Anatomy of Deflation

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April 2008

Abstract

Deflation is often associated with poor macroeconomic performance. We demonstrate that one possible explanation for this is menu costs, which imply that firms are more reluctant to reduce prices than raise them, due to asymmetries in the profit function. As a result, deflation would be characterised by prices that are "too high," and output that is therefore "too low."

We test the implications of menu cost models using a rich set of microeconomic prices that covers both inflationary and deflationary periods for Hong Kong using simple, robust statistical methods. While we find lots of evidence of asymmetry in price setting behaviour, this is generally inconsistent with the predictions of menu costs.

[1] This paper was written while the author was Research Fellow at the Hong Kong Institute for Monetary Research. Financial support was also provided by the Hong Kong Institute for Economics and Business Strategy. I think, without implication, Alex Ho and Laurent Pauwels for comments. Any remaining errors are the author's sole responsibility.

1. Introduction

Deflation is defined as a fall in the overall price level in the economy. It is often associated with negative macroeconomic shocks, and poor macroeconomic outcomes.[2] The negative outcomes may simply result simply from the negative shocks that typically cause deflation. But there are other possible causes as well. For example, deflation may lead to increased real debt burdens, higher real interest rates and, if deflation becomes entrenched in expectations, a downward spiral of decreasing demand and prices.

There is one other possibility as well, which is the subject of this paper. If price decreases are fundamentally different from price increases, then the fact that prices are decreasing may itself be a contributor to negative outcomes. We examine this possibility by unravelling the anatomy of deflation. We identify how price adjustments during one long, persistent deflationary episode differ from price adjustments during inflationary episodes both before and after it. In so doing, we identify the dimensions along which price increases and price decreases fundamentally differ. We then ask whether the differences we identify are consistent with a menu cost model, which would imply that deflation is inherently more costly than inflation.

We utilize a dataset of consumer prices for Hong Kong, which experienced continuous deflation (defined as a decreasing Consumer Price Index year-on-year) from November 1998 until June 2004. The combination of a large (cumulative 13.9% fall in prices) and long (68 months of continuously falling prices) deflation is unique in recent times for a high income economy. Hong Kong therefore provides an excellent case study to which to examine deflation.

Our dataset consists of 327 sub-indices from the Consumer Price Index at a monthly frequency over the January 1995- September 2007 period. We show that Hong Kong data exhibits significant degrees of asymmetry between price increases and price decreases, and between pricing behaviour during inflation and deflation, but

[2] In principle, deflation may also result in positive macroeconomic outcomes. For example, Bordo and Filardo (2005) study 200 years of past episodes of deflation and argue that deflation may be “good” (caused by a positive supply shock), “bad” (caused by a negative demand shock), or “ugly” (related to a negative price spiral).

that these asymmetries are generally inconsistent with the predictions of a menu cost model. We therefore find little evidence that deflation is inherently costly.

The next section examines the background and international context of Hong Kong's deflation. Section 3 outlines the predictions of the menu cost model for price-setting asymmetries, and Section 4 discusses the data. Section 5 assesses the degree of asymmetry in Hong Kong prices and compares these with the predictions of the menu cost model, while section 6 concludes.

2. Background

Deflation is not an unusual phenomenon. Indeed, in the complete panel of CPI statistics in the International Monetary Funds' International Financial Statistics (consisting of 172 countries, for varying time periods starting as early as 1957), 127 countries have experienced at least one episode of deflation, defined as a decline in the Consumer Price Index, year-over-year. Thus understanding any potential additional costs of deflation over inflation may be very important for economic policy.

Hong Kong's deflation was unusual in terms of both its severity and length. In terms of severity, it resulted in a cumulative 13.9% decline in prices. While other economies have faced larger cumulative price declines (see Table 1 for a list), these have all been less developed economies. The only possible exception is Kuwait (-21.2%), where deflation occurred over just twelve months in 1979. In contrast to Hong Kong, Japan's largest cumulative continuous deflation in year-over-year CPI was only 2.8%, and Macau's 10.8%.[3]

But where Hong Kong stands out, and provides an ideal subject for the study of deflation, is in terms of the length of continuously declining prices. Measured in terms of the year-over-year change in the CPI, prices fell continuously from November 1998 until June 2004, for a total of 68 months. The only longer deflationary episode in the IFS dataset is for Macau, for 71 months from July 1998 to May 2004.

[3] Allowing for brief departures into inflation, one can argue that Japan's deflation was longer than this. But however this is measured, Japan's overall decline in prices was smaller than Hong Kong's.

Table 1. Largest and Longest Continuous Declines in the CPI in IFS Dataset

Country	Decline	Start	End	Months
Sri Lanka	64.7%	1958M12	1959M12	12
Burundi	24.9%	2002M12	2003M1	1
Chad	21.8%	1986M1	1986M12	11
Sierra Leone	21.2%	1999M12	2000M2	2
Kuwait	21.2%	1978M12	1979M12	12
Equatorial Guinea	16.6%	1985M12	1987M11	23
Gabon	14.8%	1991M6	1991M11	5
Niger	14.7%	1986M7	1987M11	16
Democratic Republic of Congo	14.7%	1997M12	1998M6	6
Ethiopia	14.1%	1986M2	1987M7	17
Hong Kong	**13.9%**	**1998M10**	**2004M6**	**68**
Macau	10.8%	1998M6	2004M5	71
Saudi Arabia	8.3%	1983M7	1988M1	54
Japan	2.8%	1999M8	2003M9	49

The appeal of a long, continuous decline in prices is that price setting decisions by firms may be forward looking. If an economy were to experience only a short period of deflation, price setters may anticipate a return to inflation. As a result, many price setters may decline to adjust their prices downwards in the expectation of future positive inflation. In contrast, in the case of Hong Kong, deflation was persistent, and many firms reduced their prices, often multiple times, during the deflationary episode.

We illustrate the deflation for Hong Kong in Figure 1. This includes deflation within the components of the CPI included in our study (to be discussed in Section 4), and in the overall CPI for Hong Kong. The inflation rate in the CPI for Japan is included for comparison.

The link between deflation and poor macroeconomic outcomes in Hong Kong is readily apparent in Figure 2, which plots quarter-over-quarter growth rates in seasonally adjusted Gross Domestic Product over the same period. There were in fact three separate recessions within Hong Kong's deflationary period (defined as two or more consecutive quarters of falling real GDP), each coinciding with a significant worsening of deflation.

Figure 1. Inflation in Hong Kong

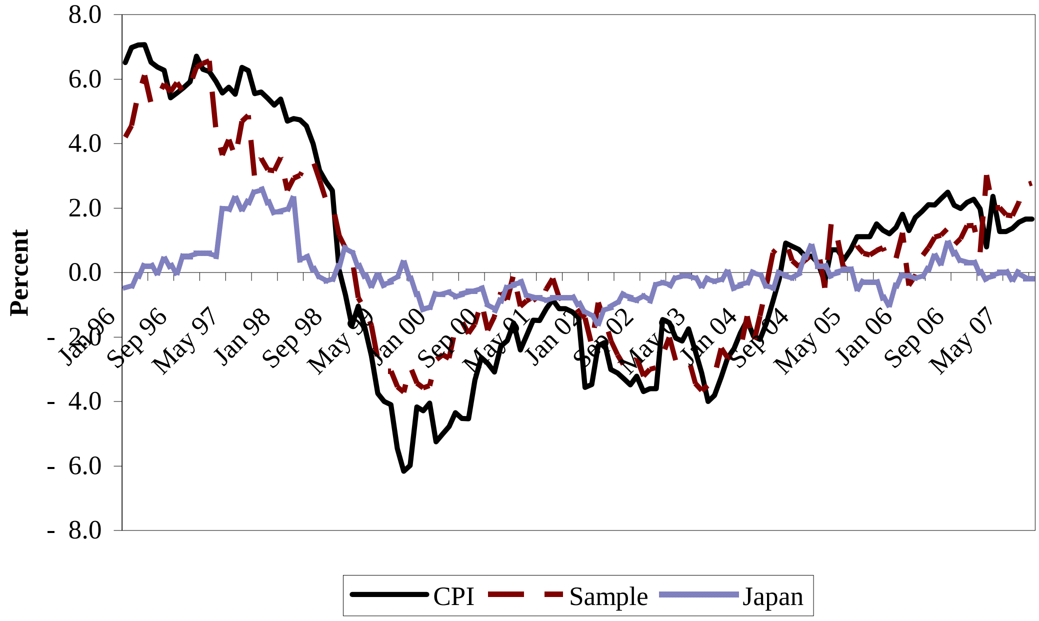
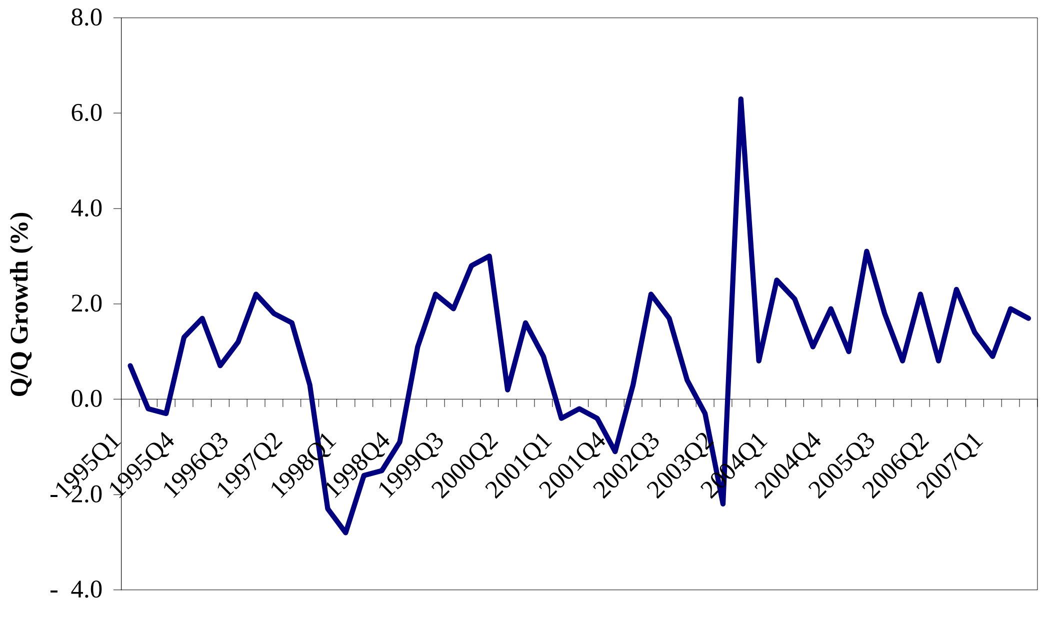


Figure 2. Hong Kong Real GDP Growth



Elsewhere, a number of papers have focused on the source of Hong Kong's deflation. For example, Genberg and Pauwels (2005) argue that the deflation was driven by declining prices of imported goods and a negative output gap; Cutler (2005) focuses on the role of a negative wealth shock; Ha and Fan (2002) find evidence of convergence between prices in Mainland China and Hong Kong that required downward price adjustment in Hong Kong; while Schellekens (2005) demonstrates that most of the deflation can be explained by cyclical factors rather than price equalization with Mainland China. Ultimately each of these explanations relies in part on Hong Kong's Currency Board System which precludes a systematic monetary policy response to domestic factors. Thus when a series of negative macroeconomic shocks resulted in an overvalued real exchange rate, adjustment to equilibrium occurred via decline in the nominal price level rather than the nominal exchange rate.[4]

Instead of focusing on the source of deflation, we will focus on the propagation of deflation, and in particular the properties of price declines compared with price increases, both during inflationary and deflationary periods.

We are not the first to use to use variation in inflation regimes to identify the nature of price setting. For example, Gagnon (2007) studied differences between low and high inflation regimes in Mexico using store-level price data; Hoffmann and Kurz-Kim (2006) focused on a period of low inflation in Germany; and Gotte and Minsch (2005) examined how firms in Switzerland adjusted prices as inflation varied between 7% and 0%. Where we differ is in the use of recent data for a high income economy that endured a sustained period of deflation for over five years.

3. A Model of Asymmetric Price Setting.

In this section, we consider a common model that may explain asymmetric price setting. The model we develop is a standard "menu cost" model, and we show that this model implies that deflations will be costly. The real response of an economy to a shock depends crucially on the speed with which prices adjust. If prices fail to adjust as readily downwards as they do upwards, for example, then deflation may be inherently more costly than inflation, since a greater degree of the shock will pass through to the real economy, rather than being absorbed via price changes.

If prices are themselves fully flexible, then this argument is moot: prices should adjust fully to both positive and negative shocks. Then the only explanation for price setting asymmetries is that the distribution of marginal cost shocks is asymmetric, and varies with the inflationary regime. But there is significant evidence elsewhere that prices are not fully flexible, because changing prices is costly to the firm. The

[4] See also Baba et al (2005) for a careful analysis of Japan's deflation based on sub-indices of the CPI.

presence of such menu costs lies at the heart of New Keynesian models of the business cycle.[5] Thus in response to shocks to the economy, prices do not fully adjust. Therefore even a purely nominal shock may be observed to have significant real effects.

Existing empirical evidence of menu costs includes Cecchetti (1986) who found that magazine prices change only infrequently, but more often when the inflation rate is higher, as implied by menu costs since higher inflation ensures that it is worth firms paying the price of adjusting their prices more often. Kashyup (1995) studied catalogue prices and found that prices are updated infrequently. Levy et al (1997) directly measured menu costs at supermarkets, and found these to be non-trivial. They also found that a supermarket chain that is required by law to place a separate tag on every item for sale experienced menu costs almost three times as high, and changed prices much less frequently, than other supermarket chains. In contrast, survey results (Blinder (1994), Blinder et al (1998) and Hall, Walsh and Yates (2000)) suggest that firms do not consider menu costs as a very important consideration when deciding whether to set prices. However, as Blanchard (1994) and Mankiw (1985) have argued, a central theme of the sticky price literature is that costs of price change that may be trivial to, and have only minor implications for profits of, the individual price setter can still have large macroeconomic effects.[6]

Other studies have looked directly at the empirical implications for menu costs in macroeconomic data. For example, Ball, Mankiw and Romer (1988) find that menu cost models can explain differing slopes of estimated Phillips curves across countries, while Devereux and Yetman (2003) find that menu costs can explain differences in the behaviour of exchange rate pass-through across countries.

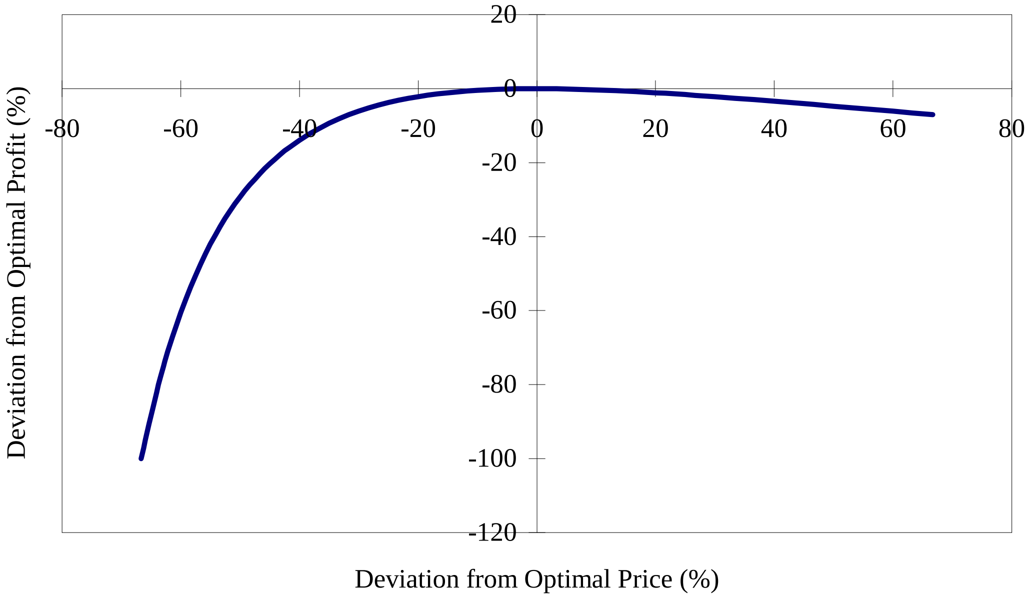
If prices are not fully flexible, firms experiencing small shocks may fail to adjust their price, as the cost of miss-pricing may be smaller than the menu cost. But the exact region within which firms fail to adjust their price depends on the firm’s profit

[5] See, for example, Woodford (2003)

[6] There is also a large volume of studies of price stickiness for Euro area economies coordinated by the European Central Bank that provides mixed evidence as well, summarised in Altissimo et al (2006) and Alvarez et al (2006).

function. But, as illustrated by Figure 3, the profit function is asymmetric.[7] Thus it is possible that negative economic shocks will be absorbed differently from positive economic shocks in the economy. If the actual price is even a little below the optimal price, a profit maximizing firm facing menu costs may wish to raise its price, while the actual price must be much further (in absolute terms) from the optimal price for a firm facing the same menu costs to desire to reduce their price.[8]

Figure 3. Firm Profits



The source of this asymmetry has been discussed extensively elsewhere.[9] A seller whose price is too low may make a loss on every item sold, and also sell additional units of output. Both of these effects create incentives for the firm to raise prices. In contrast, a seller whose price is too high stands to sell fewer units, but this is partially offset by higher profits on each unit sold. Thus firms will be less averse to prices that are too high than prices that are too low, and therefore more reluctant to reduce prices than raise them.

There is some empirical support already for such asymmetries: Peltzman (2000)

[7] This profit function is for the case of a monopolistically competitive firm if consumers consume a composite that is a Dixit-Stiglitz aggregator over differentiated goods. For a derivation of the profit function, see Appendix 1.

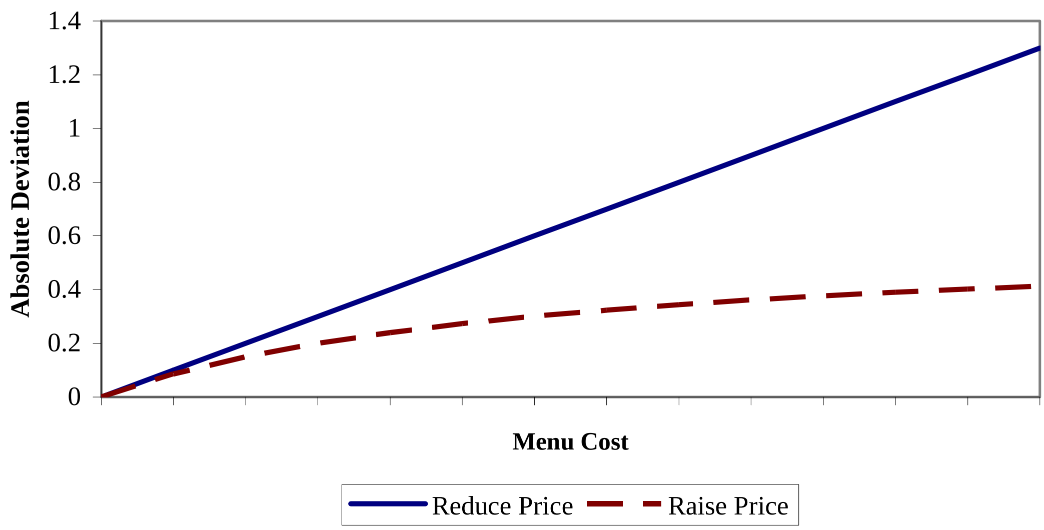
[8] For an alternative theory of asymmetric price changes, see Levy et al (2004) who identify asymmetric price adjustment in store scanner data in that small price increases are more common than small price decreases. They argue that this is because of “Rational Inattention:” consumers ignore small increases in price, creating an incentive for retailers to adjust prices asymmetrically.

[9] See, for example, Devereux and Siu (2007), Ho and Yetman (2006), Burstein (2006), Ellingsen, et al (2006), and King and Wolman (1999).

found that output prices respond to positive cost shocks twice as much as to negative shocks, and that this difference is persistent. Futher, Ellingsen et al (2006) argued that this asymmetry alone is sufficient so that the output loss resulting from a small negative inflation shock is twice as large as the output gain from a small positive inflation shock for realistic parameters.

To illustrate this asymmetry another way, Figure 4 plots the absolute value of the price deviation from the optimal price required for a firm to adjust its price across a range of different menu costs. It illustrates that for any given menu cost, the range of inaction when the price is too low (given by the area below the line) is less than the range of inaction when the price is too high. This asymmetry would potentially be further exacerbated by the presence of "strategic complementarity" among firms, in which the desired price of each firm depends in part on the price set by other firms. Thus if a portion of firms fail to adjust their price, other firms have an increased incentive not to adjust their price as well.

Figure 4. Range of Inaction
Deviation from Flexible Price

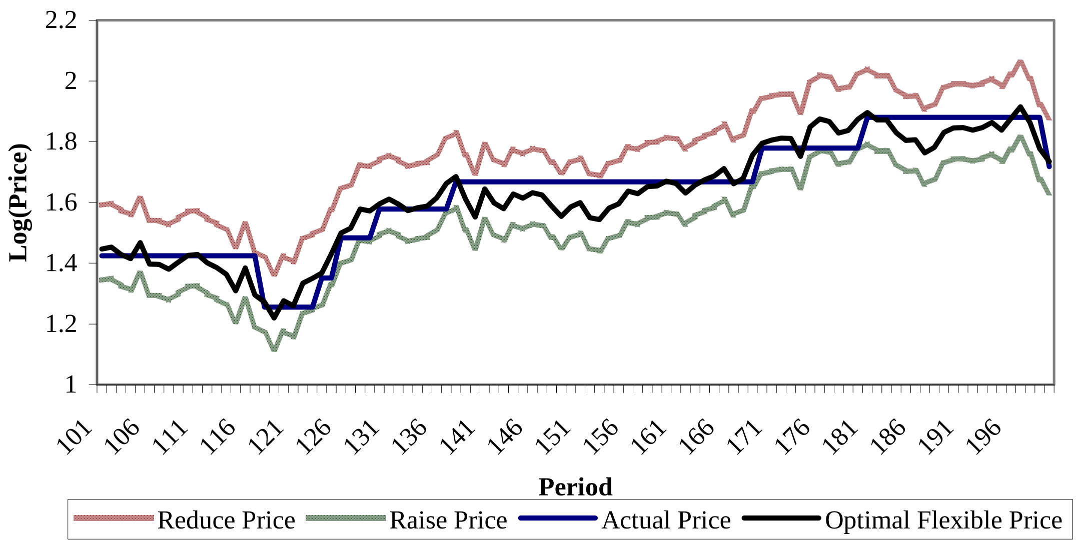


The above figure is for the case where there is no drift in prices over time, and therefore no deflation or inflation. But if we focus on the case of an inflationary environment, firms will be even more eager to increase their price in response to a shock since the real value of a price is declining over time anyway, as argued by Ball and Romer (1994, 1995). In contrast, firms will be even more reluctant to reduce prices, since prices are falling in real terms anyway. And in a deflationary environment, these arguments would reverse: firms would be less eager to increase prices, and more eager to reduce them.

So what would such asymmetries imply for the behaviour of individual prices? We simulate the behaviour of a price setter under both moderate inflation and moderate deflation, consistent with the historical experience of Hong Kong. We determine the margins at which a firm will choose to increase or decrease their price, along with the optimal price that the firm will set when it changes price, to maximise profits. Realistically, we assume that good-specific idiosyncratic shocks have a much larger bearing on price setting decisions than trend inflation, so that the desired price is volatile, and we observe both price increases and decreases during both inflationary and deflationary periods.[10]

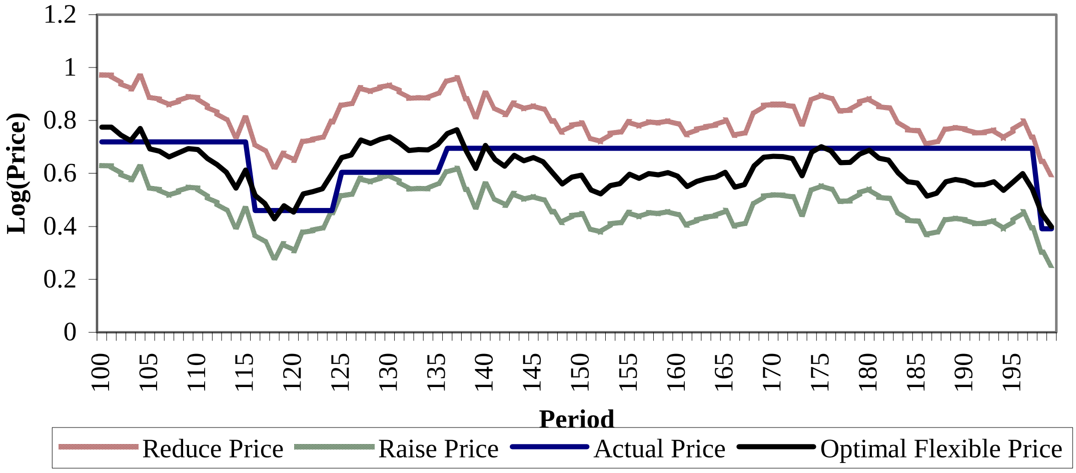
We plot 100 periods of our simulation at the average annual inflation rate between January 1996 and October 1998 (5.37%) and the average annual deflation rate between November 1998 and June 2004 (-2.78%) in Figures 5 and 6. Note that these simulations are directly comparable: the sequence of shocks is identical in each case. We also include the optimal flexible price for comparison.

Figure 5. Simulated Price Behaviour Under Moderate Inflation



[10] Our simulations are based on the assumption that marginal cost follows a random walk, and the distribution of shocks to marginal cost is symmetric. See Appendix 1 for more details.

Figure 6. Simulated Price Behaviour Under Moderate Deflation



From these and other simulations at different inflation rates (not reported), we observe the following predictions of the menu cost model:

1. Consistent with Figures 3 and 4, the range of inaction about the optimal flexible price is asymmetric: firms are more reluctant to reduce prices than raise them. As a result, when they do finally reduce prices, the resulting price change will be larger than comparable price increases.
2. Prices display mean reversion. That is, on average, price increases are followed by price decreases, and vice versa. But as a result of 1, price decreases are more likely to be followed by price increases than price increases are to be followed by price decreases. That is, price increases tend to be more persistent than price decreases.
3. The size of the bands within which firms will choose not to adjust prices is increasing in the level of inflation or deflation. That is, firms respond optimally to increases in price level drift by increasing their tolerance in the size of deviations between actual and desired prices to minimize menu costs.
4. Any given level of deflation results in a larger range of inaction than the same level of inflation.
5. As a result of 1 and 4, prices tend to be systematically higher relative to the optimal flexible price under deflation than under inflation, since declining overall prices imply that prices spend more time near the top of the interval of inaction than would be the case under inflation.

The macroeconomic consequences of deflation, which are the focus of this paper, stem from 5: if prices tend to be systematically higher under deflation than under inflation relative to their optimal level in the absence of menu costs, then this factor alone adds to the economic costs of deflation.

The source of this over-pricing is that under inflation, firms are more likely to hit the lower price bound and raise prices than hit the upper price bound and reduce prices. As a result, prices are on average significantly lower than with deflation, when prices tend to be closer to the upper bound.[11] This is the source of potential costly asymmetry that we have mentioned before. If prices are systematically "too high" under deflation, then it follows that output will be systematically "too low." Indeed, in our simulations, the difference between the average price and the optimal flexible price is 3.6% during deflation, and insignificantly different from zero during inflation, indicating that the macroeconomic costs of deflation under menu costs are potentially large. Note that this is an equilibrium level effect, and not due to a surprise deflationary: in our simulations, deflation is perfectly anticipated.

However, we cannot directly test for over-pricing in the data, since we do not know the level of the optimal flexible price. Instead we will test for evidence of menu costs indirectly, by looking at the behaviour of price changes as the level and sign of inflation changes, by testing for predictions 1 and 2 above.

In addition, we can also test for the presence of menu costs by looking at the relationship between higher moments of the price data and the inflationary environment. Ball and Mankiw (1994, 1995) argued that there are good reasons to expect to find such relationships if firms face menu costs. Suppose the distribution of price changes is symmetric about zero. There will be equal numbers of firms wishing to increase prices as reduce them, so the overall price level will remain stable, and independent of the variance of relative prices.

Now consider instead if the distribution of price changes is positively skewed. A few firms wish to raise their prices a lot, while a lot of firms wish to decrease their prices a little. With menu costs, the former firms will be more likely to change their

[11] Movement in the degree of asymmetry in the price bounds is not enough to offset this.

price, and so positive skew will result in rising prices. In contrast, negative skew will result in falling prices. This effect will be exacerbated by increased volatility, as then more firms will find it optimal to pay menu costs in order to adjust their prices.

Under trend inflation, we would expect to find that firms are more willing to raise prices than lower them, resulting in a positive relationship between skewness and the level of aggregate inflation. Under trend deflation, this process may be expected to go into reverse: firms are more willing to lower prices than raise them, resulting in negative skewness and declining prices. We would also expect to find that the size of inflation or deflation is increasing in the size of the microeconomic price changes as well, since firms will be more willing to adjust their prices the greater is the volatility that they face.

We now move on to describe in detail the data that we will later use to test for evidence of these predictions.

4. Data

We test for evidence of asymmetric price changes using a unique dataset that includes 327 components of the CPI at monthly frequency over the 153 months from January 1995 to September 2007, for a total of 50031 observations on the price level. These components together make up 45% of the overall CPI. Included within the sample are most components of the CPI that are set in the market (excluding those set by regulatory agencies), are not imputed, and are not subject to large seasonal fluctuations over time, as provided by the Hong Kong Census and Statistics Department.[12]

Note that our dataset consists of disaggregate good-level prices that are weighted averages across different locations and stores, and as such are themselves aggregate prices. This is in contrast with some other studies of price movements that focus on store-level prices, which allow for more systematic modelling of the price setting decisions by firms, such as those summarised in Alvarez et al (2006) and Altissimo et al (2006) using European data, as well as Bils and Klenow (2004), Golosov and Lucas

[12] All data series made available by the Census and Statistics Department for the purposes of this study are utilized throughout.

(2007), and Klenow and Kryvstov (2005) using US data.

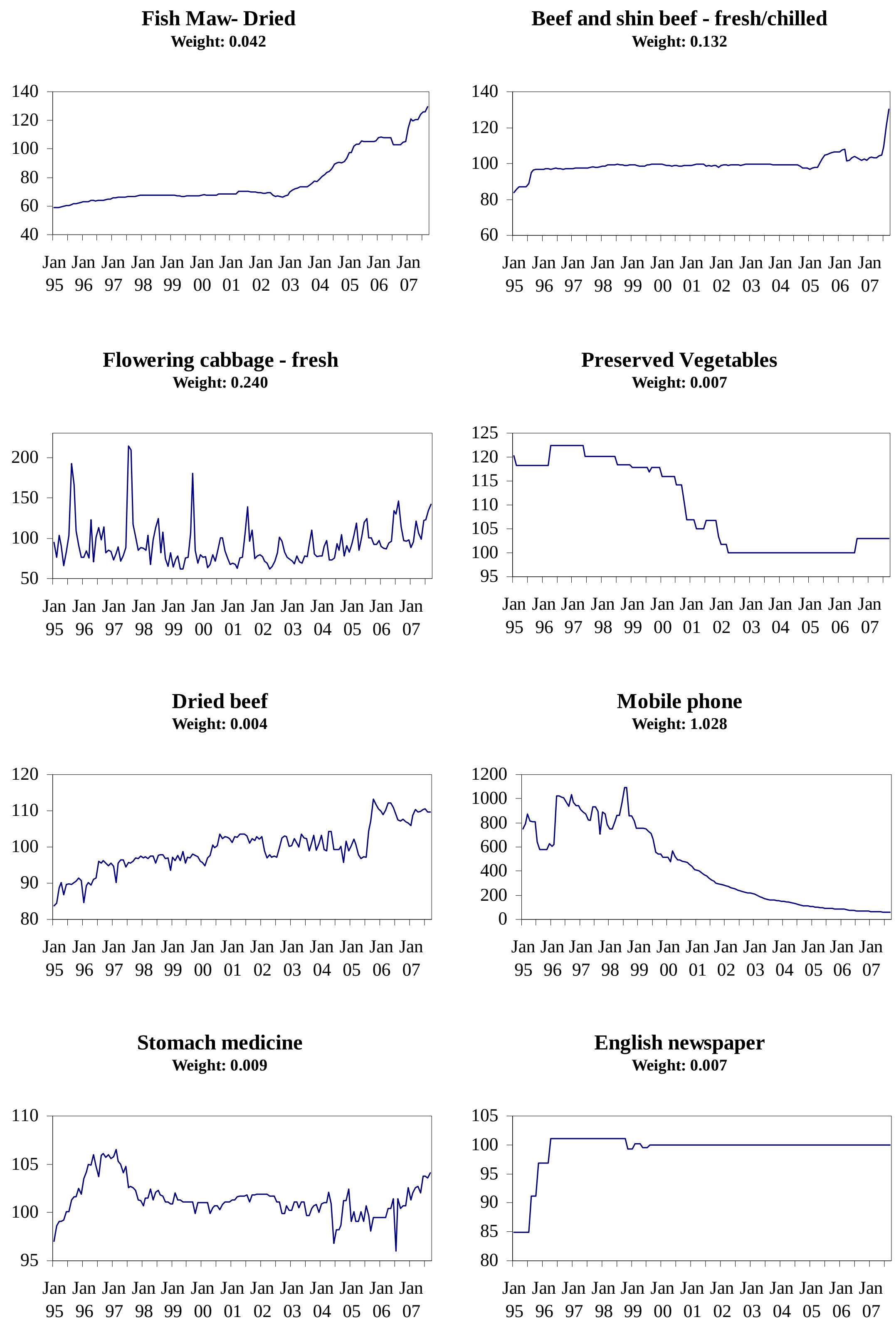
The coverage of the different major components of the CPI contained within our sample is given in Table 2. (For a further break-down by individual goods, see Appendix 2). Further, as illustrated in Figure 1 (above), the goods included in our sample broadly track the overall performance of the CPI over the sample period, which divides broadly into three periods: moderate inflation before November 1998, followed by deflation until June 2004, followed by low inflation until the end of the sample.

Table 2. Coverage (2004/2005-based weights)

Catergory	Sample	CPI	Coverage(%)
Food	22.8	25.8	88.4
Alcoholic drinks and tobacco	0.7	0.8	91.1
Clothing and Footware	1.2	4.3	27.7
Durable Goods	3.7	4.6	79.6
Miscellaneous Goods	3.6	5.0	72.7
Miscellaneous Services	13.1	16.1	81.1
Housing	0.0	30.6	0.0
Electricity, gas and water	0.0	3.4	0.0
Transport	0.0	9.5	0.0
	45.0	100.0	

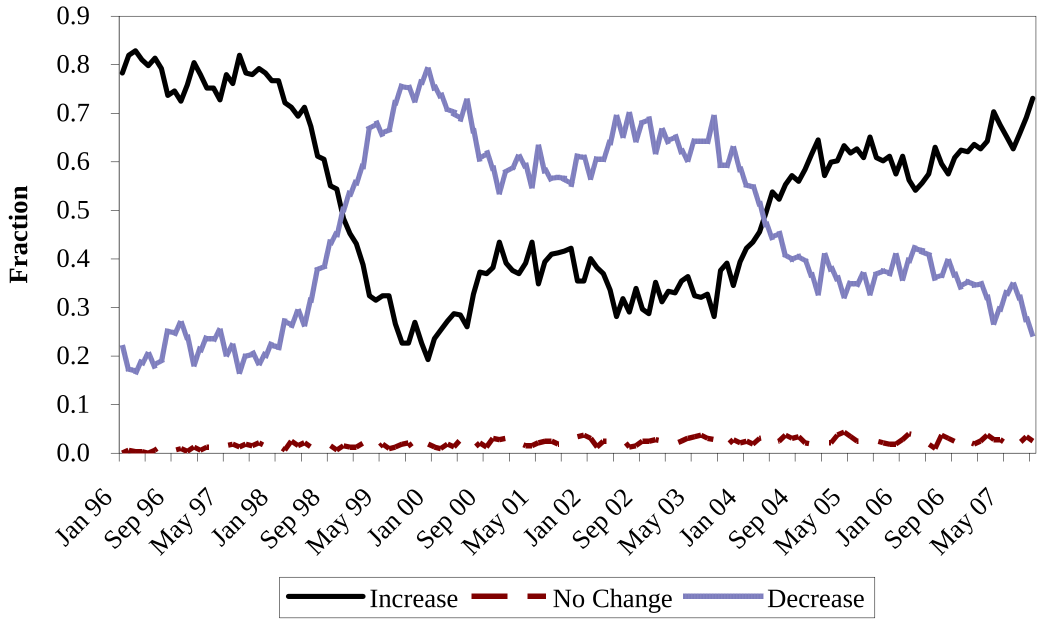
As a further illustration of the data, Figure 7 demonstrates the range of behaviour that the different price series display, along with the weight of the series in the CPI. From the volatility of the price of fresh flowering cabbage, to the steady downward price of mobile phones, to the almost constant price of English language newspapers, there is a large degree of differentiation in the price behaviour of different goods and services. This is both due to heterogeneous price setting behaviour across different goods and services, and differing numbers of individual prices being aggregated into the sub-indices of prices in our dataset.

Figure 7. Individual Price Series



Within the dataset, there is also significant variation in the number of price increases and decreases over time. Figure 8 plots the percent of all prices that are rising, falling, or remaining constant on a year-on-year basis within the panel. One can clearly see that in all periods, a significant number of goods experience both rising and falling prices, although this number varies substantially between inflationary and deflationary periods.[13,14]

Figure 8. Composition of Price Changes, year on year

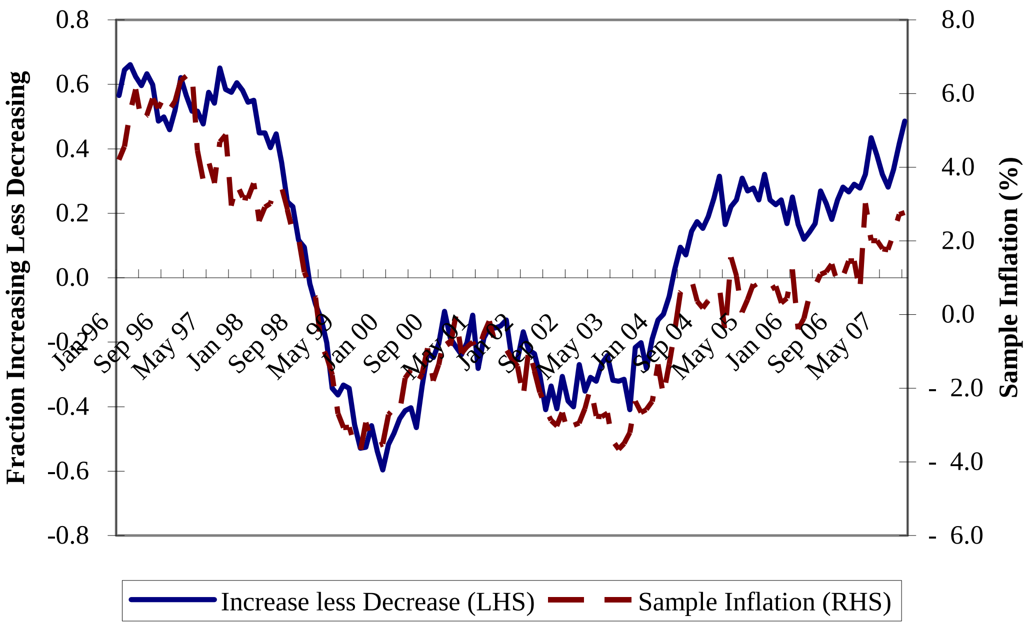


In fact, this variation alone is sufficient to explain nearly all of the variation in inflation, as illustrated by Figure 9, which plots the inflation rate against the number of goods with increasing prices less the number of goods with falling prices. The correlation coefficient between these two series is 0.94.

[13] Note that the "no change" category is defined as good categories where the price index takes on the same numerical value to one decimal place as it did twelve months earlier. There are a total of 941 such observations in the sample. A more stringent definition of "no change" would require no change in the price index in any of the intervening months as well. Approximately one third of all such observations, spread over 21 different goods, satisfy this stricter definition of "no change," with "English Newspaper" (105 observations), "Postal and Courier Services" (52), "Preserved Vegetables" (47), "Examination Fees" (36) and "Chinese Newspaper" (27) providing most of the observations.

[14] As Smith (2006) points out, whether there is deflation or inflation, some prices are typically rising while others are typically falling. The transition from inflation to deflation is a change in the balance between these two, rather than a change in the behaviour of all prices.

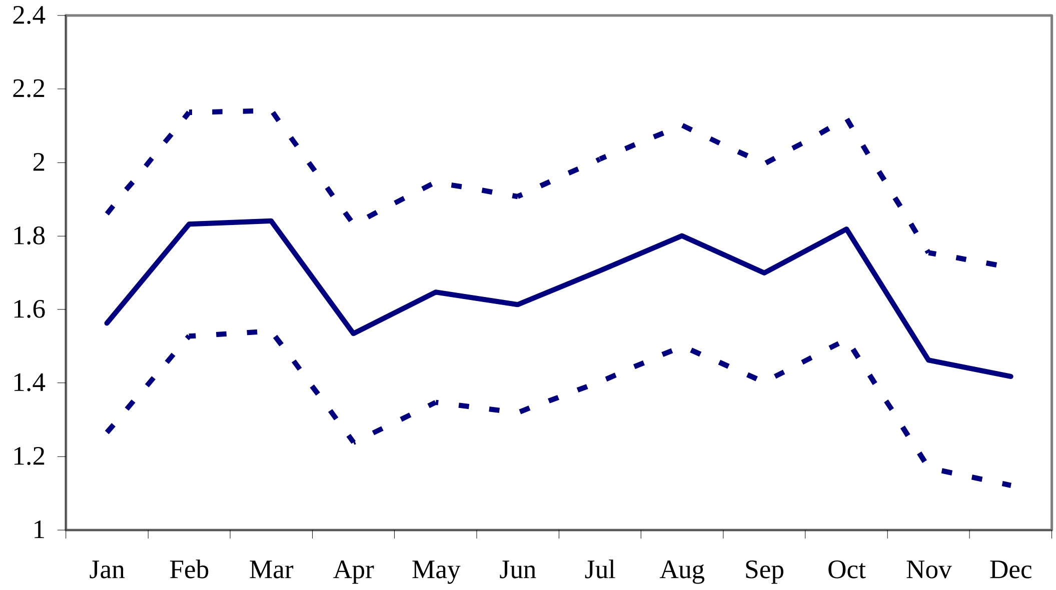
Figure 9. Qualitative Price Change vs. Inflation



In other studies, authors have found important seasonal influences in price-setting decisions. For example, Altissimo et al (2006) found on Euro area data that price changes are more likely to take place during the first quarter (especially in January) or after the summer period (especially in September), and are less frequent in July and August, while Nakamura and Steinsson (2007) found that the frequency of price changes is highest in the first quarter and lowest in the fourth quarter in US data.

We would expect any seasonal pattern in Hong Kong data to be apparent from the average magnitude of price changes in each month across the different sub-indices, as provided by monthly fixed effects from a regression with a dependent variable of month-over-month price changes. The results, together with 95% confidence bands, are reported in Figure 10. These indicate that there are important differences in price behaviour over the calendar year. In particular, price changes are largest in February/March and October and smallest at the end of the year. In the remainder of our analysis we will focus on year-on-year changes in individual price series, so that results are not influenced by seasonal patterns in the data.

Figure 10. Monthly Fixed Effects
Estimates and 95% CI



5. Tests of Asymmetry

We now test for price setting asymmetry in Hong Kong data by looking at the persistence and size of price changes between inflationary and deflationary periods, and then higher order moments, and comparing these with the predictions of the menu cost model outlined in Section 3. In comparing the data with the model, we must bear in mind that the former consists of observed price aggregates across different stores of narrowly defined goods (as opposed to prices of individual goods at a specific store), while the latter strictly applies to individual store level data. Changes in prices in the data therefore reflects decisions at the individual firm level about the size of price changes, the frequency of price changes, and the degree of synchronicity of price changes across firms. In principle, changes across one of these dimensions could be offset by changes across the others. For example, larger less frequent price changes, if spread uniformly across firms through time, may result in exactly the same observed behaviour as smaller, more frequent price changes. But this possibility is unlikely, given the variation we find in the behaviour of our microeconomic price aggregates.

We will continue our analysis under the assumption that, for narrowly defined goods (as in our sample), firms' price setting decisions for a given good are highly correlated. That is, there is a “good-specific” marginal cost shock that is sufficiently large relative to any “store-specific” shock, and there is sufficient competition among firms selling the same good in different locations, that we should expect to find behaviour of good level prices in our dataset that is broadly similar to the store level price predictions of our menu cost model.

5.1 Persistence

Recall from section 3 that one prediction of the menu cost model is that price increases should be more persistent than price decreases, especially when there is inflation. To examine the behaviour of persistence in Hong Kong price data, we first examine aggregate data and estimate the following equation,

$$\Delta P_t = \beta + \rho_1 \Delta P_{t-12} + \rho_2 D_t \Delta P_{t-12} + \varepsilon_t, \qquad (1)$$

where $\Delta P_t = \log(P_t) - \log(P_{t-12})$, D_t is a dummy variable that takes on a value of 1 when there is deflation (defined as $\Delta P_t < 0$), and time is measured in months. The results are presented in Table 3, in the top panel for the CPI, and in the lower panel for the portion of the CPI that is in our dataset.

We can see that Hong Kong inflation is much more persistent during inflationary episodes than deflationary episodes at annual frequency, both for the complete CPI and for the portion of the CPI on which we have data. This is in keeping with Burdekin and Siklos (2004), who report that inflation is more difficult to predict during deflationary episodes than inflationary ones, and in contrast to Bordo and Filardo (2005) who found that there was little difference in the degree of persistence in aggregate inflation between inflationary and deflationary episodes before World War 1.

Table 3A. Persistence- Aggregate CPI* $\Delta P_t = \beta + \rho_1 \Delta P_{t-12} + \rho_2 D_t \Delta P_{t-12} + \varepsilon_t$		
ρ_1	ρ_2	R^2
0.55 **(0.00)**		0.41
0.89 **(0.00)**	**-0.70** **(0.00)**	0.52
Table 3B. Persistence- Aggregate Sample* $\Delta P_t = \beta + \rho_1 \Delta P_{t-12} + \rho_2 D_t \Delta P_{t-12} + \varepsilon_t$		
ρ_1	ρ_2	R^2
0.50 **(0.00)**		0.36
0.64 **(0.00)**	**-0.37** **(0.01)**	0.39

* P-values in parentheses; variables that are significant at the 5% level are bold.

At first appearance, these results accord with the predictions of the menu cost model, since prices tend to fall during deflationary periods. But the predictions of the menu cost model apply not to aggregate prices, but instead to individual good prices. So our next step is to consider the individual price series for each of the 327 components for which we have data. Our estimated equation takes the form

$$\Delta P_{it} = \beta_i + \rho_1 \Delta P_{it-12} + \rho_2 D_t \Delta P_{it-12} + \rho_3 D_{it-12} \Delta P_{it-12} + \varepsilon_{it}, \qquad (2)$$

where goods are indexed by *i*, $\Delta P_{it} = \log(P_{it}) - \log(P_{it-12})$, D_{it} is a dummy variable that takes on a value of 1 when the price of good *i* is falling year-over-year, and D_t is as defined above. We also include good-level fixed effects, and incorporate robust variance-covariance estimates. The results are contained in table 4.

From these results we can see that, first, inflation persistence is simply not present in the sub-indices of the CPI on an annual basis, but is instead a result of aggregation across the different goods.[15] In fact, inflation rates at the micro level are significantly negatively correlated through time, indicating mean reversion in the price level, a result that we also found in our simulations of the menu cost model earlier.

Table 4. Persistence- Micro Sample $\Delta P_{it} = \beta_i + \rho_1 \Delta P_{it-12} + \rho_2 D_t \Delta P_{it-12} + \rho_3 D_{it-12} \Delta P_{it-12} + \varepsilon_{it}$			
ρ_1	ρ_2	ρ_3	R^2
-0.16 **(0.00)**			0.12
-0.16 **(0.00)**	0.01 (0.69)		0.12
-0.23 **(0.00)**	-0.03 (0.28)	**0.16** **(0.00)**	0.12

Second the presence of deflation in the aggregate price level has no significant separate effect on the degree of persistence at annual frequency. This is consistent with the idea that the important difference between deflation and inflation is the number of firms whose prices are rising or falling, as opposed to the behaviour of the price aggregate, as suggested by Smith (2006).

Third, when we interact the lagged price level with the sign of price changes at the microeconomic level, we find there is greater mean-reversion in the price level when prices are rising than when they are falling. That is, if prices fell in the previous year, it is less likely that the price decrease will be reversed (via a price rise in the current period) than if prices increased in the previous period. Note, however, that this is exactly the opposite of the prediction of the menu cost model.

5.2 The Size of Price Changes

Our next set of results focus on the size of price changes. We compare the size of changes in the sub-indices of the CPI between price rises and price falls, and also

[15] Clark (2006) and Bils and Klenow (2004) also report that aggregate inflation displays greater persistence than disaggregate inflation.

between inflationary and deflationary periods.

To test for differences in the size of price changes, we estimate

$$\left|\Delta P_{it}\right| = \beta_i + \gamma_0 \left|\Delta P_t\right| + \gamma_1 D_t + \gamma_2 D_{it} + \varepsilon_{it}, \quad (3)$$

where $\left|\ \right|$ indicates absolute value, and the variables are as defined above. The results are given in Table 5.

Table 5. Size of Price Changes- Sample $\left\|\Delta P_{it}\right\| = \beta_i + \gamma_0 \left\|\Delta P_t\right\| + \gamma_1 D_t + \gamma_2 D_{it} + \varepsilon_{it},$			
γ_0	γ_1	γ_2	R^2
0.39 **(0.00)**	**-0.26** **(0.00)**		0.59
0.39 **(0.00)**	**-0.33** **(0.00)**	**0.20** **(0.00)**	0.59

From the results, we can see that prices that are falling experience larger changes than prices that are rising, in agreement with the predictions of our menu cost model. But, we also find that overall price changes are smaller during deflation than during inflation, in contradiction to the predictions of the menu cost model.

5.3 Higher Order Moments

We next consider the relationship between higher order moments and the inflationary environment, as suggested by Ball and Mankiw (1994, 1995). We follow Gerlach and Kugler (2007), Verbrugge (1999), and Bryan and Cecchetti (1999) in constructing a measure of inflation within our sample at each point in time as

$$\pi_t = \frac{\sum_i w_i \Delta P_{it}}{\sum_i w_i}, \quad (4)$$

where w_i is the weight attached to each component in the CPI, and $\Delta P_{it} = \log(P_{it}) - \log(P_{it-12})$. Higher order moments are then defined as

$$m_{rt} = \sum_i w_i (\Delta P_{it} - \pi_t)^r / \sum_i w_i, \tag{5}$$

with skewness then computed as

$$SKEW_t = \frac{m_{3t}}{[m_{2t}]^{3/2}}. \tag{6}$$

As in Gerlach and Kugler (2007), we randomly assign 50% of all price observations to calculating the mean, and the remaining 50% of the observations to calculating the higher order moments. By so doing, we avoid creating any artificial correlation between the mean and the higher order moments, which may potentially lead to bias in our estimation results.[16] We also repeat our estimation procedure 100 times (since the estimates themselves now contain sampling error), and report the average estimates.

Our estimated equation takes the following form:

$$\begin{aligned} \pi_t = {} & \beta_1 D_t + \beta_2 (1 - D_t) + \delta_1 D_t STD_t + \delta_2 (1 - D_t) STD_t \\ & + \phi_1 D_t SKEW_t + \phi_2 (1 - D_t) SKEW_t + \varepsilon_t, \end{aligned} \tag{7}$$

where D_t is as defined above, STD_t is the square root of the second moment, and $SKEW_t$ is as defined in (12) above. We use Newey-West standard errors to allow for serial correlation and heteroskedasticity. The results, both across the full sample and with split samples, are given in Table 6.

Focusing on the split sample results that avoid artificial correlation in the moments, we find that higher volatility at the micro level leads to higher inflation. Aside from that, we find little evidence of systematic relationships between the moments of the data.

Gerlach and Kugler (2007) tested the relationship between the moments of inflation on Hong Kong data using the twelve main sub-components of the CPI, and found that a higher standard deviation is (weakly) related to higher inflation or

[16] The source of this bias is that an extreme positive or negative observation for an individual price increases the mean, variance, and skewness by construction, independent of any underlying economic for them to be related; see the discussion in Bryan and Cecchetti (1999). For an alternative solution to this problem, Verbrugge (1999) used the median and trimmed mean (in place of the mean) as a measure of central tendency, and the non-parametric triples U-statistic in place of skewness.

deflation, and that skewness is positively correlated with the level of inflation both under deflation and inflation, broadly in agreement with the theoretical predictions of menu costs suggested by Ball and Mankiw. But ideally, if we are seeking to model the behaviour of individual firms setting prices subject to menu costs, applying this test at a more microeconomic level should yield more accurate results. Further, greater disaggregation results in a significantly larger panel, and therefore a greater chance of identifying empirical relationships. The fact that our results provide little support for menu cost models in contrast to Gerlach and Kugler (2007) is a puzzle that we leave to future work.[17,18]

Table 6. Higher Order Moments

$$\pi_t = \beta_1 D_t + \beta_2(1-D_t) + \delta_1 D_t STD_t + \delta_2(1-D_t)STD_t$$
$$+\phi_1 D_t SKEW_t + \phi_2(1-D_t)SKEW_t + \varepsilon_t$$

	Full Sample	Split Sample
δ_1	**-0.42**	0.29
	(0.00)	(0.07)
δ_2	**0.59**	**0.38**
	(0.00)	**(0.00)**
ϕ_1	0.02	0.02
	(0.26)	(0.38)
ϕ_2	**0.04**	-0.01
	(0.00)	(0.54)
R^2	0.80	0.49

5.4 Discussion

Overall, across the three sets of tests that we have applied to Hong Kong data, we find little support for the menu cost model. But this is not due to a lack of asymmetry in price setting in Hong Kong data. We have also conducted a large number of

[17] Possible candidates to explain the difference in results found here and in Gerlach and Kugler (2007) include aggregation bias, and the fact that our sample excludes some components of the CPI (see Table 2).

[18] Bryan and Cecchetti (1999) also argued that menu costs would imply a stronger link at shorter horizons than longer ones, since at long enough horizons, all firms will have adjusted their prices, implying effectively price flexibility. We checked all horizons from 1 to 24 months, and found little variation in the estimates across horizons.

hypothesis tests based on interacting the size of price change with the inflationary environment (reported in Appendix 3), and find that in general, there are significant differences between all of the estimated parameters. So it is not the lack of asymmetry that causes us to reject the menu cost model, but rather inconsistency between the estimated asymmetries and those implied by the menu cost model.

There are several possible explanations for this. First we may have the wrong model, and the source of asymmetry is not menu costs, but instead capacity constraints (Hansen and Prescott 2005), information costs (Ball, Mankiw and Reis 2005), rational inattention (Levy et al 2004), or some other source of nominal rigidity.

Second our calibration may be a poor counterpart to real world price data. We have assumed that trend inflation is anticipated and shocks to marginal cost are permanent. This implies that whenever a firm adjusts their price, the new price will be a fixed mark-up on marginal cost, whether the price adjustment is a price increase or a price decrease. But while this seems a reasonable assumption, our results may be sensitive to alternative assumptions. For example, if negative marginal cost shocks are inherently different from positive marginal cost shocks in terms of either their size or their persistence, then price adjustment asymmetries may differ from those identified in our simulation. We leave further investigation of this issue to future work.

6. Conclusions

We have shown that menu costs imply that firms are more reluctant to reduce prices than raise them. As a consequence, deflation would be characterised by prices that are systematically “too high” relative to optimal flexible prices, resulting in lower levels of real output.

We have tested for the implications of menu cost models using a rich set of microeconomic prices that covers both inflationary and deflationary periods for Hong Kong. Given the high degree of diversity in the behaviour of individual series (see Figure 7), we have used simple, robust statistical methods, focusing on the size of price changes, the degree of mean reversion in prices, and higher order moments in our panel.

We can identify many aspects of asymmetric pricing behaviour in our data, and also in our model. But there is little agreement between the two. In particular, menu costs imply that price decreases are more likely to be reversed by future price rises than vice versa, price changes are larger during deflation than during inflation, and the skewness of price changes is positively correlated with the inflation rate. We can reject the first two of these hypotheses, and find no empirical support for the third. We therefore conclude that the menu cost model does not provide a good description of price setting behaviour during Hong Kong's deflationary period. Identifying a model of price setting that can adequately explain the asymmetries in our data is left for future work.

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Appendix 1. Profit Function and Simulations.

Suppose that consumers consume a consumption bundle that is a Dixit-Stiglitz aggregator over different types of goods (indexed by *i*) given by

$$q_t = \left[\int_i \left(q_t^i \right)^{\frac{\sigma-1}{\sigma}} di \right]^{\frac{\sigma}{\sigma-1}}. \tag{8}$$

Consumer optimisation implies demand for each good of

$$q_t^i = \left(\frac{p_t^i}{p_t} \right)^{-\sigma} q_t. \tag{9}$$

Assuming a firm's real profits are given by

$$\Pi_t^i = \left(\frac{p_t^i - mc_t^i}{p_t} \right) q_t^i, \tag{10}$$

where mc_t^i is the marginal cost of good *i*, profit maximization will imply a price given by

$$p_t^i = \frac{\sigma}{\sigma - 1} mc_t^i. \tag{11}$$

Figure 3 illustrates the profit function for $\sigma = 1.5$.

To generate the simulation results reported in Figures 5 and 6, we further assume that marginal cost follows a random walk with drift. The drift component is equal to the average inflation (deflation) rate, while the permanent marginal cost shock has a standard deviation of 5% of the marginal cost of the good. Menu costs (that is, the cost of each price change) is assumed to be 0.1% of total revenue, and the discount rate applied to future profits is given by $\beta = 0.996$. Results are robust to alternative parameter values.

Appendix 2: Sample Items (2004/2005-based weights)

Items	Weight(%)	Items	Weight(%)	Items	Weight(%)
Rice - main staple	0.27	Sweetened dates - dried and preserved	0.01	Radio	0.00
Bread	0.43	Figs - dried and preserved	0.00	Desktop computer set	0.21
European cake	0.13	Canned fruit	0.01	Computer software	0.01
Chinese cake	0.01	Hen egg	0.08	Telephone set (incl. cordless)	0.03
Chinese pudding and dessert	0.06	Salted duck egg	0.01	Mobile phone	1.03
Biscuit	0.15	Granulated white sugar	0.01	Electronic dictionary	0.03
Grouper - live	0.08	Honey	0.01	Frying pan and wok	0.02
Seabream - live	0.01	Candy	0.09	Pot	0.02
Rabbitfish - live	0.01	Chocolate	0.10	Vacuum cooking pot	0.01
Golden thread - fresh/chilled	0.18	Chewing gum	0.01	Knife and chopper	0.00
Big-eye - fresh/chilled	0.03	Soup and broth	0.08	Men's watch - electronic/ quartz/ solar	0.02
Mackerel - fresh/chilled	0.01	Bean curd	0.03	Men's watch - mechanical	0.06
Grouper - fresh/chilled	0.05	Bean curd products	0.01	Women's watch - electronic/ quartz/ solar	0.04
Sole - fresh/chilled	0.02	Bean vermicelli	0.00	Women's watch - mechanical	0.08
Horse-head - fresh/chilled	0.02	Mushroom - dried	0.04	Wall clock	0.00
Pomfret - fresh/chilled	0.09	Fungus - dried	0.01	Table clock	0.00
Hair-tail - fresh/chilled	0.01	Fried shrimp paste	0.01	Automatic camera	0.01
Seabream - fresh/chilled	0.02	Potato chips	0.05	Single-lens reflex camera	0.01
Rabbitfish - fresh/chilled	0.01	Dried pork	0.01	Video camera/ camcorder	0.06
Thread fin - fresh/chilled	0.01	Dried beef	0.00	Spectacles	0.17
Grass carp - live	0.15	Cooked nuts	0.03	Sunglasses	0.02
Mud carp - live	0.00	Dried and preserved fruit	0.02	Contact lens (excl. disposable contact lens)	0.02
Big head - live	0.06	Jelly	0.01	Keyboard instrument	0.06
Snake head - live	0.01	Cantonese restaurant/ fan-tim	5.19	Perambulator	0.00
Edible tilapia - live	0.01	Shanghainese restaurant	0.21	Vitamin	0.05
Freshwater grouper - live	0.08	Zhaozhou restaurant	0.07	Stomach medicine	0.01
Grey mullet - fresh/chilled	0.02	Hakka restaurant / Tung Kong fan-tim	0.01	Analgesics and antipyretics	0.01
Prawn and shrimp, fresh/chilled	0.06	Other Chinese restaurants	0.02	Cold remedies	0.03
Prawn and shrimp, live	0.07	Caf? (mainly serving Chinese style food)	3.42	Cough drug	0.01
Crab - live/fresh/chilled	0.08	Noodle, rice-stick and congee stall	0.36	Ointment	0.03
Squid - live/fresh/chilled	0.02	Noodle, rice-stick and congee shop	0.32	Cod liver oil	0.01
Salted and dried fish - dried	0.02	Vegetarian food shop	0.03	Antiseptics and disinfectants	0.01
Abalone - dried	0.02	Western restaurant	1.95	Herbal medicine	0.16
Scallop - dried	0.05	Japanese restaurant	0.55	Proprietary medicine	0.09
Oyster - dried	0.01	Korean restaurant	0.06	Proprietary medicine for external use	0.01
Shrimp - dried	0.01	Thai restaurant	0.12	Health and weight control supplement	0.07
Shark's fin - dried	0.01	Vietnamese restaurant	0.05	Adhesive tape/ plaster	0.01
Fish maw - dried	0.04	Malaysian / Singaporean restaurant	0.02	English newspaper	0.01
Fish - frozen	0.06	Indonesian restaurant	0.01	Chinese newspaper	0.50
Abalone - frozen	0.02	Café/tea/coffee stall (mainly non-Chinese style food)	0.87	English book (excl. textbook)	0.05
Fish - canned	0.02	Fast food shop	2.83	Chinese book (excl. textbook)	0.09
Abalone - canned	0.01	Canteen/ cafeteria	0.25	Ball pen	0.01
Fish ball and slice	0.05	Bar and lounge	0.10	Notebook	0.01
Best cut and lean meat - fresh/chilled	0.60	Dessert shop	0.03	Exercise book	0.01
Pork belly - fresh/chilled	0.01	Chinese wine	0.02	Greeting card/ postcard	0.00
Pork chop - fresh/chilled	0.05	Brandy	0.02	Computer consumables	0.01
Spare rib - fresh/chilled	0.19	Red wine	0.08	Face make-up	0.07
Liver - fresh	0.01	Cigarettes	0.62	Lipstick	0.03
Fore shank - fresh	0.01	Denim suit and jeans - men's	0.11	Perfumery	0.03
Bone - fresh	0.17	Vest and singlet - men's	0.01	Skin care products	0.38
Beef and shin beef - fresh/chilled	0.13	Briefs and boxer shorts - men's	0.01	Bath soap and toilet soap	0.07
Fillet and steak - fresh/chilled	0.02	Denim suit and jeans - women's	0.13	Shampoo and hair conditioner	0.12
Brisket - fresh/chilled	0.01	Slip and corselette - women's	0.07	Hair treatment products	0.03
Chicken - live/fresh/chilled	0.37	Brassiere - women's	0.01	Tooth paste	0.03
Duck - live/fresh/chilled	0.01	Briefs - women's	0.01	Tooth brush	0.01
Pigeon - live/fresh/chilled	0.00	Denim suit and jeans - children's	0.01	Oral sterilizing solution	0.01
Pork chop - frozen	0.03	Pants - children's	0.00	Toilet paper	0.10
Spare rib - frozen	0.00	Women's socks and stockings	0.02	Facial tissue	0.06
Ham - frozen	0.03	Women's panty hose	0.00	Face and bath towel	0.03
Fillet - frozen	0.02	Children's stockings	0.01	Sanitary napkin	0.03
Steak - frozen	0.02	Belt	0.02	Diaper for adults	0.01
Whole chicken - frozen	0.00	Necktie	0.01	Diaper for babies	0.06
Chicken wing - frozen	0.13	Knitting wool	0.01	Floor polish	0.01
Chicken leg - frozen	0.03	Dress shoes - men's	0.10	Broom and mop	0.01
Chicken breast/ fillet - frozen	0.01	Sports shoes - men's	0.16	Gold/ platinum jewellery	0.21
Sausages - frozen	0.04	Slippers - men's	0.00	Silver and costume jewellery	0.04
Barbecue pack - frozen	0.01	Dress shoes - women's	0.27	Doll and soft toy	0.04
Roasted pork	0.12	Sports shoes - women's	0.12	Building block (incl. lego)	0.01
Barbecue pork	0.08	Slippers - women's	0.01	Model	0.04
Roasted spare rib	0.00	Dress shoes - children's	0.03	Tricycle, play car and bicycle	0.00
Lo-mei	0.01	Sports shoes - children's	0.06	Electronic game and accessories	0.04
Chicken/ soy sauce chicken	0.05	Bed (incl. baby bed)	0.05	Miniature car (incl. remote control car)	0.01
Roasted duck/ goose	0.05	Wardrobe	0.04	Films and disposable camera	0.00
White cabbage - fresh	0.07	Wall cabinet	0.04	Blank video tape	0.00
Flowering cabbage - fresh	0.24	Cupboard	0.01	Compact disc record	0.05
Chinese kale - fresh	0.02	Storage shelf/ cupboard	0.02	Aquarium fish	0.01
Chinese lettuce - fresh	0.06	Sofa	0.07	Feedstuff for pets	0.09
Cabbage lettuce - fresh	0.04	Chair, stool, folding chair and rocking chair	0.01	Plant	0.01
Leaf mustard - fresh	0.00	Dining table (set)	0.01	Purchases of textbooks - Kindergarten	0.05
Chinese spinach - fresh	0.01	Writing and computer desk	0.01	Purchases of textbooks - Primary	0.19
Tientsin cabbage - fresh	0.01	Air-conditioner - electric	0.13	Purchases of textbooks - Secondary	0.27
Round cabbage - fresh	0.02	Refrigerator - electric	0.08	Religious items	0.05
European celery - fresh	0.01	Washing machine - electric	0.12	Light bulb	0.02
Chinese chive - fresh	0.00	Cooker hood - electric	0.03	Dry cell	0.03
Broccoli - fresh	0.04	Ventilator - electric	0.00	Plug, socket and adapter	0.01
Cauliflower - fresh	0.01	Electric water heater - electric	0.02	Washing basin/ bucket	0.00
Wax gourd - fresh	0.02	Electric rice cooker - electric	0.04	Crystal	0.02
Hairy gourd - fresh	0.03	Microwave oven - electric	0.03	Photo frame	0.01
Bitter gourd - fresh	0.02	Blender/ mixer - electric	0.00	Vase	0.00
Angled loofah - fresh	0.01	Electric kettle and vacuum flask - electric	0.02	Fresh flower	0.09
Green cucumber - fresh	0.02	Air purifier - electric	0.00	Feeding bottle and accessories	0.01
Egg plant - fresh	0.01	Vacuum cleaner - electric	0.04	Clothes hanger and clip	0.02
Chinese radish - fresh	0.01	Electric iron - electric	0.01	School fees - major	2.92
Green turnip - fresh	0.01	Hairdryer - electric	0.00	School fees - continuing education	0.91
Carrot - fresh	0.03	Electric shaver - electric	0.01	School fees - others (e.g. music, dancing, drawing, etc.)	0.41
String beans - fresh	0.02	Electric fan - electric	0.03	Examination fees	0.02
Tomato - fresh	0.04	Dehumidifier - electric	0.04	Boarding and lodging fees	0.02
Lotus root - fresh	0.01	Heater/ radiator - electric	0.01	Medical services	2.57
Potato - fresh	0.02	Ceiling lamp - electric	0.02	Cinema entertainment	0.17
Ginger - fresh	0.01	Desk lamp - electric	0.00	Package tours	1.65
Bean sprout - fresh	0.01	Gas stove	0.04	Expenses on parties	0.17
Sweet pepper - fresh	0.01	Television set	0.54	Charges for sports and games	0.13
Onion - fresh	0.01	Video tape recorder	0.04	Admission charges to entertainment places	0.26
Mushroom - fresh	0.03	Video disc player	0.16	Laundry services	0.04
Preserved vegetables - preserved	0.01	Hi-Fi set	0.04	Hair-dressing	0.39
Beans and peas - canned	0.01	Amplifier/ tuner	0.03	Repairs to personal and household goods	0.08
Banana - fresh	0.05	Compact disc record player	0.00	Telephone and other communications services	3.27
Pomelo - fresh	0.01	Loudspeaker	0.00	Postal and courier services	0.01
Kiwifruit - fresh	0.01	Mini disc player	0.02	Photographic and photo-printing services	0.04

Appendix 3. Additional Asymmetry Results

In addition to the asymmetry results reported in the body of the paper, we report here further asymmetries resulting from interacting the deflation and price change dummies, along with results from hypothesis tests on equality between the estimates. For persistence, we estimate

$$\Delta P_{it} = \beta_i + \rho_1 D_t D_{it-12}\Delta P_{it-12} + \rho_2 D_t(1-D_{it-12})\Delta P_{it-12} + \rho_3(1-D_t)D_{it-12}\Delta P_{it-12} + \rho_4(1-D_t)(1-D_{it-12})\Delta P_{it-12} + \varepsilon_{it}, \quad (12)$$

and obtain the following results:

Table A1. Persistence- Micro Sample $\Delta P_{it} = \beta_i + \rho_1 D_t D_{it-12}\Delta P_{it-12} + \rho_2 D_t(1-D_{it-12})\Delta P_{it-12} + \rho_3(1-D_t)D_{it-12}\Delta P_{it-12} + \rho_4(1-D_t)(1-D_{it-12})\Delta P_{it-12} + \varepsilon_{it}$				
ρ_1	ρ_2	ρ_3	ρ_4	R^2
0.08 **(0.00)**	**-0.75** **(0.00)**	**-0.44** **(0.00)**	**-0.06** **(0.03)**	0.20

The results on tests of equality between the different coefficients are contained in Table A2. We find that there is no significant difference in the persistence of price changes once we account for different behaviour between increasing and decreasing prices, but that all other test statistics are significant, indicating that there are important differences in the degree of mean reversion in prices, between increases and decreases, and between inflation and deflation.

Table A2. Persistence- Micro Sample*	
Null Hypothesis	*t*-Statistic
P1. Price increases are more likely to be reversed than price decreases.	**4.04** **(0.00)**
P2. Price changes are more likely to be reversed when there is deflation than when there is inflation.	1.09 (0.28)
P3. Price increases during deflation are more likely to be reversed than price increases during inflation.	**21.89** **(0.00)**
P4. Price decreases during inflation are more likely to be reversed than price decreases during deflation.	**19.17** **(0.00)**
P5. Price increases during inflation are more likely to be reversed than price decreases during deflation.	**3.89** **(0.00)**
P6. Price increases during deflation are more likely to be reversed than price decreases during inflation.	**7.53** **(0.00)**
P7. Price decreases during inflation are more likely to be reversed than price increases during inflation.	**8.78** **(0.00)**
P8. Price increases during deflation are more likely to be reversed than price decreases during deflation.	**24.35** **(0.00)**

* This table contains *t*-statistics (p-values) of a test with the null hypothesis of equality of the persistence in inflation.

We also consider interacting the two dummies in the regression of the size of price change,

$$\begin{aligned}|\Delta P_{it}| = \beta_i + \gamma_0 |\Delta P_t| + \gamma_1 D_t D_{it} + \gamma_2 D_t (1 - D_{it}) + \gamma_3 (1 - D_t) D_{it} \\ + \gamma_4 (1 - D_t)(1 - D_{it}) + \varepsilon_{it}.\end{aligned} \tag{13}$$

We also consider the largest month-over-month change in a price in each twelve month period as an alternative dependent variable, and present the results in Table A3.

Table A3. Size of Price Changes- Sample				
$\left\|\Delta P_{it}\right\| = \beta_i + \gamma_0 \left\|\Delta P_t\right\| + \gamma_1 D_t D_{it} + \gamma_2 D_t (1 - D_{it}) + \gamma_3 (1 - D_t) D_{it} + \gamma_4 (1 - D_t)(1 - D_{it}) + \varepsilon_{it}$				
γ_1	γ_2	γ_3	γ_4	R^2
5.08 **(0.00)**	**3.48** **(0.00)**	**3.92** **(0.00)**	**5.36** **(0.00)**	0.59
$\text{Max}\left\|P_{it-j} - P_{it-j-1}\right\| = \beta_i + \gamma_0 \left\|\Delta P_t\right\| + \gamma_1 D_t D_{it} + \gamma_2 D_t (1 - D_{it}) + \gamma_3 (1 - D_t) D_{it} + \gamma_4 (1 - D_t)(1 - D_{it}) + \varepsilon_{it}$				
γ_1	γ_2	γ_3	γ_4	R^2
0.051 **(0.00)**	**0.050** **(0.00)**	**0.055** **(0.00)**	**0.059** **(0.00)**	0.80

We explore these asymmetries further with tests on the parameter estimates, as reported in Table A4. While some results are mixed, the large number of significant results is again clear evidence that the nature of price changes varies between increases and decreases, and between inflationary and deflationary regimes. In particular, price changes are generally larger during inflation than during deflation, and price increases are relatively large when prices are rising, while price decreases are relatively large when prices are falling.

Table A4. Size of Price Changes- Sample*		
Null Hypothesis	Dependent Variable	
	$\lvert \Delta P_{it} \rvert$	Max $\lvert P_{it-j} - P_{it-j-1} \rvert$
S1. |Price rises| > |Price falls|	**-3.16** **(0.00)**	**27.87** **(0.00)**
S2. |Price changes during inflation| > |Price changes during deflation|	**6.77** **(0.00)**	**14.94** **(0.00)**
S3. |Price increases during inflation| > |Price increases during deflation|	**25.43** **(0.00)**	**12.41** **(0.00)**
S4. |Price decreases during deflation| > |Price decreases during inflation|	**12.89** **(0.00)**	**-7.83** **(0.00)**
S5. |Price increases during inflation| > |Price decreases during deflation|	**1.96** **(0.05)**	**38.38** **(0.00)**
S6. |Price increases during deflation| > |Price decreases during inflation|	**-4.36** **(0.00)**	**9.58** **(0.00)**
S7. |Price increases during inflation| > |Price decreases during inflation|	**13.60** **(0.00)**	**18.80** **(0.00)**
S8. |Price decreases during deflation| > |Price increases during deflation|	**22.50** **(0.00)**	**-22.74** **(0.00)**

* This table contains *t*-statistics (p-values) of a test with the null hypothesis of equality of the absolute value of the size of price changes. A positive test statistic indicates agreement with the statement in the first column; a negative coefficient disagreement.