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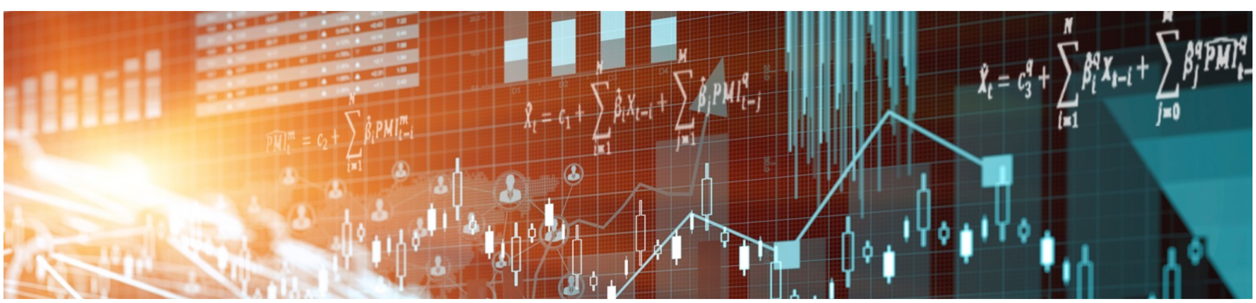

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Price-Level Dispersion versus Inflation-Rate Dispersion: Evidence from Three Countries

by

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Abstract

Inflation can affect both the dispersion of commodity-specific price levels across locations (relative price variability, RPV) and the dispersion of inflation rates (relative inflation variability, RIV). Some menu-cost models and models of consumer search suggest that the RIV-inflation relationship could differ from the RPV-inflation relationship. However, most empirical studies examine only RIV, finding that RIV is high when inflation is high. We examine city-level retail price data from Japan, Canada and Nigeria, and find that the impact of inflation on RIV differs from its effect on RPV. In particular, positive inflation shocks reduce RPV but raise RIV.

Bank topic: Inflation and prices
JEL codes: E31; E50

Résumé

L’inflation peut avoir un effet sur la dispersion des niveaux de prix de certains produits dans plusieurs régions du monde (variabilité des prix relatifs, VPR) et sur la dispersion des taux d’inflation (variabilité de l’inflation relative, VIR). D’après une partie des modèles de coûts d’affichage et des modèles de prospection qui illustrent les démarches des consommateurs, la relation entre inflation et VIR pourrait différer de la relation entre inflation et VPR. Or, la plupart des études empiriques sont focalisées sur la VIR : elles déterminent que la VIR est élevée quand l’inflation est forte. Nous nous intéressons à l’évolution des prix de détail dans un échantillon de villes japonaises, canadiennes et nigérianes. L’inflation a des effets différents sur la VIR et sur la VPR. En particulier, des chocs d’inflation positifs font baisser la VPR mais monter la VIR.

Sujets : Inflation et prix
Codes JEL : E31; E50

Non-Technical Summary

This paper provides new evidence on the relationship between aggregate inflation and the dispersion of relative prices within countries. Standard theory suggests that relative price dispersion across sellers of homogeneous commodities in different locations can result from frictions in price setting among sellers, imperfect transmission of price information to competing sellers or prospective consumers, or transportation costs. Related theoretical literature has also identified mechanisms by which aggregate monetary shocks and equilibrium price inflation across sellers can amplify these relative price differences. This includes theories of costly price adjustment, asymmetric price information between consumers and sellers, and costly consumer search.

The empirical relationships between inflation and relative prices have been investigated extensively, typically using one or more of these theories to inform the choice of statistical model. For the most part, this literature has adopted variation in relative rates of inflation (RIV) as the measure of price dispersion. Primarily owing to data limitations, few empirical papers have examined the effects of inflation on variation in relative price levels (RPV), even though this concept of dispersion is the primary focus of most theories of the costs of inflation. However, some theories of costly price adjustment and consumer search predict that inflation may have opposite effects on RPV and RIV. Although the RIV-inflation relationship is commonly studied, drawing many conclusions from this literature about the empirical RPV-inflation relationship is difficult, given the paucity of direct estimates available.

This paper utilizes detailed data on city-level price series for specific consumer goods from three different country data sources to examine the relationships between inflation and both RIV and RPV. The data cover a large number of cities in each of three countries that differ in levels of economic development and inflation episodes: Canada during the 1920s and 1930s, Japan between January 2000 and December 2006, and Nigeria between January 2001 to December 2006. We find that the impact of inflation on RIV is very different from its effect on RPV. For all three countries, we find a V-shaped relationship between price dispersion and unanticipated inflation when RIV is the measure of dispersion, in line with the existing literature—that is, positive and negative inflation shocks increase RIV. However, when RPV is used to measure dispersion, in both the Canadian and Japanese data, we find a monotonic *negative* association between RPV and unanticipated inflation, whereas anticipated inflation tends to increase RPV. Taken together, our results are consistent with the predictions of some consumer-search, Calvo-price and signal-extraction models.

1 Introduction

This paper provides new evidence on the relationship between aggregate inflation and the dispersion of relative prices within countries. Standard theory suggests that relative price dispersion across sellers of homogeneous commodities in different locations can arise due to frictions in price setting among sellers, the transmission of price information to competing sellers or prospective consumers, or transportation costs. An extensive literature has identified mechanisms through which aggregate monetary shocks and equilibrium price inflation across sellers could amplify these relative price differences. For example, some theories of costly price adjustment predict that relative prices become more dispersed across sellers of identical products as the absolute value of inflation rises owing to asynchronous price adjustments across sellers.[1] Several theories of noisy price information for sellers (e.g., Hercowitz, 1982; Cukierman, 1983) imply that larger inflation shocks contribute to higher price dispersion, while theories of costly consumer search suggest that positive economy-wide inflation shocks increase consumer incentives to search for lower prices and may potentially *decrease* price dispersion (e.g., Reinganum, 1979; Head and Kumar, 2005).[2]

An extensive body of literature has investigated the empirical relationships between inflation and relative prices, typically using one or more of these theories to inform the choice of statistical model. For the most part, this literature has adopted variation in relative rates of inflation as the measure of price dispersion: what we refer to as *relative inflation variability* (RIV).[3] Few empirical papers have examined the effects of inflation on the variation in relative price levels, which we refer to as *relative price variability* (RPV), even though this concept of dispersion is the primary focus of most theories of the costs of inflation. This choice is often made because RPV requires detailed price data in currency units rather than the more commonly reported price indexes that suffice for RIV measures (Parsley, 1996). From the perspective of some theoretical models, the impact of inflation on price dispersion can be inferred from inflation-RIV relationships that are amenable to reduced-form estimation.[4] However, for other models, including some models of costly price adjustment and consumer search, inflation may have opposite effects on RPV and RIV (see Hajzler and Fielding, 2014; Danziger, 1987), and the economic interpretation of an RIV-inflation relationship is less clear. Moreover, as we

[1]This is true, for example, when price changes are asynchronous across sellers in the menu-cost models of Rotemberg (1983), Sheshinski and Weiss (1977), or in standard Calvo-price models.

[2]The welfare costs of inflation-induced price dispersion are potentially large: for example, Damjanovic and Nolan (2010) show, in the context of a standard macroeconomic model with nominal price rigidity, that price dispersion across producers of homogeneous goods arising from inflation shocks can have first-order effects on consumer welfare as a result of an inefficient reallocation of labour.

[3]Our terminology follows Parsley (1996), although several authors have referred to RIV as either relative price variability or "relative price-change variability."

[4]For example, Parks (1978) demonstrates that, in an extended version of standard producer signal-extraction models, the effect of changes in inflation rates on RIV is qualitatively the same as the effect on RPV.

discuss below, the literature has reported a wide range of statistical relationships between relative price dispersion and inflation. With few existing estimates of the RPV-inflation relationship to compare, it is difficult to draw many conclusions about the relationship between inflation and price dispersion from this literature.

To provide new insights into the empirical relationship between inflation and RPV and RIV measures of price dispersion, we utilize data on city-level price series for detailed consumer goods from three different country data sources. The data cover a large number of cities in each of three countries that differ in levels of economic development and inflation episodes: Canada during the 1920s and 1930s, Japan between January 2000 and December 2006, and Nigeria between January 2001 and December 2006. Unlike most previous work, we use average retail prices rather than price indices. This allows us to examine both the dispersion of product-level inflation rates (i.e., the change of prices across time) *and* the dispersion of relative price levels for each good. Our sample also includes episodes of deflation and a range of inflation values, which allows us to assess whether the relationship between inflation and price dispersion varies systematically with the level of inflation. Overall, average inflation rates in Canada and Japan are quite similar, as are average levels of RIV and RPV. The mean and variance of inflation rates in Nigeria are higher, but RIV and RPV are somewhat lower.

We select these three countries for study based on the comparability of the corresponding price data in terms of reporting frequency and structure which, to our knowledge, is not provided by other publicly available micro-level retail price series. For each country, our data include the average monthly price of specific items (mainly food items) in local currency based on information from multiple retail locations within cities. Most of the goods are relatively homogeneous, such as specific vegetables or cuts of meat, but there are also some items that may vary more in terms of quality (such as a towel or a pair of men's shoes). These data are similar to the city- and district-level average price data used in related work by Parsley (1996) and Caglayan et al. (2008).[5] Because they consist of prices of relatively undifferentiated products consumed by a typical household, with wide coverage of the major cities in each of the three countries, they are ideal for understanding the effects of inflation at an aggregate national level.

Using an ARCH model to decompose inflation into anticipated and unanticipated components, we estimate the effect of both components on RIV and RPV. We deliberately impose minimal functional form restrictions on our statistical models, and consider a range of alternative functional forms. This decision is motivated by two observations.

[5] Although the price data examined in these papers are similar to ours along several dimensions, we have not attempted to use these data for making direct comparisons of empirical model estimates owing to some key discrepancies in data structure. The US city-level prices considered in Parsley (1996) are reported at a quarterly frequency and the Turkish price data in Caglayan et al. (2008), while at a monthly frequency, report prices for 15 districts (across three types of vendors) within a single city (Istanbul). We would expect these differences in the frequency and geographical distribution of price observations to matter for the parameter estimates, though the empirical relationships of interest could be qualitatively similar across these datasets. Other publicly available datasets containing city-level prices (e.g., prices across European cities studied in Crucini et al., 2005), are reported only for a few years on an annual basis.

First, as discussed above, the theoretical literature suggests several different relationships between inflation and price dispersion. By adopting a flexible approach, we allow the data to determine which theoretical forces are predominant. Second, this flexibility addresses the criticism that imposing certain functional form restrictions has substantially impacted the results of the previous empirical literature (see, for example, Jaramillo, 1999).

Our empirical results indicate that anticipated and unanticipated inflation have different impacts on price dispersion. For all three countries, we find a familiar V-shaped relationship between price dispersion and unanticipated inflation when RIV is the measure of dispersion—that is, positive and negative inflation shocks increase RIV.[6] For Canada, the effects of positive and negative shocks are symmetric. For Japan and Nigeria, the relationships are not symmetric across positive and negative inflation shocks—in Japan, negative inflation shocks have a larger effect on RIV than positive shocks, while the opposite is true in Nigeria. When RPV is used to measure dispersion, in both the Canadian and Japanese data, we find a monotonic *negative* association between RPV and unanticipated inflation, whereas anticipated inflation tends to increase RPV. Finally, for both RPV and RIV, the relationship between dispersion and anticipated inflation is often statistically insignificant across the three country samples, with no systematic pattern in the directions of these relationships.

These findings are consistent with the predictions of some consumer-search, Calvo-price and signal-extraction models. For example, the search models of Reinganum (1979) and Bénabou and Gertner (1993) imply that RPV is monotonically decreasing in unanticipated inflation, but RIV can be a U- or V-shaped function of unanticipated inflation when inflation shocks are sufficiently persistent (Hajzler and Fielding, 2014). Choi's (2010) multi-sector, Calvo sticky-price model predicts the U-shaped relationship between *anticipated* inflation and RIV, whereas the signal-extraction models of Hercowitz (1982) and Cukierman (1983) predict a V-shaped relationship between RIV and *unanticipated* inflation, which is consistent with our findings. Although these theoretical perspectives offer plausible interpretations of the relationships uncovered in our three country datasets, we view this evidence as suggestive, since our empirical exercise is not designed to formally evaluate which theoretical model best fits the data.

Previous work using product-level price data across locations to investigate inflation-dispersion linkages (e.g., Lach and Tsiddon, 1992; Reinsdorf, 1994; Parsley, 1996; Silver and Ioannidis, 2001; Konieczny and Skrzypacz, 2005; Caglayan et al., 2008) has produced a range of estimates of the relative importance of anticipated and unanticipated inflation on price and inflation dispersion, with disagreement over whether the effect of inflation is monotonic or symmetric across positive and negative inflation rates. Our results suggest that the disagreement in the findings of this literature is not simply due to cross-country differences. Indeed, we find systematic differences between the RPV and RIV functions *within* each of the countries we examine. Using a relatively long sample for Canada (18 years of monthly data), we also repeat our exercise for different 8-year

[6]This relationship has been documented *inter alia* in Parks (1978), Lach and Tsiddon (1992), Caglayan et al. (2008), and Becker and Nautz (2012).

subsamples, which allows us to isolate the impact of the large deflation of the early 1930s and the moderate inflation of the late 1930s.[7] We find that our estimates of the impact of unanticipated inflation on RIV and RPV remain relatively stable across these subsamples. However, our estimates of the impact of anticipated inflation on RPV do vary considerably across subsamples: the deflation of the early 1930s seems to lessen the effect of anticipated inflation on price dispersion.[8]

Most closely related to this paper is work by Parsley (1996), Konieczny and Skrzypacz (2005), and Caglayan et al. (2008). Like ours, these papers are concerned with differences in empirical relationships, depending on whether one looks at RPV and RIV. The key difference in our work is that we estimate a statistical model that accommodates a broad set of potential RPV- and RIV-inflation relationships implied by theory. Parsley (1996), for example, uses data on the average retail prices across US cities to examine how inflation impacts RPV and RIV. However, his empirical approach assumes that the effects of inflation are monotonic, and he does not distinguish between anticipated and unanticipated inflation. Konieczny and Skrzypacz (2005) and Caglayan et al. (2008) allow for non-monotonicity in the estimated relationships, but attention is restricted to identical and symmetric relationships for both RPV and RIV.[9] Our findings suggest that imposing symmetric relationships for positive and negative inflation shocks is not always appropriate, and that *a priori* imposition of a particular functional form is likely to lead to misleading conclusions concerning actual inflation-dispersion relationships.

The paper is organized as follows. Section 2 contains an overview of the related literature, and Section 3 describes the statistical model. Section 4 describes the data, and Section 5 reports the model estimates. Section 6 concludes.

2 Theories and Existing Empirical Evidence

The empirical literature on inflation and price dispersion is motivated by several classes of theoretical model, which have different implications for the relationship between RPV, RIV and inflation. Early empirical work on RIV measures was motivated by price-signal extraction models (Lucas, 1973; Barro, 1976; Hercowitz, 1982; Cukierman, 1983). When demand and supply elasticities vary across producers, positive or negative inflation shocks increase *both* RPV and RIV (Parks, 1978).[10] Bomberger and Makinen (1993) further

[7]In 1931 and 1932, annual CPI deflation was roughly 9%, while inflation in 1935 and 1937 was between 2% and 3%.

[8]Caglayan and Filiztekin (2003) also present evidence that anticipated inflation has a significant impact on RPV and RIV only during periods of relatively low, stable inflation.

[9]Our results are more directly comparable to Caglayan et al. (2008) and Parsley (1996), who also examine average district- and city-level prices, than to Konieczny and Skrzypacz (2005) and Kaplan et al. (2016), who consider the prices of individual stores across locations.

[10]The Barro-Lucas signal extraction model implies a positive effect of unanticipated inflation *volatility* on price dispersion across sellers (rather than across products). This is more accurately measured by the conditional variance of the inflation forecast rather than the magnitude of inflation shocks (Grier and Perry,

argue that differences in downward price stickiness across producers results in negative inflation shocks having a larger effect on RIV than positive shocks. In contrast to these theories, Danziger (1987) shows that, in the menu-cost models of Rotemberg (1983) and Sheshinski and Weiss (1977), RPV is increasing in the absolute value of inflation, but the relationship between RPV and anticipated inflation could take different forms (including, for example, a V-shape or an inverted U-shape), depending on the range of inflation and the frequency of the data. Head and Kumar (2005) and Head et al. (2010) find that monetary-search models imply a U-shaped relationship between anticipated inflation and RPV measures of price dispersion across sellers, with the minimum at a positive inflation rate.[11] The Calvo-price model of Crucini et al. (2010) implies a similar non-monotonic relationship with respect to unanticipated inflation, with inflation shocks increasing RPV and RIV more strongly when trade costs are high and prices are flexible.[12]

There is an extensive literature that uses price index data (i.e., RIV measures) to ask whether these theoretical predictions are consistent with the data. Evidence for a V- or U-shaped response of RIV, measured as the variance in inflation rates across commodity categories, has been documented using consumer and producer price index data for a number of different countries, for different mean inflation rates, and for anticipated and unanticipated inflation (Parks, 1978; Glezakos and Nugent, 1986; Jaramillo, 1999; Aarstol, 1999; Dabús, 2000; Binette and Martel, 2005; Becker and Nautz, 2009).[13] Choi (2010) also finds a U-shaped relationship between inflation and RIV across producer prices during periods of relatively low inflation—with a turning point different from zero—and a positive monotonic (but much weaker) relationship during high-inflation periods in the United States and Japan. Chaudhuri et al. (2013) present similar evidence using UK CPI data. Becker and Nautz (2012) examine RIV measures constructed from CPI sub-indices across 27 European Union countries, and find somewhat different results: there is a non-monotonic, V-shaped function in both anticipated and unanticipated inflation, with a turning point at a positive inflation rate. We differ from these papers in our use of average prices for goods across cities instead of price indices, which allows us to compare how inflation impacts RIV and RPV measures of price dispersion.

Our work is closest to Parsley (1996) and Caglayan and Filiztekin (2003), who ex-

1996).

[11] Hajzler and Fielding (2014) show that, in the search models of Reinganum (1979) and Bénabou and Gertner (1993), RPV is monotonically decreasing in unanticipated inflation but RIV can be a linear, U-, or V-shaped function of unanticipated inflation (with a turning point at zero).

[12] Consistent with their theory, Hickey and Jacks (2011) find evidence of a positive relationship between price dispersion and price inflexibility across products for a subset of products in our pre-war Canadian data.

[13] There are a few exceptions. For example, Silver and Ioannidis (2001) examine RIV for 9 European countries and find a negative effect of unanticipated inflation. However, they assume a linear model, precluding the identification of a non-monotonic relationship in the data. Although Aarstol (1999) and Binette and Martel (2005) find evidence of a V-shaped relationship between RIV and unanticipated inflation, the effects of positive and negative shocks are asymmetric, which Binette and Martel (2005) interpret as evidence against the Barro-Lucas signal-extraction theory.

amine the average prices of goods across cities/districts in the United States and Turkey, respectively. While Parsley also finds that inflation leads to increased price dispersion, he does not distinguish between anticipated and unanticipated inflation, and his empirical approach assumes that the effects of inflation are monotonic. Caglayan and Filiztekin also find that when average inflation is low, RPV and RIV both rise with increases in the absolute values of anticipated and unanticipated inflation. However, the effects of both anticipated and unanticipated inflation on price dispersion decline significantly as inflation increases. Our approach differs in that we estimate a statistical model that accommodates a broad set of potential RPV- and RIV-inflation relationships implied by theory. Cross-country comparisons show that the specific relationship between inflation and RPV/RIV measures of price dispersion can vary substantially.

Our estimates of the inflation-RIV and inflation-RPV relationships are qualitatively similar to a number of papers that measure price dispersion using store-level price quotes rather than average prices across cities. This work builds on the pioneering contribution of Reinsdorf (1994), who estimated the impact of inflation on RPV and RIV using monthly prices for grocery items across stores located in nine US cities between 1980 and 1982. Although our estimates are qualitatively similar to those of Reinsdorf (1994), we differ in using average prices across many cities, and in comparing different countries experiencing a range of inflation episodes.[14]

Other work using store-level data has also found a positive relationship between RIV and inflation. Lach and Tsiddon (1992) use product-level price data from a sample of stores in Isreal, and find a strong positive association between RIV and anticipated inflation for most product categories, with a smaller effect from unanticipated inflation.[15] Konieczny and Skrzypacz (2005) use product-level price data across sellers in different locations in Poland to study the effects of inflation on both RPV and RIV, considering both monotonic linear and symmetric V-shaped functions of anticipated and unanticipated inflation. Consistent with Lach and Tsiddon (1992) and Parsley (1996), they find that the average effects of anticipated and unanticipated inflation on RIV are positive in linear models (i.e., when the marginal effects of *both* anticipated and unanticipated inflation are assumed to be linear). However, they find that unanticipated inflation does not have a significant impact on RPV in linear or symmetric V-shaped specifications.[16] Caglayan et al.

[14]Tommasi (1993) also estimates the impact of inflation on RPV and RIV using relative prices across sellers within a city (Buenos Aires), but unlike Reinsdorf, he does not decompose inflation into anticipated and unanticipated components, and restricts positive and negative inflation to impact price dispersion symmetrically. Recent work by Kaplan et al. (2016) also seeks to understand the pricing decisions of individual retail stores within a city.

[15]Lach and Tsiddon (1992) interpret this as evidence that costly price adjustment matters more in accounting for observed inflation-RIV relationships than imperfections in producers' ability to anticipate inflation.

[16]Lach and Tsiddon (1992) and Konieczny and Skrzypacz (2005) also address Danziger's (1987) concern over the range of possible RIV-inflation relationships implied by menu-cost models by noting that the average period between successive price adjustments is sufficiently infrequent for a V-shaped relationship to be expected to hold, even in Danziger's stylized model.

(2008) use district-level average price data from Istanbul and allow for non-monotonicity in the estimated relationships, but restrict attention to identical and symmetric relationships for both RPV and RIV. They find that both RPV and RIV increase with anticipated and unanticipated inflation when average inflation is low, but that the effects of anticipated (and unanticipated) inflation on price dispersion decline as inflation increases.

The statistical models employed in these papers restrict the functional form of the relationship (linear or V-shaped) to be the same for both anticipated and unanticipated inflation. However, differing relationships implied by alternative theoretical models suggest that this restriction may not be valid. Moreover, a V-shaped relationship for RIV does not necessarily entail a V-shaped relationship for RPV. We therefore depart from this previous work by relaxing the assumption of symmetry in the responses to positive and negative inflation shocks, which may otherwise severely bias parameter estimates.

The wide range of theoretical predictions for the effects of inflation on both RPV and RIV (along with the equally wide-ranging estimates in the empirical literature) motivates the empirical model discussed in Section 3. The model allows for a variety of functional forms, including linear, U-shaped and V-shaped functions, and functions that have a turning point at some value of inflation other than zero. This allows us to compare the effects of anticipated and unanticipated inflation on both RIV and RPV within the same datasets. Subsequent sections show that, in our data, the estimated relationships between RPV and unanticipated inflation are monotonic and negative, whereas the estimated relationships between RIV and unanticipated inflation, and between RPV and anticipated inflation, are not.

3 Inflation and Relative Price Dispersion

We seek to estimate the effect of anticipated and unanticipated inflation on RPV and RIV. The monthly data that we use are described in Section 4.

RPV is measured as the coefficient of variation across locations in the price level of product i in location j in period t, which we denote as p_{ijt}:

$$v_{it} = \sqrt{\frac{1}{N} \sum\nolimits_j \left(\frac{p_{ijt}}{\bar{p}_{it}} - 1 \right)^2}, \tag{1}$$

where $\bar{p}_{it}$ is the average price across locations. Denoting the rate of change of the price of product i over period t in location j as $\pi_{ijt} = \Delta \ln(p_{ijt})$, and average product-specific inflation as $\bar{\pi}_{it} = \Delta \ln(\bar{p}_{it})$, RIV is measured as the standard deviation across locations of the rate of change of prices:[17]

$$w_{it} = \sqrt{\frac{1}{N} \sum_{j} \left(\pi_{ijt} - \bar{\pi}_{it}\right)^2}. \tag{2}$$

Our analysis uses the deseasonalized values of each price-dispersion measure (v_{it}^D, w_{it}^D) and the anticipated and unanticipated components of deseasonalized commodity-level price inflation (π_{it}^A, π_{it}^U).

We propose a sufficiently general empirical model to accommodate a broad range of statistical relationships implied by theory. For this purpose, we decompose inflation into its expected and unexpected terms using an ARCH model of aggregate inflation:

$$\pi_{it}^D = \pi_{it}^A + \pi_{it}^U, \tag{3}$$

$$\pi_{it}^A = \gamma_{0i} + \gamma_{1i} \cdot \pi_{it-1}^D + \gamma_{2i} \cdot \pi_{it-2}^D + \gamma_{3i} \cdot t, \tag{4}$$

$$\pi_{it}^U \sim N\left(0, h_{it}^2\right), \tag{5}$$

$$h_{it}^2 = \delta_{0i} + \delta_{1i} \cdot \left(\pi_{it-1}^U\right)^2, \tag{6}$$

where h_{it}^2 is the conditional variance of the inflation forecast, capturing inflation uncertainty.[18] The γ and δ parameters are specific to each commodity i; in other words, the dynamics of inflation are allowed to vary across goods. We consider a number of alternative RPV- and RIV-inflation models, each with the following general form:

$$\ln(v_{it}^D) = \kappa_{0i}^v + \kappa_{1i}^v \cdot \ln(v_{it-1}^D) + \kappa_{2i}^v \cdot t + F_i^v\left(\pi_{it}^U\right) + G_i^v\left(\pi_{it}^A\right) + H_i^v\left(h_{it}\right) + u_{it}^v, \tag{7}$$

$$\ln(w_{it}^D) = \kappa_{0i}^w + \kappa_{1i}^w \cdot \ln(w_{it-1}^D) + \kappa_{2i}^w \cdot t + F_i^w\left(\pi_{it}^U\right) + G_i^w\left(\pi_{it}^A\right) + H_i^w\left(h_{it}\right) + u_{it}^w. \tag{8}$$

Here, the u_{it} terms are error terms, the κs are fixed parameters estimated separately for each commodity, the $F(\cdot)$, $G(\cdot)$ and $H(\cdot)$ terms represent commodity-specific non-linear functions.

With respect to unanticipated inflation, $F(\cdot)$ should accommodate the V-shaped response of RPV and RIV to inflation shocks implied by the signal-extraction model, as well as the linear relationship possible in some search models. We do this by fitting a

[17]The relationship between RIV and RPV is non-linear, More specifically, intra-market RIV for each commodity is

$$w_{it} \approx \sqrt{v_{it}^2 + v_{it-1}^2 - 2\text{COV}\left(\ln(p_{ijt}), \ln(p_{ijt-1})\right)}.$$

[18]Our inflation-forecasting approach follows Grier and Perry (1996), Fielding and Mizen (2008) and Becker and Nautz (2009), among others. In the case of Canada, where the time-series sample is large enough, it is possible to extend equation (6) by including a moving-average term (i.e., fitting a GARCH model). The GARCH-based results corresponding to Table 2 are available on request. In the GARCH-based results, when the coefficient on h_{it}^2 is significantly different from zero (which is in most cases), all coefficient estimates are similar to those in Table 2.

piecewise-linear function:

$$F_i^x = \kappa_{3i}^x \cdot \pi_{it}^{UP} + \kappa_{4i}^x \cdot \pi_{it}^{UN}, \qquad x \in \{v, w\}, \tag{9}$$

where $\pi_{it}^{UP} = \max\left\{0, \pi_{it}^U\right\}$, and $\pi_{it}^{UN} = \min\left\{0, \pi_{it}^U\right\}$. This functional form encompasses monotonic positive and negative relationships, but also allows for a V-shaped relationship.

Menu-cost and sticky-price models imply an even wider range of possible functions in anticipated inflation: the relationship may be monotonically increasing, U-shaped or V-shaped, and the turning point is not necessarily at $\pi^A = 0$. We fit alternative versions of equations (7)-(8) with different parameterizations of the G-function. The first is a quadratic function:

$$G_i^x = \kappa_{5i}^x \cdot \pi_{it}^A + \kappa_{6i}^x \cdot \left(\pi_{it}^A\right)^2, \quad x \in \{v, w\}. \tag{10}$$

We compare this quadratic parameterization with a piecewise-linear parameterization that has been used in some other papers:

$$G_i^x = \kappa_{5i}^x \cdot \pi_{it}^{AP} + \kappa_{6i}^x \cdot \pi_{it}^{AN}, \qquad x \in \{v, w\}. \tag{11}$$

Here, $\pi_{it}^{AP} = \max\left\{0, \pi_{it}^{AN}\right\}$ and $\pi_{it}^{AN} = \min\left\{0, , \pi_{it}^A\right\}$, and equation (11) allows for a V-shaped curve with a turning point at zero. In Appendix A, we also explore the possibility of fitting a non-parametric G-function. Equation (10) is equivalent to the relationship estimated by van Hoomissen (1988), Fielding and Mizen (2008), and Choi (2010), as well as Aarstol (1999) when $\kappa_{5i}^w = 0$. When $\kappa_{5i}^x = \kappa_{6i}^x$, equation (11) is equivalent to regressing dispersion on the absolute value of expected inflation (e.g., Becker and Nautz, 2009) while allowing for possible asymmetric effects of positive and negative inflation, as found in Debelle and Lamont (1997) and Caglayan et al. (2008).

Following Grier and Perry (1996) and Aarstol (1999), we allow for the possibility that RPV and RIV also depend either on the standard deviation of the inflation forecast ($H_i^x = \kappa_{7i}^x \cdot h_{it}$) or on the variance ($H_i^x = \kappa_{7i}^x \cdot h_{it}^2$).[19] A positive relationship with price dispersion ($\kappa_{7i} > 0$) is consistent not only with classical models of imperfect producer information on aggregate and idiosyncratic cost shocks (e.g., Lucas, 1973), where a larger variance in the unpredictable component of inflation results in a higher amount of price dispersion, but also with some menu-cost models. For example, in a model of costly price adjustment where sellers follow an Ss pricing rule, Vavra (2014) shows that volatility in the frequency of price changes is positively related to price-change dispersion, while the frequency of price changes itself is not.

[19] See also Beaulieu and Mattey (1999), who consider the effects on price dispersion of the unconditional variation in estimated marginal costs across firms.

4 The Data

The models in Section 3 are applied to datasets from Canada, Japan and Nigeria. Each dataset contains monthly city-level retail prices for consumption items (mainly food, but also some non-food items), and is most similar to the US dataset used by Parsley (1996), but reported at a monthly frequency. In this section, we describe the construction of the RPV, RIV and inflation variables, and present some descriptive statistics.

4.1. Canada

Following Hajzler and MacGee (2012), our data are from monthly issues of the *Canada Labour Gazette*, for the period November 1922–November 1940. This publication lists the monthly average price across sampled stores in each of 69 cities, reported in tenths of cents. The full dataset covers prices for 52 items, and we focus on the prices of 42 items for which there are only a few missing observations.[20] (Several items with systematic gaps in the price series in the middle of the sample were dropped in particular, since continuity in the price series is essential owing to the time-series nature of our analysis.) The cities and grocery items are listed in Appendix B. For each of the 42 items, we construct the variables v_{it}, w_{it} and $\bar{\pi}_{it}$ according to the definitions in Section 3. The corresponding deseasonalized series v_{it}^D, w_{it}^D and $\bar{\pi}_{it}^D$ are constructed from regressions of v_{it}, w_{it} and $\bar{\pi}_{it}$ on a set of dummy variables for each month (February – December).

4.2. Japan

The Japanese price series are from data published by the Center for International Price Research[21] and documented by Crucini et al. (2010). This monthly dataset spans the period January 2000–December 2006; the prices of 146 household grocery items and 163 other household goods are reported for 70 cities over this period. These prices are averages over a number of stores in each city, reported in yen. The cities and commodities are listed in Appendix B. For each of the 309 commodities, we construct the variables v_{it}, w_{it} and $\bar{\pi}_{it}$ as for Canada, and then deseasonalize each series.

4.3. Nigeria

The Nigerian price series are from the dataset published by the Nigerian National Bureau of Statistics (www.nigerianstat.gov.ng) and documented by Fielding (2010). This monthly dataset spans the period January 2001–December 2006; the prices of 22 household grocery items and 16 other household goods and services are reported for each of

[20]The dataset does not include cities in Newfoundland and Labrador because this province did not become part of Canada until 1949.

[21]These data are available at: `www.vanderbilt.edu/econ/cipr/japan.html`

Table 1: Descriptive Statistics for the Three Different Samples

	Canada		Japan		Nigeria	
	mean	within-commodity std. dev.	mean	within-commodity std. dev.	mean	within-commodity std. dev.
$\ln(v_{it}^D)$	-2.21	0.187	-1.944	0.138	-2.678	0.531
$\ln(w_{it}^D)$	-2.87	0.245	-3.152	0.388	-3.844	1.440
π_{it}^A	-0.001	0.010	-0.001	0.006	0.007	0.018
π_{it}^U	0	0.025	0	0.026	0	0.061
π_{it}^A (trimmed)	-0.001	0.010	-0.001	0.006	0.001	0.018
π_{it}^U (trimmed)	0	0.022	0	0.016	0	0.049

Averages of price-dispersion measures and inflation across cities and commodities are reported at monthly frequency.

the 36 state capitals, plus the federal capital, Abuja.[22] These prices are averages over a number of stores and markets in each city, reported in kobo.[23] As with the Canadian data, our attention is limited to those price series without systematic gaps in the time series, and we exclude price series for which there is little or no price variation over the sample period (which constrain our ability to estimate meaningful RPV-inflation relationships). The cities and commodities are listed in Appendix B. For each of the 38 items, we construct the variables v_{it}, w_{it} and $\bar{\pi}_{it}$ and deseasonalize each series using the same method as for Canada.

4.4. Descriptive statistics

Our three datasets span three different economies—pre-war Canada, modern Japan, and modern Nigeria—and encompass different mixes of consumer goods. The Japanese data are the most comprehensive, since the Canadian and Nigerian datasets include only those items that would typically be available in local retail outlets (Canada) or traditional markets (Nigeria), the typical consumer not having access to large stores or supermarkets on a regular basis.[24] Some items in the datasets reflect cultural idiosyncrasies: for example, lard in pre-war Canada, salted fish guts in Japan, and kola nuts in Nigeria. This heterogeneity could explain why some (though not all) of our results vary across countries.

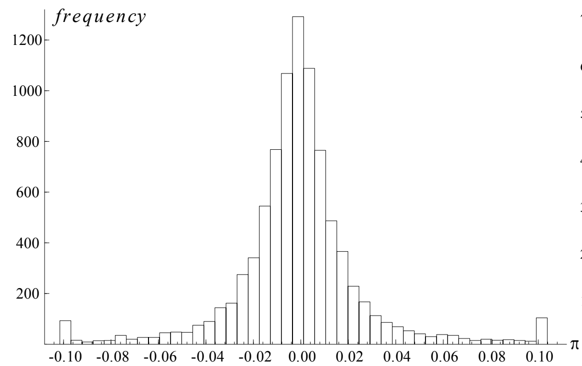
Some key characteristics of the data are summarized in Table 1 and Figures 1a-2c.

[22]These 38 items are a subset of the items in the National Bureau of Statistics dataset. Excluded from our sample are (i) alcoholic beverages, the prices of which are not recorded in states with a Muslim majority population; and (ii) a range of packaged and branded food and other household items (for example, a tin of Andrews liver salts, a packet of 20 Benson and Hedges cigarettes, a Bic biro). These items are mostly sold in large stores, not in traditional markets and for many the average value of v_{it} is extremely low. There is reason to suspect that the prices of some of these items are set centrally, and are not controlled by local retailers, so there is little scope for cross-city variation in their posted price.

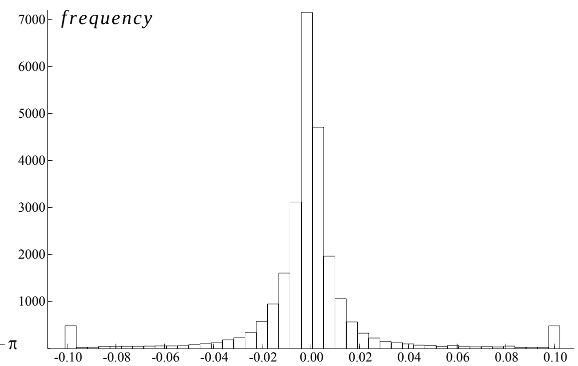
[23]100 kobo = one naira $\approx$ one US cent in 2001.

[24]The Nigerian dataset also includes some locally provided services, including accommodation and taxis.

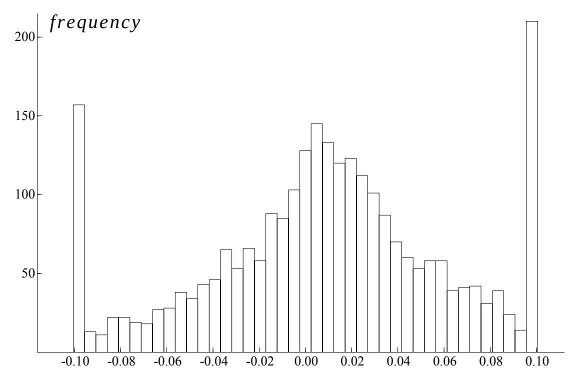
Figure 1: Distribution of Inflation (π_{it}) Trimmed at $\pm 10\%$.



(a) Canada



(b) Japan

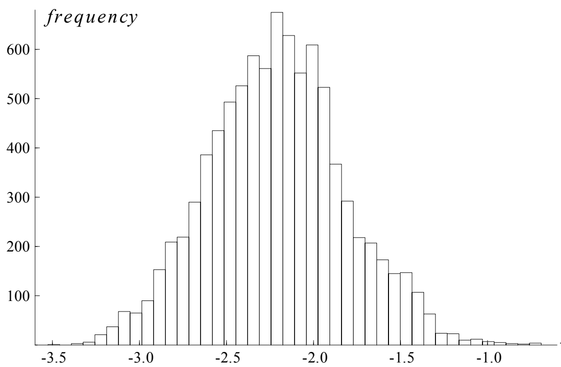


(c) Nigeria

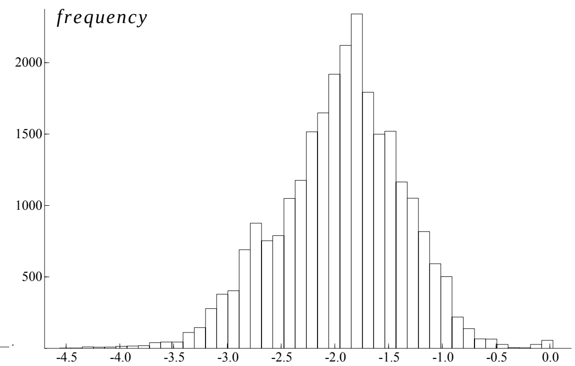
Figures 1a-1c illustrate the distribution of inflation ($\bar{\pi}_{it}^{D}$) across all the items in each sample, while Figures 2a-2c illustrate the corresponding distributions of $\ln(v_{it}^{D})$. Canada's average inflation rate over the whole interwar period is very similar to Japan's average inflation in the early 21st century. However, the Canadian data exhibit more volatility, mainly because of a deflation and subsequent inflation between 1931 and 1934, and a spike at the beginning of the Second World War. Average inflation in Nigeria over 2001-2006 is a percentage point higher than the Canadian and Japanese averages, and exhibits higher volatility. Figures 1a-1c show that the individual inflation series are not normally distributed: there is excess kurtosis in all three countries. This means that it will be important to ascertain whether our regression results are affected by outliers in the inflation distribution. For this reason, two versions of each regression are fitted: one with the original inflation series (π_{it}^{A}, π_{it}^{U}), and another with the series trimmed at $\pm 10\%$ per month.

Means and standard deviations over time for both trimmed and untrimmed π_{it}^{A} and π_{it}^{U} series are included in Table 1. These series are constructed by applying the ARCH model in equations (3)-(6) to each of the $\bar{\pi}_{it}^{D}$ series. Nigeria has a standard deviation of

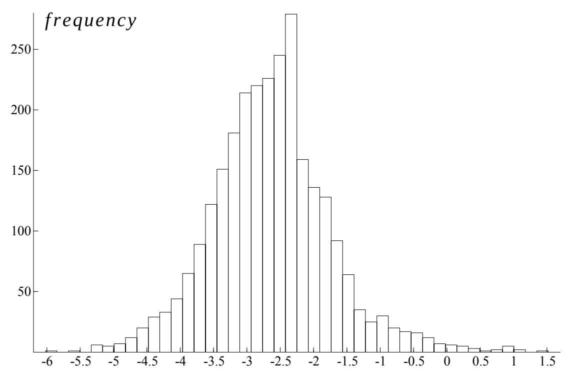
Figure 2: Distribution of Relative Price Variability ($\ln(v_{it}^D)$).



(a) Canada



(b) Japan



(c) Nigeria

anticipated and unanticipated inflation (both trimmed and untrimmed) roughly twice as high as that in Canada and Japan. This difference is not surprising: like many other developing countries, Nigeria faces macroeconomic shocks that are larger than those typical of developed countries in most eras.

Table 1a shows that the mean values of $\ln(v_{it}^D)$ and $\ln(w_{it}^D)$ are similar in Canada and Japan, and slightly lower in Nigeria. Figures 2a-2c show that in all three countries, the price-dispersion variables are approximately normally distributed.

5 Results

Equations (7)-(8) are time-series regression equations to be fitted for each commodity i. In Canada, where the number of months $T = 217$ and commodities $M = 42$, it is possible to fit the regression equations simultaneously using seemingly unrelated regressions (SUR) and estimate a variance-covariance matrix for all of the parameters in all of the commodity-specific equations. This matrix can be used to compute standard errors on the average values of the parameters across all commodities ($\frac{1}{M}\sum_i \kappa_{ni}^x$) using the Delta Method. Our discussion will focus on these averages, which indicate the pattern of the RPV and RIV relationships for a typical commodity. In Japan, $T < M$, so it is not possible to fit the regression equations simultaneously, and we assume an orthogonal variance-covariance matrix when computing the standard errors on the average parameter values. In Nigeria, M is almost as large as T, so while it is possible to fit the regression equations simultaneously, the estimates of the elements of the variance-covariance matrix will be imprecise. Therefore, we also assume orthogonality.

Tables 2-7 report estimates of the average parameter values in equations (7)-(8). For each country there are two tables: one for RPV (measured as $\ln(v_{it}^D)$) and one for RIV (measured as $\ln(w_{it}^D)$). In each table, there are four sets of parameter estimates using trimmed inflation and four using untrimmed inflation. These estimates correspond to the two alternative parameterizations of the G-function and the two alternative parameterizations of the H-function described in Section 3. (The parameters of the H-function are statistically insignificant, except in the Canadian RPV case, where a higher variance of inflation shocks reduces dispersion. The results do not vary significantly across the alternative parameterizations of this function.) T-ratios are reported underneath the parameter estimates, with parameters significant at the 5% level highlighted in bold.

We first discuss the estimated effects of unanticipated inflation, as captured by the parameters on π_{it}^{UP} and π_{it}^{UN}. Then we discuss the estimated effects of anticipated inflation, as captured by the parameterizations of the G-function.

5.1. The effects of unanticipated inflation

The broad relationship between RPV / RIV and unanticipated inflation in the three countries can be summarized as follows:

	Canada	*Japan*	*Nigeria*
RPV equation	negative monotonic	negative monotonic	insignificant
RIV equation	V-/U-shaped	V-/U-shaped	V-/U-shaped

Reinsdorf (1994) also finds a negative monotonic relationship between unanticipated inflation and dispersion in relative prices *within* cities using US price data during the 1980-82 disinflation period. Our results suggest that this relationship also holds for price dispersion between cities and in different inflation contexts. However, they differ from results when more restrictive functional forms are imposed (e.g., Caglayan et al., 2008; Konieczny and Skrzypacz, 2005).

In both the Canadian and Japanese RPV results (Tables 2 and 4), the curve is significantly steeper for negative shocks than for positive ones. In Canada, a one-percentage-point positive inflation shocks reduces RPV (as measured by v_{it}^D) by about 0.5%; a one-percentage-point negative inflation shock raises RPV by about 1%. In Japan, a one-percentage-point positive inflation shock reduces RPV by about 1%; a one-percentage-point negative inflation shock raises RPV by about 1.5%. The within-commodity standard deviation of unanticipated inflation is about two percentage points in both countries, whereas the standard deviation of RPV is about 15%, so the order of magnitude of the RPV response to a typical shock to inflation is in the region of 10-20% of one standard deviation of the dependent variable.

The V-shaped relationship for RIV is consistent with the findings of many inter-market RIV studies discussed in Section 2. In all three countries, the absolute size of the estimated effect of inflation shocks on RIV is greater than the absolute size of the estimated effect on RPV. In Japan, this difference is particularly large: a one-percentage-point inflation shock (positive or negative) raises RIV by 20-30%. The within-commodity standard deviation of RIV in Japan is just under 40%, so a typical inflation shock (about two percentage points) raises RIV by more than one standard deviation. In Canada and Nigeria the unanticipated inflation coefficients are much smaller: a one-percentage-point inflation shock raises RIV by about 3%, or if it is a negative shock in Nigeria, by about half this much.[25] Although the RPV estimates for Canada and Japan are similar, the Japanese RIV coefficients are much larger. Moreover, positive and negative shocks increase RIV symmetrically in the case of Canada, but the RIV-inflation relationship is asymmetric in both Japan and Nigeria. Nevertheless, there is a common pattern in the results, with monotonic RPV functions in contrast to V-shaped RIV functions.

The combined negative monotonic relationship between RPV and unanticipated inflation and the V-shaped relationship between RIV and inflation shocks are consistent with the search theories of Reinganum (1979) and Bénabou and Gertner (1993). The V-shaped RIV-inflation relationship is also consistent with Parks's (1978) signal extraction model, although the monotonic negative relationship for RPV is not. According to this theory, both dispersion in prices and rates of price change increase in response to positive and negative inflation shocks. Although both mechanisms are potentially at work in the data, one interpretation of our findings is that the forces associated with costly consumer search tend to dominate, at least in low-inflationary environments such as those in Canada and Japan during our sample periods.

5.2. The effects of anticipated inflation

There is more cross-country heterogeneity in the estimated effect of anticipated inflation than in the effect of unanticipated inflation. In Canada, there is a significant coefficient on the quadratic term in the RPV equation, with a turning point insignificantly different from zero. The standard deviation of anticipated inflation is close to one percentage point. If anticipated inflation deviates by one percentage point from its sample mean (which is close to zero), the implied rise in RPV is roughly 2%. This significance of

[25] Using trimmed inflation, the effect of the negative shock in Nigeria is not quite statistically significant. This is the only substantial difference between the trimmed and untrimmed inflation results in the tables.

Table 2: Average Parameter Values in the Models of RPV ($\ln(v_{it}^D)$) in Canada

	A		B		C		D	
	untrimmed inflation	trimmed inflation	untrimmed inflation	trimmed inflation	untrimmed inflation	trimmed inflation	untrimmed inflation	trimmed inflation
$\ln(v_{it-1}^D)$	**0.757**	**0.758**	**0.756**	**0.757**	**0.758**	**0.758**	**0.756**	**0.757**
	(110.5)	(111.1)	(110.4)	(110.7)	(110.8)	(110.9)	(110.3)	(110.7)
π_{it}^A	-0.332	-0.272			-0.324	-0.293		
	(-0.793)	(-0.649)			(-0.776)	(-0.701)		
$100 \cdot (\pi_{it}^A)^2$	**2.119**	**2.150**			**2.035**	**2.033**		
	(2.964)	(3.005)			(2.848)	(2.845)		
π_{it}^{AP}			0.127	0.080			0.016	0.076
			(0.307)	(0.193)			(0.037)	(0.182)
π_{it}^{AN}			**-2.090**	**-2.068**			**-2.018**	**-2.052**
			(-6.852)	(-6.754)			(-6.516)	(-6.629)
π_{it}^{UP}	**-0.505**	**-0.564**	**-0.513**	**-0.568**	**-0.513**	**-0.568**	**-0.514**	**-0.564**
	(-5.581)	(-6.003)	(-5.688)	(-6.069)	(-5.659)	(-6.035)	(-5.694)	(-6.026)
π_{it}^{UN}	**-0.922**	**-0.933**	**-0.924**	**-0.925**	**-0.911**	**-0.931**	**-0.915**	**-0.924**
	(-9.922)	(-9.901)	(-9.982)	(-9.851)	(-9.788)	(-9.874)	(-9.890)	(-9.842)
$100 \cdot (h_{it})^2$	**-3.896**	**-3.681**	**-2.679**	**-2.788**				
	(-4.686)	(-4.892)	(-4.686)	(-4.400)				
$100 \cdot h_{it}$					**-0.125**	**-0.113**	**-0.083**	**-0.091**
					(-3.484)	(-3.200)	(-4.087)	(-2.418)

T-ratios in parentheses

Table 3: Average Parameter Values in the Models of RIV ($\ln(w_{it}^D)$) in Canada

	A		B		C		D	
	untrimmed inflation	trimmed inflation	untrimmed inflation	trimmed inflation	untrimmed inflation	trimmed inflation	untrimmed inflation	trimmed inflation
$\ln(w_{it-1}^D)$	**0.476**	**0.477**	**0.474**	**0.474**	**0.476**	**0.476**	**0.473**	**0.473**
	(51.31)	(51.30)	(50.72)	(50.74)	(51.15)	(51.17)	(50.54)	(50.64)
π_{it}^A	-0.799	-0.820			-0.757	-0.83		
	(-1.134)	(-1.161)			(-1.076)	(-1.178)		
$100 \cdot (\pi_{it}^A)^2$	-1.951	-2.011			-2.025	-2.105		
	(-1.343)	(-1.384)			(-1.407)	(-1.463)		
π_{it}^{AP}			-9.425	-9.500			-9.608	-9.562
			(-1.480)	(-1.484)			(-1.507)	(-1.492)
π_{it}^{AN}			-0.404	-0.384			-0.351	-0.380
			(-0.567)	(-0.537)			(-0.489)	(-0.528)
π_{it}^{UP}	**2.674**	**2.884**	**2.671**	**2.900**	**2.657**	**2.868**	**2.661**	**2.883**
	(13.07)	(13.71)	(13.08)	(13.81)	(12.97)	(13.62)	(13.02)	(13.74)
π_{it}^{UN}	**-2.708**	**-2.797**	**-2.721**	**-2.814**	**-2.688**	**-2.784**	**-2.697**	**-2.799**
	-12.56)	(-12.81)	(-12.64)	(-12.90)	(-12.46)	(-12.76)	(-12.54)	(-12.84)
$100 \cdot (h_{it})^2$	0.771	-0.617	1.148	0.582				
	(0.346)	(-0.239)	(0.694)	(0.285)				
$100 \cdot h_{it}$					3.847	-8.449	1.629	-1.703
					(0.385)	(-0.734)	(0.236)	(-0.180)

T-ratios in parentheses

Table 4: Average Parameter Values in the Models of RPV ($\ln(v_{it}^D)$) in Japan

	A		B		C		D	
	untrimmed inflation	trimmed inflation	untrimmed inflation	trimmed inflation	untrimmed inflation	trimmed inflation	untrimmed inflation	trimmed inflation
$\ln(v_{it-1}^D)$	**0.738**	**0.736**	**0.740**	**0.737**	**0.738**	**0.736**	**0.739**	**0.737**
	(168.9)	(167.9)	(170.1)	(169.2)	(168.9)	(167.9)	(170.4)	(169.4)
π_{it}^A	**-2.089**	**-1.966**			**-1.998**	**-1.875**		
	(-1.799)	(-1.676)			(-1.725)	(-1.602)		
$100 \cdot (\pi_{it}^A)^2$	-5.472	-5.431			-5.687	-5.652		
	(-0.946)	(-0.939)			(-0.979)	(-0.973)		
π_{it}^{AP}			**12.59**	**12.57**			**13.32**	**13.30**
			(2.175)	(2.171)			(2.255)	(2.251)
π_{it}^{AN}			2.000	1.587			1.991	1.576
			(1.323)	(1.023)			(1.321)	(1.018)
π_{it}^{UP}	**-1.044**	**-1.093**	**-1.044**	**-1.093**	**-1.044**	**-1.093**	**-1.043**	**-1.091**
	(-10.65)	(-10.91)	(-10.71)	(-10.96)	(-10.61)	(-10.86)	(-10.66)	(-10.90)
π_{it}^{UN}	**-1.506**	**-1.495**	**-1.514**	**-1.502**	**-1.500**	**-1.489**	**-1.511**	**-1.499**
	(-15.71)	(-15.45)	(-15.95)	(-15.67)	(-15.58)	(-15.32)	(-15.88)	(-15.60)
$100 \cdot (h_{it})^2$	3.715	3.714	2.959	2.967				
	(1.309)	(1.308)	(1.098)	(1.101)				
$100 \cdot h_{it}$					2.195	2.218	1.542	1.676
					(0.482)	(0.487)	(0.342)	(0.371)

T-ratios in parentheses

Table 5: Average Parameter Values in the Models of RIV ($\ln(w_{it}^D)$) in Japan

	A		B		C		D	
	untrimmed inflation	trimmed inflation	untrimmed inflation	trimmed inflation	untrimmed inflation	trimmed inflation	untrimmed inflation	trimmed inflation
$\ln(w_{it-1}^D)$	**0.198**	**0.196**	**0.201**	**0.200**	**0.198**	**0.197**	**0.201**	**0.200**
	(30.64)	(30.46)	(31.19)	(31.10)	(30.65)	(30.47)	(31.24)	(31.12)
π_{it}^A	**-47.31**	**-47.34**			**-46.48**	**-46.51**		
	(-2.445)	(-2.447)			(-2.400)	(-2.403)		
$100 \cdot (\pi_{it}^A)^2$	-32.69	-32.75			-28.54	-28.80		
	(-0.182)	(-0.182)			(-0.157)	(-0.159)		
π_{it}^{AP}			52.66	51.61			53.57	52.72
			(0.940)	(0.922)			(0.960)	(0.945)
π_{it}^{AN}			40.79	37.75			40.55	37.68
			(1.526)	(1.414)			(1.519)	(1.412)
π_{it}^{UP}	**23.70**	**24.63**	**23.36**	**24.29**	**23.72**	**24.65**	**23.39**	**24.32**
	(16.00)	(16.59)	(15.63)	(16.23)	(15.93)	(16.53)	(15.64)	(16.24)
π_{it}^{UN}	**-30.33**	**-30.95**	**-30.05**	**-30.69**	**-30.36**	**-31**	**-30.13**	**-30.76**
	(-19.97)	(-20.35)	(-19.80)	(-20.19)	(-19.95)	(-20.34)	(-19.84)	(-20.23)
$100 \cdot (h_{it})^2$	69.32	69.32	80.51	80.52				
	(1.148)	(1.148)	(1.378)	(1.378)				
$100 \cdot h_{it}$					117.1	117.1	124.9	125.0
					(1.136)	(1.136)	(1.221)	(1.222)

T-ratios in parentheses

Table 6: Average Parameter Values in the Models of RPV ($\ln(v_{it}^D)$) in Nigeria

	A		B		C		D	
	untrimmed inflation	trimmed inflation	untrimmed inflation	trimmed inflation	untrimmed inflation	trimmed inflation	untrimmed inflation	trimmed inflation
$\ln(v_{it-1}^D)$	**0.616**	**0.608**	**0.617**	**0.609**	**0.614**	**0.608**	**0.617**	**0.609**
	(39.12)	(38.28)	(39.30)	(38.23)	(39.10)	(38.28)	(39.22)	(38.25)
π_{it}^A	1.148	0.357			1.298	0.369		
	(0.417)	(0.453)			(0.472)	(0.469)		
$100 \cdot (\pi_{it}^A)^2$	0.142	0.302			0.045	0.286		
	(0.105)	(0.794)			(0.033)	(0.754)		
π_{it}^{AP}			1.369	-0.026			1.236	-0.144
			(1.283)	(-0.033)			(1.151)	(-0.179)
π_{it}^{AN}			-2.094	-1.276			-2.421	-1.481
			(-1.042)	(-0.732)			(-1.201)	(-0.846)
π_{it}^{UP}	0.110	0.426	0.028	0.346	0.136	0.397	0.039	0.342
	(0.433)	(1.276)	(0.112)	(1.041)	(0.538)	(1.193)	(0.153)	(1.027)
π_{it}^{UN}	-0.034	-0.448	-0.028	-0.444	-0.049	-0.42	-0.035	-0.438
	(-0.137)	(-1.298)	(-0.111)	(-1.277)	(-0.198)	(-1.218)	(-0.14)	(-1.259)
$100 \cdot (h_{it})^2$	2.628	-1.828	1.137	-1.371				
	(0.786)	(-0.455)	(0.42)	(-0.326)				
$100 \cdot h_{it}$					50.38	-28.71	24.15	-19.72
					(1.085)	(-0.507)	(0.626)	(-0.334)

T-ratios in parentheses

Table 7: Average Parameter Values in the Models of RIV ($\ln(w_{it}^D)$) in Nigeria

	A		B		C		D	
	untrimmed inflation	trimmed inflation	untrimmed inflation	trimmed inflation	untrimmed inflation	trimmed inflation	untrimmed inflation	trimmed inflation
$\ln(w_{it-1}^D)$	**0.125**	**0.121**	**0.124**	**0.121**	**0.124**	**0.121**	**0.123**	**0.121**
	(7.715)	(7.563)	(7.661)	(7.575)	(7.621)	(7.563)	(7.612)	(7.566)
π_{it}^A	-7.868	-5.147			-7.468	-5.084		
	(-1.041)	(-0.925)			(-0.989)	(-0.914)		
$100 \cdot (\pi_{it}^A)^2$	4.365	1.065			1.065	1.065		
	(1.065)	(1.124)			(1.023)	(1.112)		
π_{it}^{AP}			**5.525**	**4.300**			**5.331**	**4.271**
			(1.978)	(1.997)			(1.898)	(1.979)
π_{it}^{AN}			**14.69**	**5.889**			**13.95**	**5.65**
			(2.597)	(1.786)			(2.462)	(1.703)
π_{it}^{UP}	**3.315**	**3.420**	**3.172**	**3.402**	**3.313**	**3.396**	**3.181**	**3.385**
	(5.034)	(4.044)	(4.829)	(4.040)	(5.055)	(4.017)	(4.858)	(4.021)
π_{it}^{UN}	**-1.416**	-0.899	**-1.408**	**-1.019**	**-1.412**	-0.886	**-1.425**	-1.009
	(-2.036)	(-1.035)	(-2.033)	(-1.171)	(-2.032)	(-1.020)	(-2.059)	(-1.160)
$100 \cdot (h_{it})^2$	2.44	10.25	4.927	10.28				
	(0.426)	(1.561)	(1.060)	(1.458)				
$100 \cdot h_{it}$					33.74	143.6	65.38	142.9
					(0.424)	(1.576)	(0.995)	(1.475)

T-ratios in parentheses

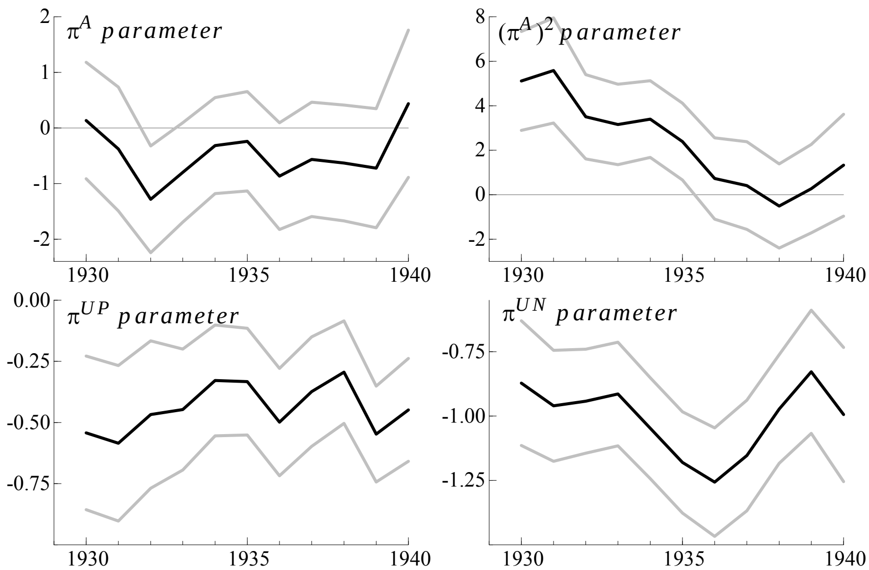
the quadratic term is consistent with the piecewise-linear regression estimates, insofar as $\partial \ln \left(v_{it}^{D}\right) / \partial \pi_{it}^{AP}$ is positive and $\partial \ln \left(v_{it}^{D}\right) / \partial \pi_{it}^{AN}$ is negative. The non-parametric estimates in Appendix A suggest that the function is indeed quadratic, with $\partial \ln \left(v_{it}^{D}\right) / \partial \pi_{it}^{AP}$ increasing in π_{it}^{AP}, which may explain why the coefficient on π_{it}^{AP} is imprecisely estimated. In the RIV equation, there are no significant coefficients on any of the anticipated inflation terms, although the non-parametric estimates in Appendix A suggest a significant and approximately quadratic relationship (a rare case of similarity between RPV results and RIV results).

In Japan, the results differ, since the quadratic RPV model does not produce any significant coefficients, but in the piecewise-linear model, the coefficient on π_{it}^{AP} is positive and significant at the 5% level. This provides (weak) evidence that RPV is increasing in anticipated inflation, at least when the inflation rate is greater than zero. The standard deviation of anticipated inflation in Japan is about 0.6 percentage points. The estimated parameter on π_{it}^{AP} indicates that a one-standard-deviation rise in anticipated inflation, when positive, can be expected to raise RPV by around 8%. By contrast, the piecewise-linear RIV model does not produce any significant results for anticipated inflation, whereas the quadratic model produces a significant negative effect of π_{it}^{A}, though without any significant non-linearity. A one-standard-deviation rise in anticipated inflation can be expected to reduce RIV by around 30%. If RPV is increasing in anticipated inflation and RIV is decreasing in anticipated inflation, then the choice of an optimal inflation target will certainly depend on whether RPV or RIV matters more to policy-makers.

The results for Nigeria differ from those for Canada and Japan. There are no significant effects of anticipated inflation in the RPV equation or in the quadratic version of the RIV equation. However, the piecewise-linear version of the RIV equation suggests a positive monotonic function, consistent with Parsley's (1996) findings using similar US city-level price data and Lach and Tsiddon's (1992) findings using price data at the level of the retailer in Israel. The effect is marginally significant at the 5% level. The standard deviation of trimmed anticipated inflation in Nigeria is about 1.8 percentage points, and a standard deviation increase in π_{it}^{A} can be expected to raise RIV by around 9%.

The heterogeneity of the anticipated inflation effects across countries does have a theoretical interpretation. As shown by Danziger (1987), in a menu-cost model the shape of the RPV-inflation function depends on trend inflation and the shape of a typical firm's cost function. Table 1 shows that the distribution of trend inflation in Nigeria differs from the distributions in Canada and Japan. Moreover, given their differences in levels of economic development, it is plausible that menu costs vary across the three countries we study. Finally, it is worth emphasizing the substantial within-country heterogeneity between the RPV effects and the RIV effects. A significant anticipated inflation effect for one does not necessarily entail a significant effect for the other.

Figure 3: Recursive estimates of the Canadian RPV-inflation parameters.



Black line: Parameter Estimates. Grey lines: $\pm$ two std. errors.

5.3. Parameter stability across time

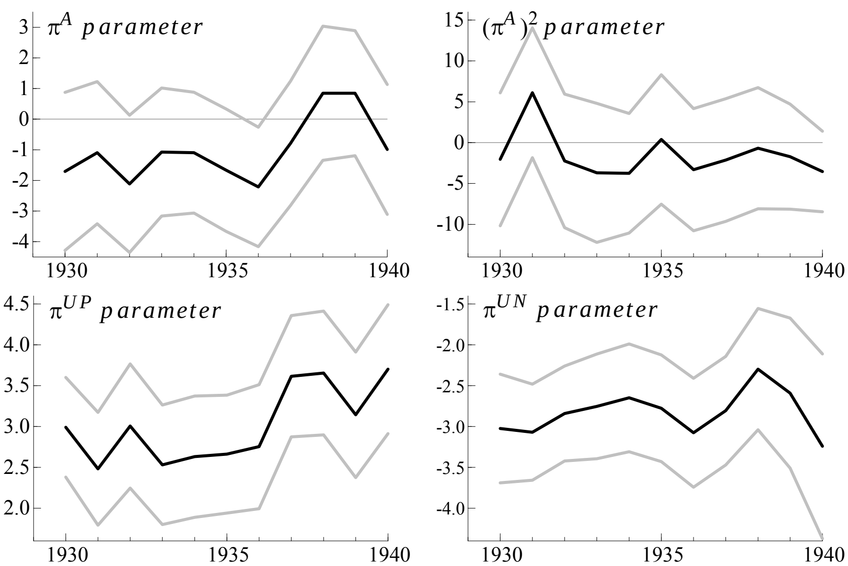
An important question is whether the effects of inflation on RPV and RIV are stable over time.[26] The Japanese and Nigerian sample periods are too short (2000–2006 and 2001–2006, respectively) to address the question of parameter stability. However, the much longer sample period in Canada (1922–1940) allows us to investigate the stability of the subsample parameters of equations (7)-(8).

To do this, we fit the two equations to eight-year subsamples, the first ending in December 1930, the second in December 1931, and so on to the last subsample, ending in November 1940. Each subsample has 96 observations, except the first (missing January 1923) and the last (missing December 1940), which have 95 observations. Since the fraction of observations that include the Great Contraction (1929–1933) varies across subsamples, any impact of the Depression should appear as differences in parameter estimates across subsamples.

The charts in Figure 3 illustrate the π^A and π^U parameter estimates in equation

[26]Choi (2010) and Caglayan and Filiztekin (2003) both ask a similar question. Choi (2010) studies parameter stability in the RIV-inflation relationship using CPI data for the United States (1978–2007) and for Japan (1970–2006), and finds a positive relationship during the high-inflation periods of the 1970s and 1980s for both countries, whereas the U-shape is prevalent during recent decades of low inflation. Using disaggregated annual price data in Turkey, Caglayan and Filiztekin (2003) find that the effects of inflation on RPV and RIV are significant during the relatively low-inflation 1948–1975 period, but are mainly insignificant during the 1976–1997 rising-inflation period.

Figure 4: Recursive estimates of the Canadian RIV-inflation parameters.



Black line: Parameter Estimates. Grey lines: $\pm$ two std. errors.

(7)—the RPV model—using untrimmed inflation and quadratic forms for the β- and ψ-functions. The subsample results in this figure correspond to the whole-sample results in the first column in Table 2.[27] The charts in Figure 4 illustrate the equivalent estimates for equation (8)—the RIV model. The subsample results in this figure correspond to the whole-sample results in the first column in Table 3. In both figures, the parameter estimates are indicated by the black lines, with the 95% confidence interval in grey. In each chart, the horizontal axis indicates the last year in the subsample corresponding to the parameter estimate measured on the vertical axis.

Figure 3 suggests that the estimated relationship between RPV and anticipated inflation does vary across subperiods. The $(\pi^A)^2$ parameter is significantly greater than zero in subsamples ending in 1935 or earlier, but its value falls over time, and is insignificantly different from zero in later subsamples. By the final subsample, neither the mean π^A parameter nor the mean $(\pi^A)^2$ parameter is significantly different from zero. The relationship between RPV and unanticipated inflation is more stable. The π^{UP} and π^{UN} parameter estimates are significantly below zero in all subsamples, with little change in the value of the parameters.

Figure 4 shows there is little change in the RIV parameter estimates. Estimates of the π^A parameters remain insignificantly different from zero throughout the sample period. The π^{UP} parameter estimate is significantly greater than zero for the whole sample period,

[27]The key patterns discussed here also hold for the parameter estimates in the other versions of equation (7), which are not reported.

and the π^{UN} parameter estimate is significantly less than zero, as in Table 3.

The contrast between the stability and significance of the π^{U} parameters here with the insignificance or instability of the π^{A} parameters reinforces the impression that there is more heterogeneity in the effects of anticipated inflation than in the effects of unanticipated inflation. RPV can be expected to be lower with large positive inflation shocks, and higher with large negative shocks; RIV can be expected to be higher with large positive or negative shocks. The effects of anticipated inflation seem to vary somewhat across countries and over time.

6 Summary and Conclusion

Economic theory suggests the possibility of a wide range of different relationships between the dispersion of region-specific relative price levels and the aggregate inflation rate (either anticipated or unanticipated). The same is true of the dispersion of inflation rates. Existing evidence has produced an equally wide range of different results, although methodological heterogeneity limits the extent to which different sets of results can be compared. One key question that needs to be answered is whether the impact of inflation on price-level dispersion resembles its impact on inflation-rate dispersion. This matters if, for example, monetary policy-makers care about dispersion of a particular kind, or about both kinds.

In this paper, we fit the same set of models to datasets from Canada, Japan and Nigeria to examine the relationship between price-level dispersion and aggregate inflation. We compare our estimates of this relationship to the more commonly studied relationship between inflation-rate dispersion and aggregate inflation. With regard to the effects of unanticipated inflation, we find similar results across all three countries. Large negative inflation shocks tend to increase both price-level and inflation-rate dispersion. However, if they have any affect at all, large positive inflation shocks tend to increase inflation-rate dispersion but *reduce* price-level dispersion. These effects are consistent with some models of price dispersion based on search costs, and imply that a monetary policy-maker who cares about price-level dispersion might respond very differently to an aggregate inflation shock than one who cares about inflation-rate dispersion.

With regard to the effects of anticipated inflation, we find evidence of substantial heterogeneity across the two measures of dispersion, as well as across countries and for Canada (where the sample period is long enough to examine this) over time. This heterogeneity is consistent with some of the theories based on menu costs (see, for example, Danziger, 1987). This means that any generalizations about the effect of anticipated inflation on dispersion are likely to be highly misleading.

These results suggest that to assign a welfare level to different values of aggregate inflation, we need to know how to value reductions in price-level dispersion relative to reductions in inflation-rate dispersion. Such an exercise requires modelling the sources of welfare loss associated with dispersion, both in terms of how an increase in dispersion represents a loss of economic efficiency and how it impacts real consumption inequality between regions. This is a subject for future research.

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Appendices

A A Semi-Parametric Model of RPV and RIV

As noted in the literature review, there is some diversity in the way that existing papers parameterize the relationship between RPV/RIV and anticipated inflation, and the quadratic and piecewise-linear functions in equations (10)-(11) do not encompass all of them. (For example, these equations do not allow for a V-shaped function with a turning point at a positive inflation rate.) However, we can also fit a semi-parametric model similar to the ones used by Fielding and Mizen (2008) and Choi (2010). In this model, the parameterizations of the G-function in equations (10)-(11) are replaced by a non-parametric estimate of the function, using the method described by Robinson (1988) and Härdle (1992, Chapter 9.1). Here, we present estimates of a semi-parametric model applied to the Canadian data that are relevant to the discussion in the main text. Results for the other countries are available on request.

Robust estimation of a semi-parametric model requires a large number of observations, so now the data are pooled across all grocery items, and the following regression equation is fitted to the panel:

$$\ln\left(x_{it}^{D}\right) = \kappa_0 + \kappa_1 \cdot \ln\left(x_{it-1}^{D}\right) + \kappa_2 \cdot \pi_{it}^{UP} + \kappa_3 \cdot \pi_{it}^{UN} + \kappa_4 \cdot t + \beta\left(\pi_{it}^{A}\right) \tag{A1}$$
$$+ \kappa_5 \cdot h_{it} + \eta_1 \cdot \ln\left(x_{i0}^{D}\right) + \eta_2 \cdot \pi_{i}^{UP} + \eta_3 \cdot \pi_{i}^{UN} + \eta_4 \cdot \pi_{i}^{A} + \eta_5 \cdot h_i + u_{it},$$

where $x \in \{v, w\}$. The second row of the equation contains a term in the initial value of price dispersion, and terms in the mean values of the different regressors: $y_i = \frac{1}{T}\sum_t y_{it}$. These terms are included to control for unobserved heterogeneity across the different grocery items.

The first step in fitting equation (A1) to the data is to create transformed regressors that are orthogonal to π_{it}^{A}. This is achieved by fitting a non-parametric regression equation for each of the regressors other than π_{it}^{A}:

$$y_{it} = \beta^{y}\left(\pi_{it}^{A}\right) + \tilde{y}_{it}. \tag{A2}$$

Here, $\tilde{y}_{it}$ is a regression residual. The non-parametric function $\beta^{y}(\cdot)$ is fitted in the same way as the function $\beta(\cdot)$, which is described below. The κ and η parameters in equation (A1) are then estimated using the following regression equation:

$$\ln\left(x_{it}^{D}\right) = \kappa_0 + \kappa_1 \cdot \ln\left(\tilde{x}_{it-1}^{D}\right) + \kappa_2 \cdot \tilde{\pi}_{it}^{UP} + \kappa_3 \cdot \tilde{\pi}_{it}^{UN} + \kappa_4 \cdot \tilde{t} + \kappa_5 \cdot \tilde{h}_{it} \tag{A3}$$
$$+ \eta_1 \cdot \ln\left(\tilde{x}_{0}^{D}\right) + \eta_2 \cdot \tilde{\pi}_{i}^{UP} + \eta_3 \cdot \tilde{\pi}_{i}^{UN} + \eta_4 \cdot \tilde{\pi}_{i}^{A} + \eta_5 \cdot \tilde{h}_i + \varepsilon_{it}.$$

Here, ε_{it} is a regression residual. Finally, the shape of $\beta(\cdot)$ is estimated using the following non-parametric regression equation:

$$\varepsilon_{it} = \beta\left(\pi_{it}^{A}\right) + u_{it}. \tag{A4}$$

There are several different kernel density estimators that could be used to estimate the shape of $\beta(\cdot)$. The results reported below are based on one particular kernel density function, but results using other kernel density functions that are robust to outliers (such as the Epanechnikov Kernel) produce similar results.[28] First, we choose specific values of anticipated inflation at which the derivative of $\beta(\cdot)$ is to be estimated. These values are equidistant points within the observed range of π_{it}^{A}. (The estimate at each point is independent of the others; enough points are chosen for the shape of $\beta(\cdot)$ to be clear.) At any particular point π_0, the derivative β_0 is estimated by fitting a linear regression equation using weighted least squares. The regression equation is:

$$\varepsilon_{it} = \alpha_0 + \beta_0 \cdot \pi_{it}^{A} + u_{it}, \tag{A5}$$

and the weights W_{it} are as follows:

$$W_{it} = \frac{15}{16}\left(1 - \left(\frac{\pi_0 - \pi_{it}}{4z}\right)^2\right)^2 \quad \text{if } |\pi_0 - \pi_{it}| < 4z, \quad \text{else } W_{it} = 0. \tag{A6}$$

Here, z is a smoothing parameter, and the truncation of the weighting function at $\pi_0 \pm 4z$ ensures that extreme outliers do not influence the estimates. The standard error of β_0 is estimated using a bootstrap with 100,000 replications.

First of all, we discuss the RPV results. Figures A1-A3 illustrate the derivative of the β-function in the $\ln(v_{it}^{D})$ equation at different anticipated inflation rates for alternative values of z between 1% and 2%,[29] along with the corresponding standard error bars. (The "butterfly shape" of the error bars arises from the fact that there are fewer observations at more extreme values of anticipated inflation.) Note that the figures are drawn to different scales, so that each function occupies the whole chart and its shape is clear. As the value of z increases, the function becomes flatter but the error bars become smaller. In principle, it is possible to select an "optimal" value of z based on an in-sample forecast error criterion. However, in our case, the mean squared forecast error changes very little within the range of z shown.[30] Nevertheless, all of the figures show a line that is approximately straight, that is, a β-function that is approximately quadratic. The turning point of the β-function is indicated by the point at which the line in the figure crosses the y-axis; this is always at a positive anticipated inflation rate. We can compare Figures A1-A3 with a figure based on the parameters of the quadratic model reported in Table 2 (panel C) in the

[28] The kernel density function here is used, for example, in Deaton and Paxson (1998). See Fan (1992, 1993) for a discussion of the properties of alternative kernel density functions.

[29] Recall that the inflation data are monthly, so typical absolute anticipated inflation rates are less than 1%.

[30] For smaller values of z, the forecast errors are larger.

main text. The imposition of a quadratic functional form produces a curve similar to the one in the semi-parametric model with $z = 1\%$. (The standard errors associated with the semi-parametric model are smaller, so a turning point at zero can be rejected with more confidence.)

Table A1 reports estimated values of κ_2 and κ_3 (the unanticipated inflation parameters) in the RPV equation for the different values of z, along with the corresponding t-ratios.[31] The parameter estimates are not very sensitive to the choice of z; they have the same sign as the estimates reported in Table 2 of the main text (implying a negative monotonic function), and are significantly different from zero. Their absolute value is somewhat smaller than in Table 2 and, in the case of κ_3, this difference is statistically significant. However, the overall conclusions regarding the effect of unanticipated inflation on RPV are unchanged.

Next, we discuss the anticipated inflation effects in the RIV function shown in Figures A4-A6. Figure A4 shows that with $z = 1\%$, there is a smooth and approximately quadratic function with a significantly negative slope for inflation rates below 0.25% and a significantly positive slope for inflation rates above 0.75%. Generally, the curve for RIV with $z = 1\%$ is quite similar to the curve for RPV with $z = 1\%$; both indicate that the minimal level of dispersion is reached when inflation is positive. Recall that the parametric models in Table 3 of the main text do not produce any significant anticipated inflation effect. One possible explanation for this difference is that the parametric results are confounded by extreme values of inflation (when π_{it}^A is outside the range shown in the figures) at which the quadratic relationship fails to hold. This suspicion is reinforced by the observation that the slope of the $\beta(\cdot)$ function is insignificantly different from zero at all levels of anticipated inflation when we set $z \geq 2\%$, as shown in Figure A6.

Table A2 reports estimated values of κ_2 and κ_3 (the unanticipated inflation parameters) in the RIV equation for the different values of z, along with the corresponding t-ratios. The parameter estimates are again not very sensitive to the choice of z; they have the same sign as the estimates reported in Table 3 of the main text (implying a V-shaped function), and are significantly different from zero. Their absolute value is again somewhat smaller than in Table 3, and for both parameters this difference is statistically significant. However, the overall conclusions regarding the effect of unanticipated inflation on RPV are unchanged.

[31] Other parameter estimates are available on request.

Table A1: Unanticipated Inflation Coefficients in the Semi-Parametric Model of $ln(v_{it}^{D})$

	$z = 1.0$	$z = 1.5$	$z = 2.0$
π_{it}^{UP}	-0.361	-0.314	-0.300
	(-6.311)	(-6.035)	(-6.044)
π_{it}^{UN}	-0.503	-0.601	-0.616
	(-7.684)	(-10.086)	-(10.841)

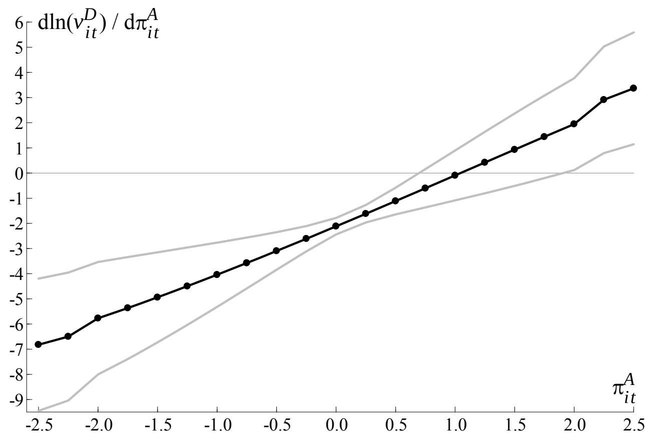
T-ratios in parentheses

Table A2: Unanticipated Inflation Coefficients in the Semi-Parametric Model of $ln(w_{it}^{D})$

	$z = 1.0$	$z = 1.5$	$z = 2.0$
π_{it}^{UP}	1.522	1.558	1.573
	(13.671)	(14.567)	(14.975)
π_{it}^{UN}	-0.768	-0.852	-0.850
	(-6.012)	(-6.943)	(-7.059)

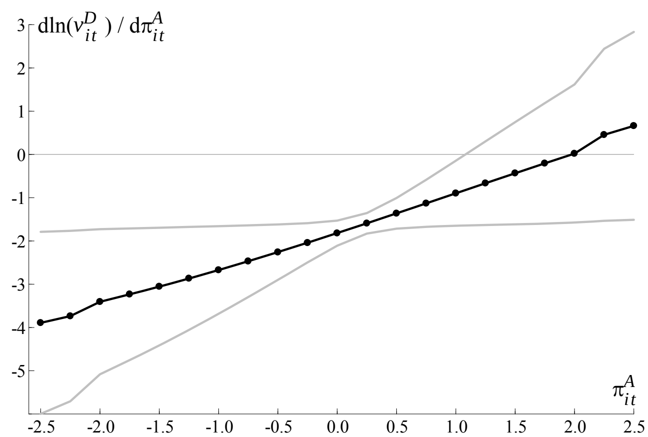
T-ratios in parentheses

Figure A1: Semi-Parametric Estimates of $\partial \ln(v_{it}^{D})/\partial\pi_{it}^{A}$: ($z = 1\%$).



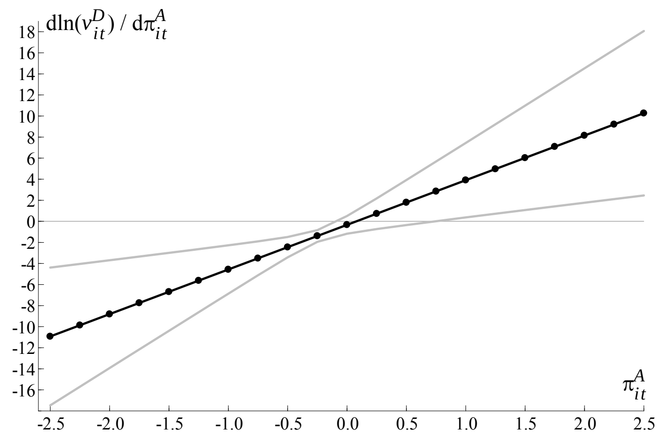
Black line: Marginal effect. Grey lines: 95% confidence interval.

Figure A2: Semi-Parametric Estimates of $\partial \ln(v_{it}^{D})/\partial\pi_{it}^{A}$: ($z = 1.5\%$).



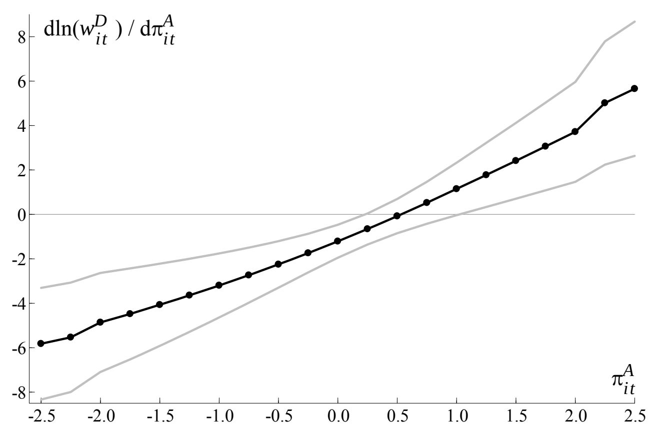
Black line: Marginal effect. Grey lines: 95% confidence interval.

Figure A3: Semi-Parametric Estimates of $\partial \ln(v_{it}^{D})/\partial \pi_{it}^{A}$: $(z = 2\%)$.



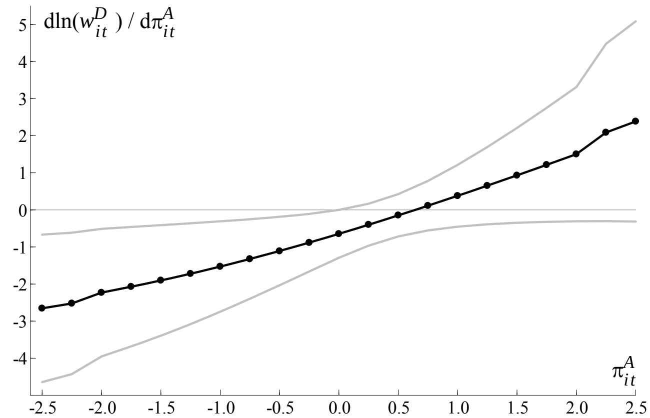
Black line: Marginal effect. Grey lines: 95% confidence interval.

Figure A4: Semi-Parametric Estimates of $\partial \ln(w_{it}^{D})/\partial \pi_{it}^{A}$: $(z = 1\%)$.



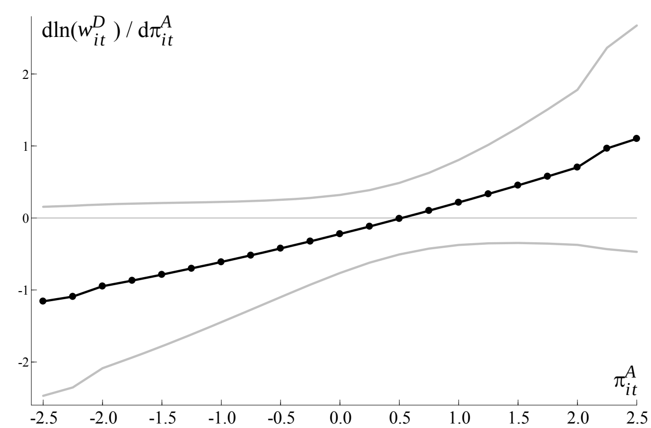
Black line: Marginal effect. Grey lines: 95% confidence interval.

Figure A5: Semi-Parametric Estimates of $\partial \ln(w_{it}^D)/\partial \pi_{it}^A$: ($z = 1.5\%$).



Black line: Marginal effect. Grey lines: 95% confidence interval.

Figure A6: Semi-Parametric Estimates of $\partial \ln(w_{it}^D)/\partial \pi_{it}^A$: ($z = 2\%$).



Black line: Marginal effect. Grey lines: 95% confidence interval.

B Items and Cities Included in the Three Samples

Table B1: Items Included in the Canadian Dataset

Fresh food	Fresh food	Dry & packaged food
Bacon (unsliced)	Onions	Coffee
Bacon (sliced)	Potatoes (15lb bag)	Corn (canned)
Butter (creamery)	Potatoes (100lb bag)	Corn syrup
Butter solids	Rib roast	Currants
Cheese	Round steak	Flour
Eggs (cooking)	Salt cod	Peaches (canned)
Eggs (fresh)	Salt mess pork	Peas (canned)
Finnan haddie	Shoulder roast	Prunes
Ham (sliced)	Sirloin steak	Raisins
Lard	Soda biscuits	Rice
Leg of lamb	Stewing beef	Rolled oats
Milk	Veal shoulder	Salmon (canned)
Mutton leg roast		Sugar (granulated)
		Sugar (yellow)
		Tapioca
		Tea
		Tomatoes (canned)

Table B2: Cities Included in the Canadian Dataset

Amherst	Nova Scotia	Stratford	Ontario
Halifax	Nova Scotia	Sudbury	Ontario
New Glasgow	Nova Scotia	Timmins	Ontario
Sydney	Nova Scotia	Toronto	Ontario
Truro	Nova Scotia	Windsor	Ontario
Windsor	Nova Scotia	Woodstock	Ontario
Charlottetown	Prince Edward Is.	Hull	Quebec
Bathurst	New Brunswick	Montréal	Quebec
Fredericton	New Brunswick	Quebec	Quebec
Moncton	New Brunswick	Saint Hyacinthe	Quebec
Saint John	New Brunswick	Saint Jean	Quebec
Belleville	Ontario	Sherbrooke	Quebec
Brantford	Ontario	Sorel	Quebec
Brockville	Ontario	Thetford Mines	Quebec
Chatham	Ontario	Trois Rivières	Quebec
Cobalt	Ontario	Brandon	Manitoba
Fort William	Ontario	Winnipeg	Manitoba
Galt	Ontario	Moose Jaw	Saskatchewan
Guelph	Ontario	Prince Albert	Saskatchewan
Hamilton	Ontario	Regina	Saskatchewan
Kingston	Ontario	Saskatoon	Saskatchewan
Kitchener	Ontario	Calgary	Alberta
London	Ontario	Drumheller	Alberta
Niagara Falls	Ontario	Edmonton	Alberta
North Bay	Ontario	Lethbridge	Alberta
Orillia	Ontario	Medicine Hat	Alberta
Oshawa	Ontario	Fernie	British Columbia
Ottawa	Ontario	Nanaimo	British Columbia
Owen Sound	Ontario	Nelson	British Columbia
Peterborough	Ontario	New Westminster	British Columbia
Port Arthur	Ontario	Prince Rupert	British Columbia
Saint Catharines	Ontario	Trail	British Columbia
Saint Thomas	Ontario	Vancouver	British Columbia
Sarnia	Ontario	Victoria	British Columbia
Sault Ste Marie	Ontario		

Table B3: Items Included in the Japanese Dataset

(i): *Food at Home*				
Asparagus	Clams in soy sauce	Furikake seasonings	Oranges	Sausages
Bacon	Cooked curry	Grapefruit	Peanuts	Scallops
Baked fish bars	Cream puffs	Green peppers	Pickled cabbage	Sea bream
Bananas	Croquettes	Gyoza	Pickled plums	Shiitake mushrooms
Bean curd	Cucumbers	Hen's eggs	Pickled radishes	Shimeji mushrooms
Bean sprouts	Cuttlefish	Horse mackerel	Pork cutlets	Soy sauce
Bean jam buns	Deep fried chicken	Ice cream	Pork loin	Soybean paste
Bean jam cakes	Devil's tongue jelly	Imported beef	Pork shoulder	Spaghetti
Beef loin	Dried bonito fillets	Imported cheese	Potato chips	Spinach
Beef shoulder	Dried horse mackerel	Instant curry	Powdered milk	Steamed fish cakes
Biscuits	Dried laver	Jam	Prawns	Sugar
Boiled beans	Dried sardines	Jelly	Pudding	Sweet bean jelly
Boiled noodles	Dried mushrooms	Kasutera cakes	Pumpkins	Sweet potatoes
Boxed lunches	Dried small sardines	Kidney beans	Radishes	Tangle in soy sauce
Broccoli	Dried tangle	Kimuchi	Red beans	Taros
Broiled eels	Dried young sardines	Kiwi fruits	Rice (not koshihikari)	Tomatoes
Burdock	Edible oil	Lemons	Rice (koshihikari)	Tuna fish
Butter	Eggplants	Lettuce	Rice balls	Uncooked noodles
Cabbage	Enokidake mushrooms	Liquid seasonings	Rice cakes	Veg in soy sauce
Cakes	Fermented soybeans	Liver	Rice crackers	Vinegar
Candies	Fish in soybean paste	Lotus roots	Roast ham	Wakame seaweed
Canned oranges	Flavor seasonings	Mackerel	Salad	Welsh onions
Canned peaches	Flounder	Margarine	Salmon	Wheat crackers
Capelin	Fresh milk (bottled)	Mayonnaise	Salted cod roe	Wheat flour
Carrots	Fresh milk (cartons)	Seasoned rice	Salted fish guts	White bread
Cheese	Fried bean curd	Mochi rice-cakes	Salted salmon	White potatoes
Chicken	Fried fish patties	Nagaimo	Sandwiches	Worcester sauce
Chinese cabbage	Frozen croquettes	Octopus	Sardines	Yellowtail
Chocolate	Frozen pilaf	Onions	Saury	Yogurt
Clams				

Table B3: Items Included in the Japanese Dataset

(ii): *Other Items*				
Drink	**Household items**	Rolled toilet paper	Mini disk player	Toothbrushes
100% fruit drinks	Air conditioner	Rush floor covering	Notebook	Toothpaste
Black tea	Alarm clock	Scrubbing brush	Pants for exercise	
Calpis	Bathtub	Sealed kitchen ware	Pencil cases	**Apparel**
Canned coffee	Bed	Sewing machine	Pencils	Adults' canvas shoes
Coffee beans	Boards	Sheets	Personal computer	Baby clothes
Foaming liquors	Carpet	Sitting table	Roses	Baseball cap
Green tea (Bancha)	Chest of drawers	Telephone set	Soccer ball	Belt
Green tea (Sencha)	Curtains	Toilet seat	Swimming suit	Boy's short pants
Import beer	Dining set	Towel	Toy car	Child's canvas shoes
Import whisky	Dishes	Vacuum cleaner	TV set (CRT)	Child's shoes
Import wine	Electric iron	Wardrobes		Child's undershirt
Instant coffee	Electric pot	Washing machine	**Pharmacy items**	Handkerchief
Local beer	Electric rice cooker	Water purifier	Chinese medicine	Import handbag
Local whisky 40%+	Fabric softener	Wine glass	Cold medicine	Import necktie
Local whisky 43%+	Facial tissue		Contact lens cleaner	Import watch
Mineral water	Fluorescent fittings	**Sports and leisure**	Dermal medicine	Local handbag
Sake (grade A)	Fluorescent lamp	Baseball gloves	Disposable diapers	Local necktie
Sake (grade B)	Food wrap	Bicycle	Eyewashes	Local watch
Sports drinks	Fragrance	Building blocks	Face cream	Men's briefs
Vegetable juice	Gas cooking table	Camera	Face lotion	Men's business shirt
	Gasoline	Carnations	Foundation	Men's shoes
Restaurant food	Glasses	Chrysanthemums	Hair dye	Men's suit materials
Chicken and rice	Hot water equip.	Computer game	Hair liquid	Men's umbrella
Chinese noodles	Import pan	Copy paper	Hair rinse	Men's undershirt
Coffee	Insecticide	Doll	Health drinks	Pantyhose
Curry and rice	Kitchen cabinet	Dry electric battery	Import shaver	Slips
Gyudon beef on rice	Kitchen detergent	Film	Lipstick	Suitcase
Hamburger steaks	Laundry detergent	Fishing rod	Local shavers	Women's blue jeans
Hamburgers	Local pan	Gardening soil	Plasters	Women's sandals
Hand rolled sushi	Microwave oven	Golf clubs	Sanitary napkins	Women's shoes
Japanese noodles	Moth balls	Import tennis racket	Shampoo	Women's socks
Shrimp and rice	Quilt	Local tennis racket	Stomach medicine	Women's zori sandals
Sushi rolled in laver	Refrigerator	Marking pens	Spectacles	Woollen yarn
	Rice bowl	Mini disk media	Toilet soap	

Table B4: Cities Included in the Japanese Dataset

Akita	Kobe	Otsu
Aomori	Kochi	Saga
Asahikawa	Kofu	Saitama
Atsugi	Koriyama	Sakura
Chiba	Kumamoto	Sapporo
Fuchu	Kyoto	Sasebo
Fukui	Maebashi	Sendai
Fukuoka	Matsue	Shizuoka
Fukushima	Matsumoto	Tachikawa
Fukuyama	Matsuyama	Takamatsu
Gifu	Mito	Tokorozawa
Hakodate	Miyazaki	Tokushima
Hamamatsu	Morioka	Tokyo
Higashi-Osaka	Nagano	Tottori
Himeji	Nagaoka	Toyama
Hirakata	Nagasaki	Tsu
Hiroshima	Nagoya	Ube
Itami	Naha	Utsunomiya
Kagoshima	Nara	Wakayama
Kanazawa	Niigata	Yamagata
Kasugai	Nishinomiya	Yamaguchi
Kawaguchi	Oita	Yokohama
Kawasaki	Okayama	Yokosuka
Kitakyushu	Osaka	

Table B5: Items Included in the Nigerian Dataset

Fresh food	Apparel & Household Items
Bananas	Embroidery lace (per metre)
Beans (brown)	Guinea brocade (per metre)
Beans (white)	Khaki drill (per metre)
Beef	Mattress
Carrots	Men's shoes
Chicken (agricultural)	Pillow
Chicken (locally produced)	Poplin (per metre)
Gari (white)	Singlet
Gari (yellow)	Women's shoes
Guinea corn	
Irish potatoes	Services
Kola nuts	Blood test
Maize (white)	Rent for a flat
Maize (yellow)	Rent for a bungalow
Okra	Rent for a room with parlour
Onions	Rent for a room
Oranges	Room in a hotel
Rice (locally produced)	Taxi fare (per kilometre)
Salt	
Sweet potatoes	
Tomatoes	
Yams	

Table B6: Cities Included in the Nigerian Dataset

City	State	City	State
Abakaliki	Ebonyi	Jalingo	Taraba
Abeokuta	Ogun	Jos	Plateau
Abuja	Federal Capital Territory	Kaduna	Kaduna
Ado-Ekiti	Ekiti	Kano	Kano
Akure	Ondo	Katsina	Katsina
Asaba	Delta	Lafia	Nasarawa
Awka	Anambra	Lokoja	Kogi
Bauchi	Bauchi	Maiduguri	Borno
Benin City	Edo	Makurdi	Benue
Birnin Kebbi	Kebbi	Minna	Niger
Calabar	Cross River	Oshogbo	Osun
Damaturu	Yobe	Owerri	Imo
Dutse	Jigawa	Port Harcourt	Rivers
Enugu	Enugu	Sokoto	Sokoto
Gombe	Gombe	Umuahia	Abia
Gusau	Zamfara	Uyo	Akwa Ibom
Ibadan	Oyo	Yenagoa	Bayelsa
Ikeja	Lagos	Yola	Adamawa
Kano	Kano		