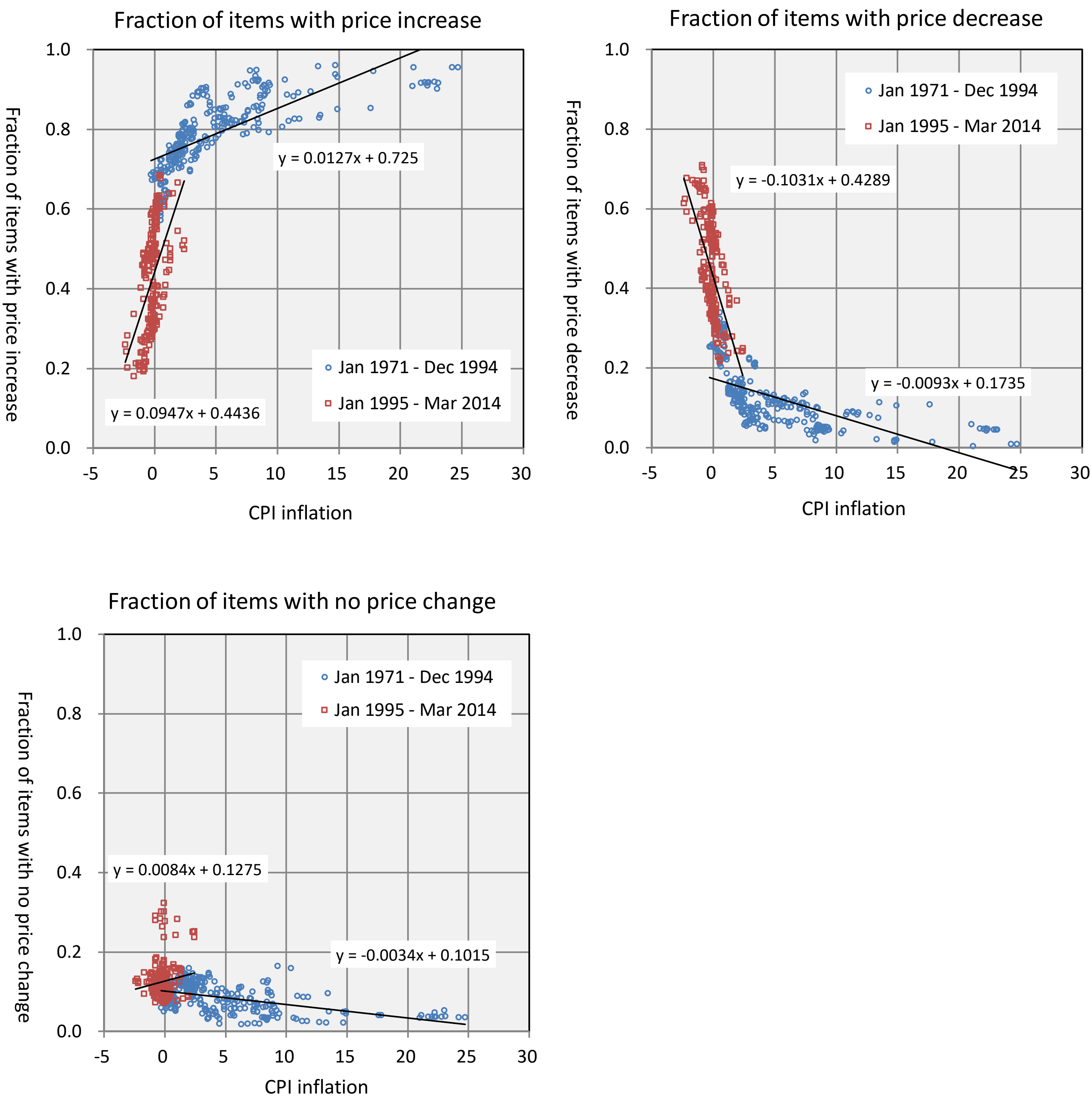
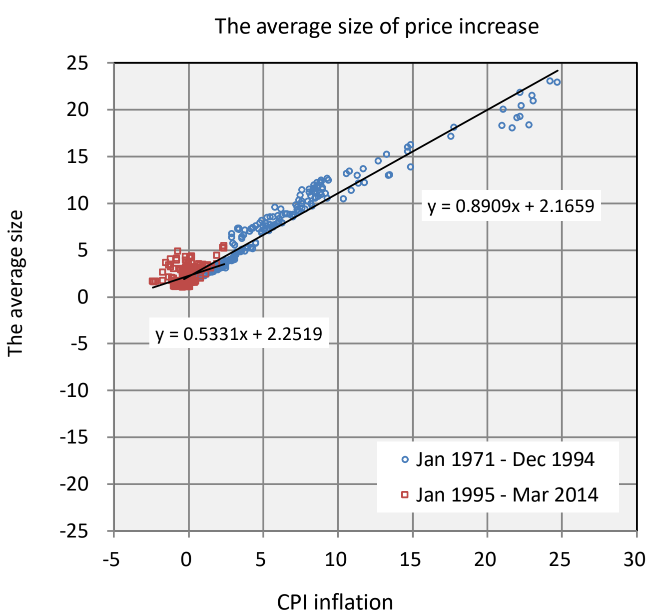


Figure 11: Average size of price changes



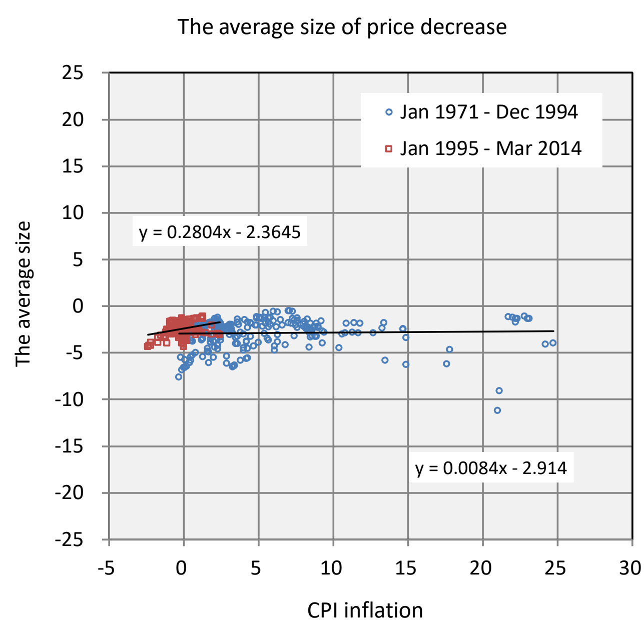


Figure 12: Price change distributions for Japan, US, Canada, and UK, March 2014

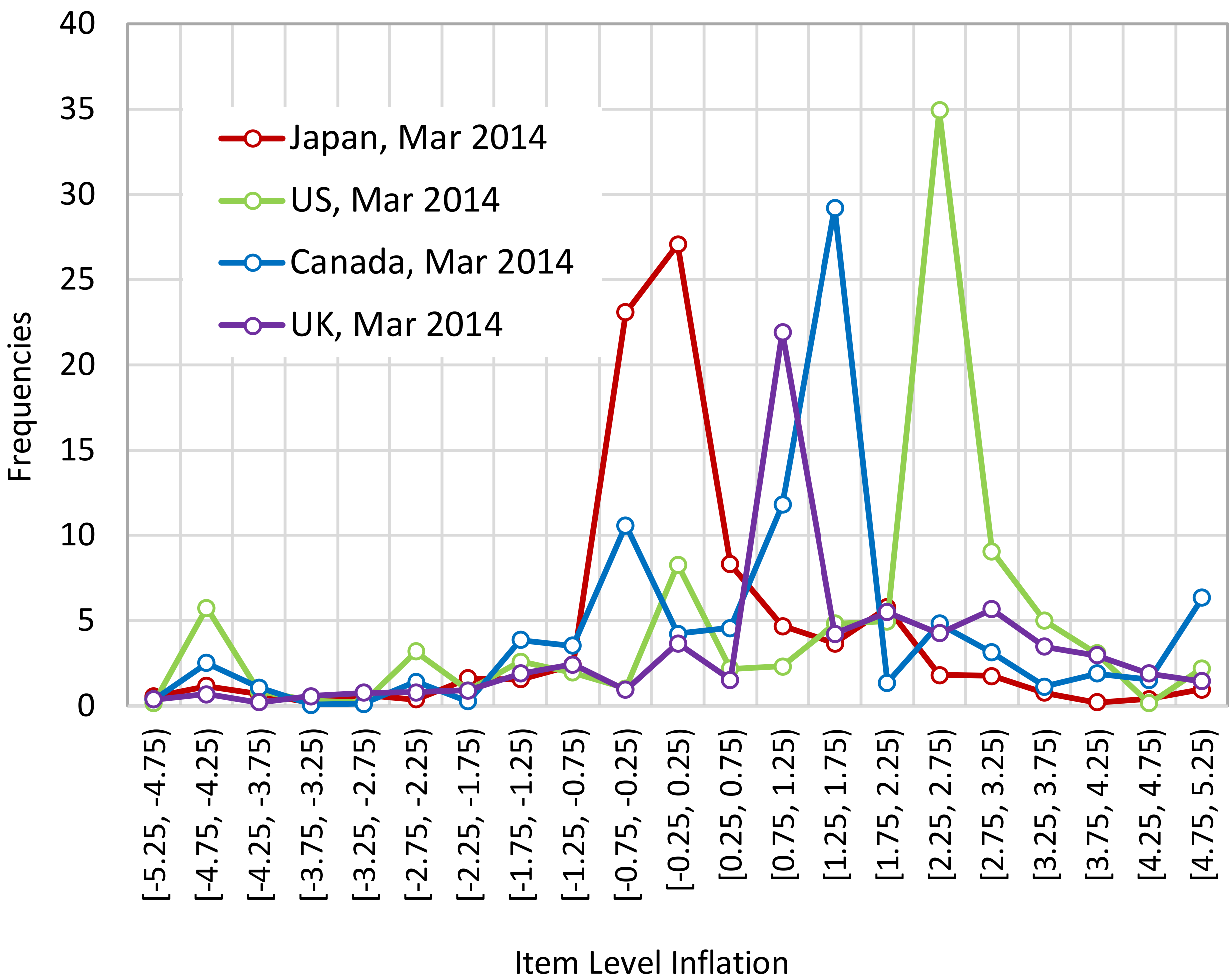
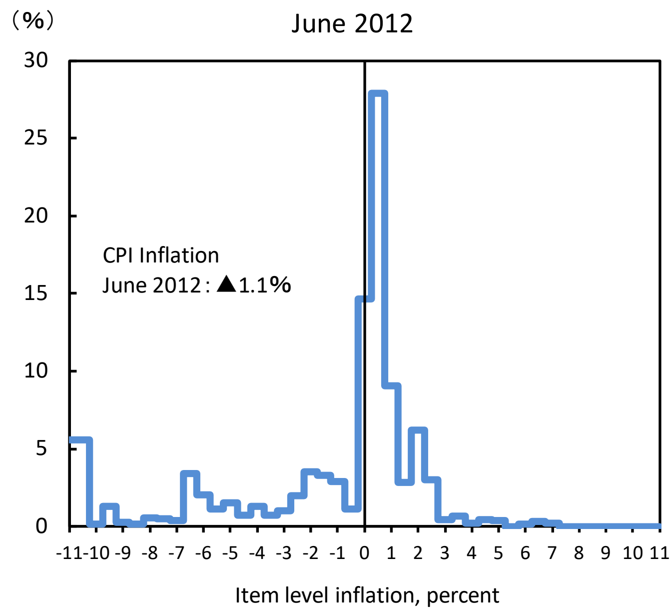


Figure 13: Price change distribution for Switzerland



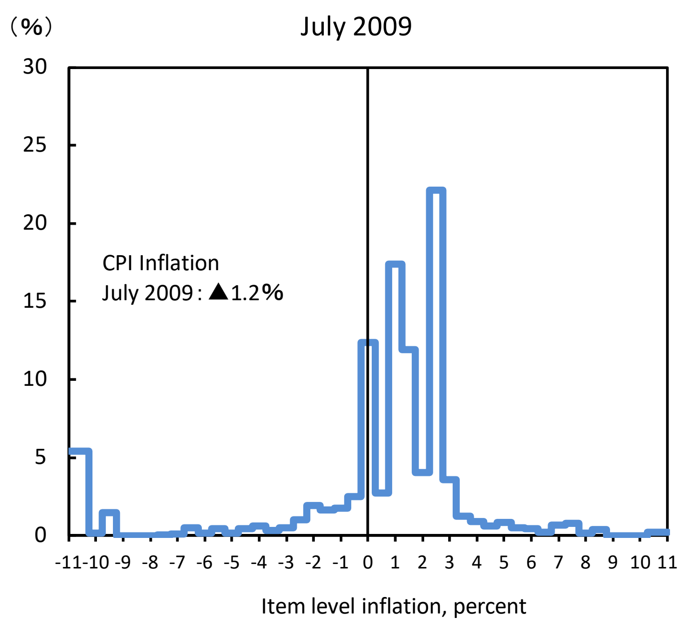


Figure 14: Fraction of items with no price change conditional on the inflation rate

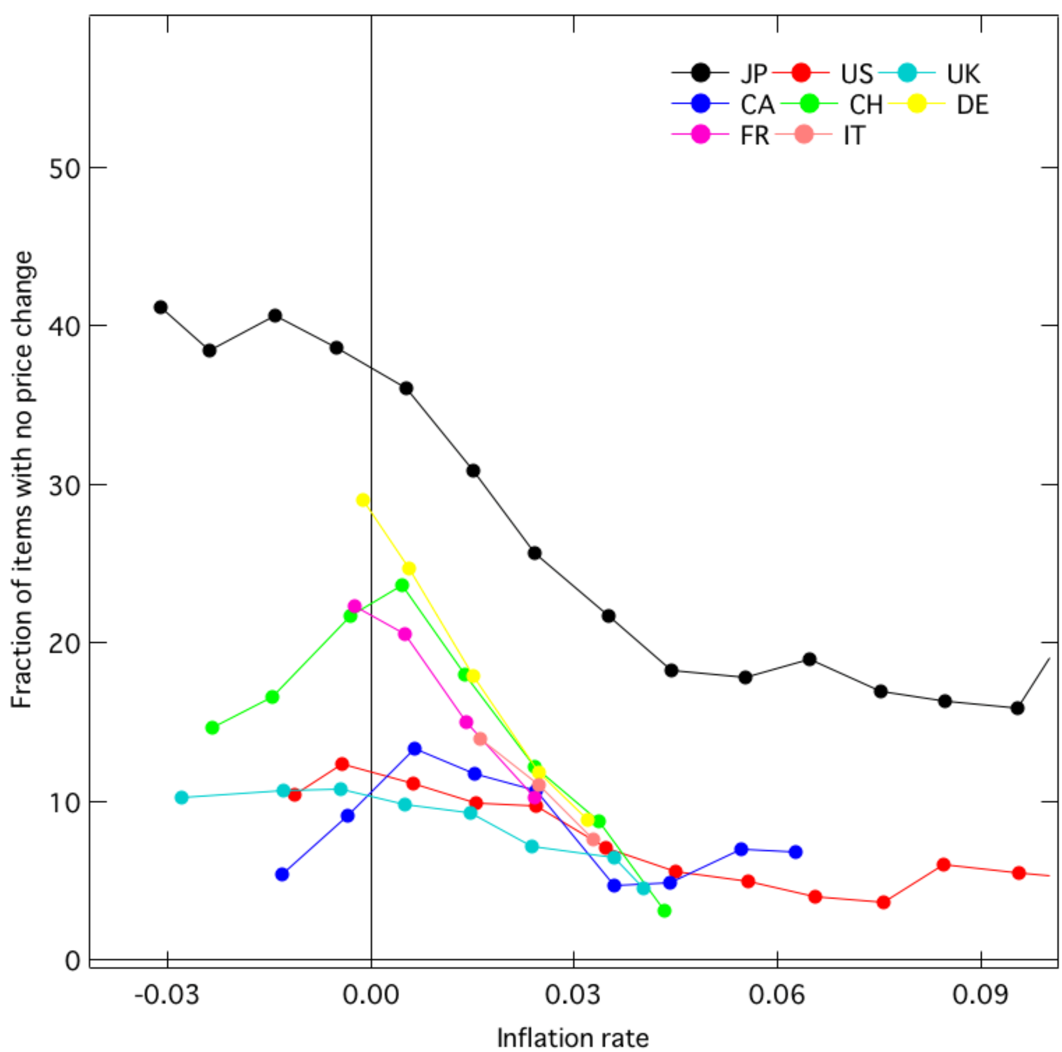


Figure 15: Mode of the price change distribution conditional on the inflation rate

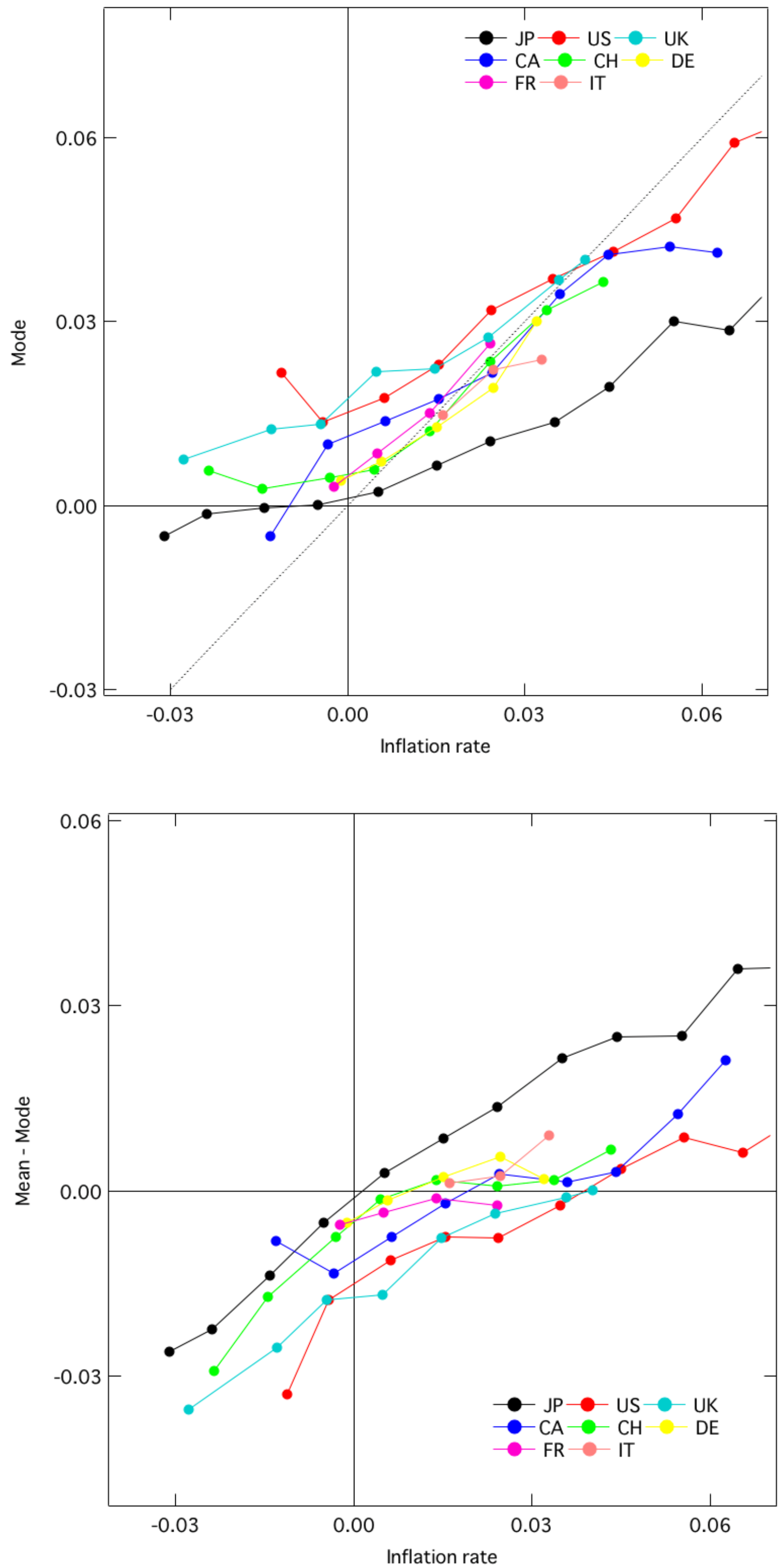


Figure 16: Simulation result for the item-level price change distribution conditional on the mean of the distribution

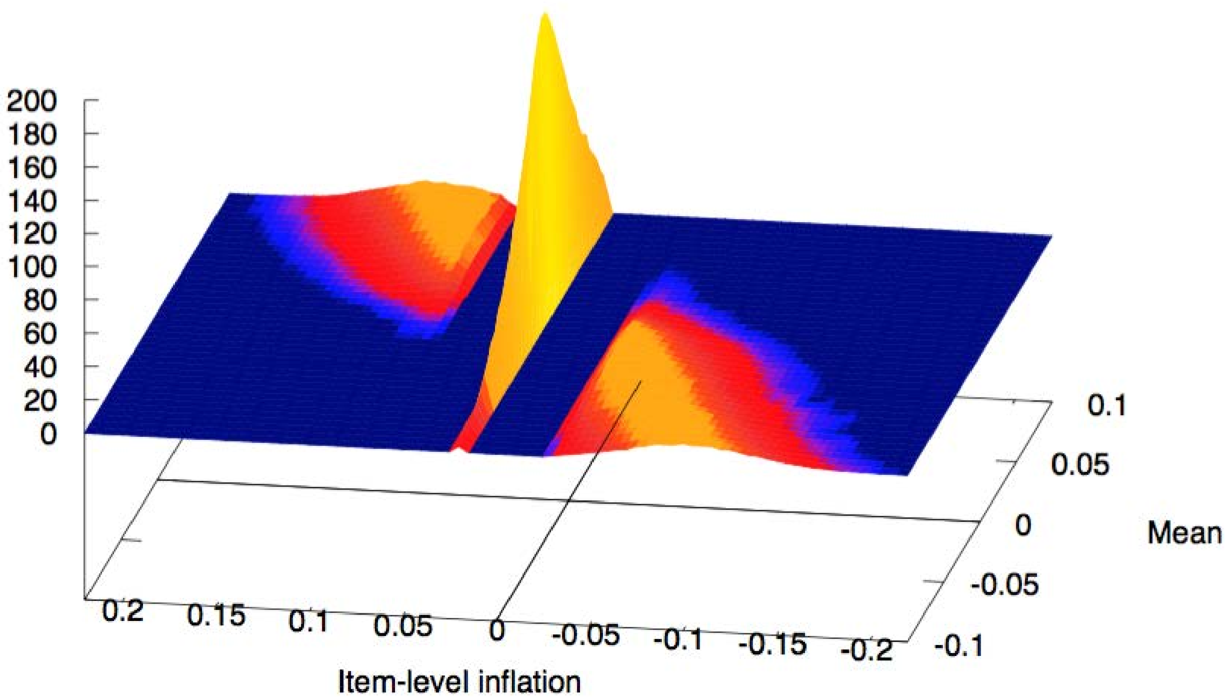
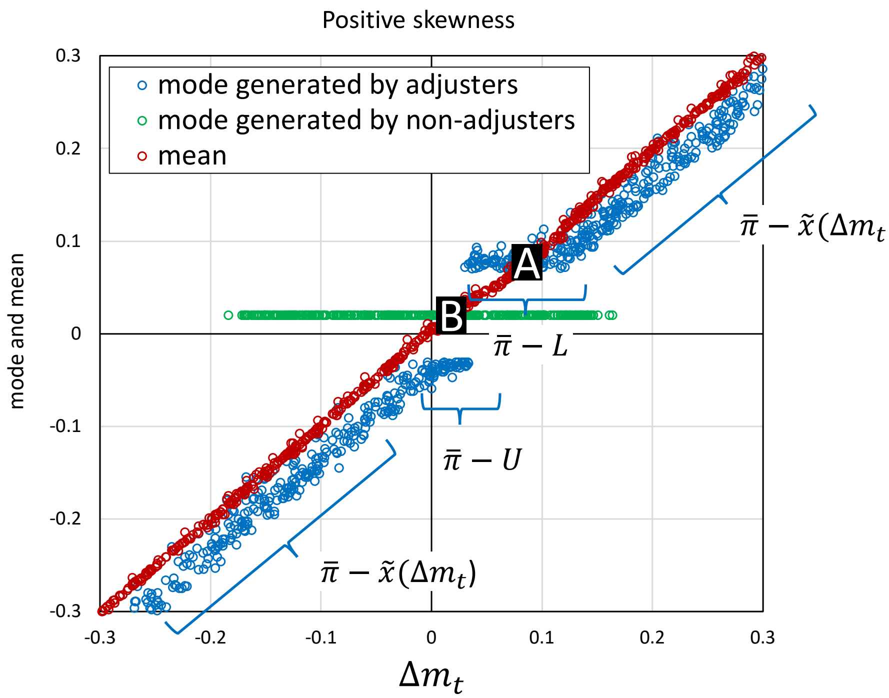


Figure 17: Mode and mean of the item-level price change distribution as a function of Δm_t



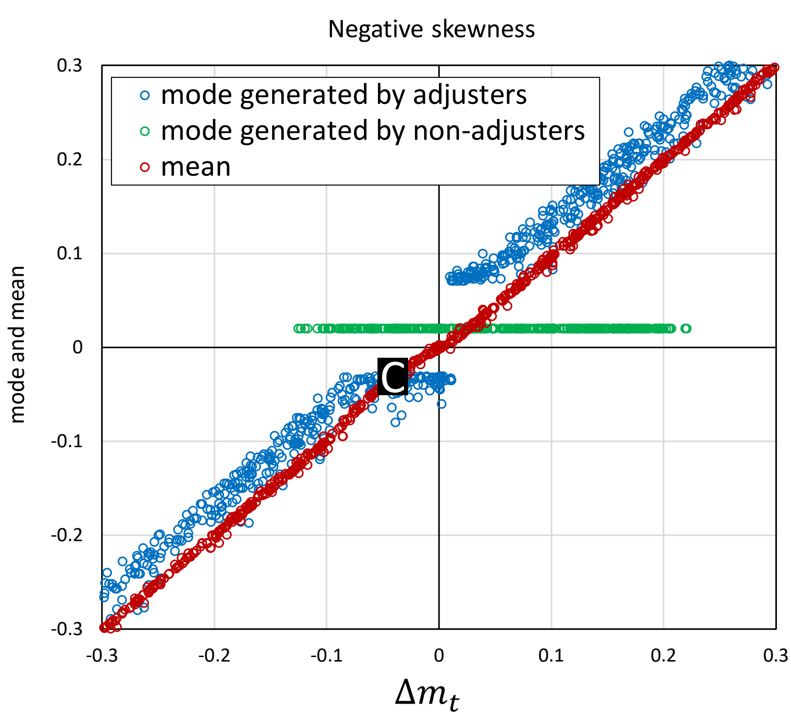


Figure 18: Simulation result for the cross-sectional SD of the item-level price change distribution

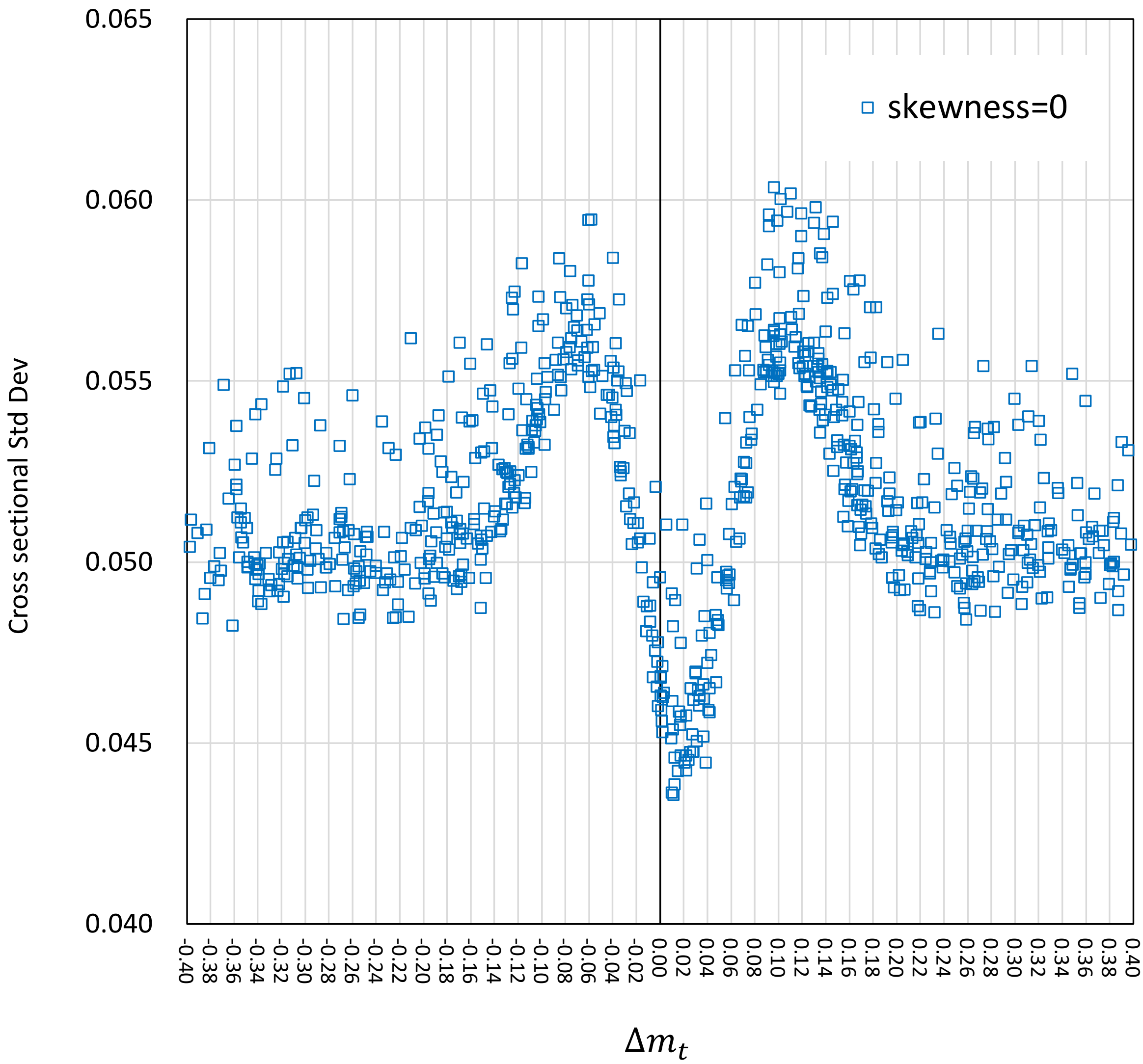


Figure 19: Relative price variability conditional on the inflation rate