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# Price change dispersion and time-varying pass-through to consumer prices

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## Abstract

This paper examines the relationship between the dispersion of changes in prices and the medium-run exchange rate pass-through in Swiss data. The prices considered are the elementary indices that form the basic building blocks for the construction of the CPI. The results indicate that fluctuations in the cross-sectional dispersion of changes in these price indices inform about variation in aggregate pass-through at business cycle frequencies. Because these data are readily available at monthly frequencies, they can be used in real time to help gauge the pass-through of exchange rate changes to retail prices.

*JEL Classification:* E30, E31, F31

*Keywords:* Exchange rate pass-through, heterogeneity, aggregate implications of price change dispersion

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# 1 Introduction

There is ample empirical evidence that exchange rate pass-through is rarely complete, i.e., local currency prices of foreign products do not respond fully to exchange rates. A large body of literature examines factors at the firm level that lead to incomplete pass-through. These studies typically focus on the pricing decision of the firm under monopolistic competition. They demonstrate how prices respond to changes in the exchange rate and derive a range of implications for monetary policy and macroeconomic stability.<sup>1</sup> Another vein of the literature has documented that pass-through has declined in the past few decades across a wide range of goods. Some authors argue that the composition of imports has shifted away from products with high pass-through towards products with low pass-through; others emphasize that prices have become more sticky as a result of increased foreign competition or the more stable inflationary environment.<sup>2</sup>

This paper contributes to a small but growing body of evidence regarding fluctuations in exchange rate pass-through at business cycle frequencies.<sup>3</sup> We examine the relationship between price change dispersion and medium-run pass-through at the consumer price level in data for Switzerland. Two forms of price change dispersion are considered. One is the dispersion of price changes for a given product category across time (product category-level dispersion), and the other is the dispersion of price changes across product categories for a given month (month-level dispersion). The analytical framework proceeds from the price-setting problem under monopolistic competition with Calvo-type price rigidity. It can be shown that the degree of pass-through is affected by the import share, the frequency of price adjustment, the elasticity of firms' optimal markups with respect to their relative price, and the persistence of the exchange rate. In the empirical analysis, we document that the price change dispersion affects the exchange rate pass-through to consumer prices in monthly data for Switzerland. The price changes considered are changes in price indices of the lowest-level aggregates in the CPI (elementary CPI indices). The estimates suggest considerable variation in pass-through over the period 2000 to 2016.

This paper builds on work by [Berger and Vavra \(2013\)](#), who find a strong positive empirical relationship between the dispersion of import price changes and medium-run exchange rate pass-through in micro data for the US. Berger and Vavra then build a structural price-setting model with various forms of heterogeneity to examine the sources of the correlation between price change dispersion and pass-through. We extend the first of these two contributions by Berger and Vavra in three directions. First, while they examine the

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<sup>1</sup>For a recent survey, see [Burststein and Gopinath \(2015\)](#).

<sup>2</sup>See [Campa and Goldberg \(2005\)](#), [Gust et al. \(2010\)](#) and [Taylor \(2000\)](#), respectively.

<sup>3</sup>See [Berger and Vavra \(2013\)](#) and [Forbes et al. \(2015\)](#).

pass-through in US data, we employ data for Switzerland, an economy that differs greatly from the US economy in many respects. Second, we focus on pass-through to retail prices, whereas Berger and Vavra consider import prices. The focus on retail prices reflects the fact that CPI inflation plays a pivotal role in the monetary policy strategy of most central banks, including the Swiss National Bank (SNB). Third, while Berger and Vavra use prices at the micro level, we are interested in price indices at the lowest aggregation level of the CPI. This has pros and cons. On the one hand, the elementary CPI indices are readily available within a few days after the end of each month at the time of the monthly CPI release. Our dispersion measures can thus be updated without any significant time delay or effort, and the information from these measures can be used in real time to help gauge the pass-through of exchange rate changes to consumer prices. On the other hand, we lose sight of some information that allows researchers using micro-level data to dig deeper.

Moving from import to retail prices and from micro prices to elementary price indices has various further consequences. One is that the pass-through is lower in retail prices than in import prices because retail prices include a price component for domestic retail services.<sup>4</sup> Another follows from the fact that changes in elementary price indices are averages of micro-level price changes from one month to the next. The prices of some varieties of a product may have changed over this period, while others may have remained constant. Therefore, we assume nominal price rigidity in the form of a staggered price setting whereas Berger and Vavra consider a flexible-price model in the corresponding part of their study. They can do this because their micro-level import price data allow them to calculate the changes in each item's price and the corresponding changes in the exchange rate over periods between two consecutive price adjustments. Finally, micro-level import prices have the advantage that the country of origin is known for each item. Bilateral exchange rates can therefore be used, while some trade-weighted effective rate indices must be resorted to when working with CPI elementary indices.

The rest of the paper is organized as follows. Section 2 sets out the theoretical framework. The price-setting problem is analyzed, and the implications for the factors determining the exchange rate pass-through are explored. Section 3 shows empirical results for the relationship between the dispersion of price changes and pass-through, where the price changes are changes in the elementary CPI indices of product categories with an import share of greater than or equal to 70 percent. Section 4 presents estimates of the time-varying pass-through to these indices over the period 2001 to 2016. Results for the pass-through to the full set of elementary CPI indices are also considered. Section 5 contains concluding remarks.

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<sup>4</sup>Bacchetta and van Wincoop (2003) give a theoretical analysis, while Campa and Goldberg (2010) provide empirical evidence across 21 OECD economies.

## 2 Analytical framework

This section explores the relationship between the dispersion of changes in prices and exchange rate pass-through to retail prices. We start with the price setting at the firm level under fully flexible prices. Then, price stickiness is incorporated into the analysis. Attention then turns to the aggregate prices of a product category (represented by the basic CPI components in our empirical analysis), and it is shown how changes in product category prices are affected by changes in the exchange rate and other variables.

Studying the pass-through to prices at the firm level allows us to focus on the pass-through conditional on price adjustment. This is an issue that can be analyzed in a timeless setting with flexible prices, as [Burstein and Gopinath \(2015\)](#) or [Berger and Vavra \(2013\)](#) have done. However, the assumption of flexible prices is not appropriate for the elementary CPI indices considered in this paper. These price indices are averages of retail micro prices, some changed and some unchanged from the previous period. Therefore, we consider a model with nominal price stickiness along the lines of [Calvo \(1983\)](#). In this model, the staggering of price changes across price setters in the economy (i.e., the distribution of price vintages) matters for the pass-through of exchange rate changes to the prices of a product category.

The analysis is partial equilibrium in nature and is limited to the product market. We do not distinguish explicitly between the price setting problem of the producer and the retailer.

### 2.1 Pass-through when prices are flexible

For the analysis of pass-through under flexible prices, we follow the set-up of [Burstein and Gopinath \(2015\)](#), which has also been used by [Berger and Vavra \(2013\)](#). Consider a profit maximizing firm that produces variety  $i$  of product category  $j$ . There is no overlap in varieties produced by different firms. The desired local currency price  $\tilde{p}_{i,j,t}$  is described as

$$\tilde{p}_{i,j,t} = \mu_{i,j,t} + mc_{i,j,t}, \quad (2.1)$$

where  $mc_{i,j,t}$  denotes the marginal cost and  $\mu_{i,j,t}$  is the markup of price over marginal cost. All lower-case variables are in logs.

The markup is assumed to depend on the relative price,  $\mu_{i,j,t} = \mu_{i,j}(\tilde{p}_{i,j,t} - p_t)$ , where  $p_t$  denotes the aggregate price level. The marginal cost depends on the nominal exchange rate  $e_t$ , the quantity sold  $q_{i,j,t}$ , and other costs  $z_{i,j,t}$  that impact marginal costs but are assumed to be orthogonal to the exchange rate:  $mc_{i,j,t} = mc_{i,j}(e_t, q_{i,j,t}, z_{i,j,t})$ .

Approximating the level of the markup and the marginal cost around their steady-state

levels, the desired price  $\tilde{p}_{i,j,t}$ , up to a first-order approximation, is given by

$$\tilde{p}_{i,j,t} = -\Gamma_{i,j}(\tilde{p}_{i,j,t} - p_t) + \alpha_{i,j}e_t + mc_q q_{i,j,t} + z_{i,j,t}, \quad (2.2)$$

where  $\alpha_{i,j} \equiv \frac{\partial mc_{i,j}(\cdot, \cdot)}{\partial e}$  is the partial elasticity of marginal costs (expressed in the domestic country's currency) to the exchange rate, and  $\Gamma_{i,j} \equiv -\frac{\partial \mu_{i,j}(\cdot)}{\partial (\tilde{p}_{i,j,t} - p_t)}$  is the elasticity of the markup with respect to the relative price. [Berger and Vavra \(2013\)](#) refer to  $\alpha_{i,j}$  as “import intensity” and to  $\Gamma_{i,j}$  as “markup responsiveness”. The latter reflects the model of pricing to market developed by [Dornbusch \(1987\)](#) and [Krugman \(1987\)](#), which implies a negative relationship between markups and relative prices  $\tilde{p}_{i,j,t} - p_t$ . If  $\Gamma_{i,j} > 0$ , an individual firm's desired markup varies with the relative price, i.e., firms with a low relative price face a high desired markup, while firms with a high relative price face a low desired markup. As a result, firms will move their prices less than one for one after cost shocks.

To simplify the exposition and focus on the main ideas, we assume  $mc_q \equiv \frac{\partial mc_{i,j}(\cdot, \cdot)}{\partial q} = 0$ , implying constant-returns-to-scale production technology for all firms. Furthermore, without loss of generality, we assume  $\frac{\partial mc_{i,j}(\cdot, \cdot)}{\partial z_{i,j}} = 1$ . With these assumptions, Eq. (2.2) reduces to

$$\tilde{p}_{i,j,t} = \frac{1}{1 + \Gamma_{i,j}} (\alpha_{i,j}e_t + \Gamma_{i,j}p_t + z_{i,j,t}), \quad (2.3)$$

and the change in the desired price can be written as

$$\Delta \tilde{p}_{i,j,t} = \frac{1}{1 + \Gamma_{i,j}} (\alpha_{i,j} \Delta e_t + \Gamma_{i,j} \Delta p_t + \Delta z_{i,j,t}). \quad (2.4)$$

According to Eq. (2.4), changes in the desired price are affected by changes in the exchange rate, in aggregate prices, and in other cost factors. Because  $p_{i,j,t}$  is a component of  $p_t$ , a change in the exchange rate, in addition to the direct effect, has an indirect effect through  $p_t$ . This indirect effect is ignored, reflecting the partial equilibrium nature of our analysis. Assuming  $\Delta p_t = \Delta z_{i,j,t} = 0$ , we obtain an explicit expression for the direct effect of a change in the exchange rate on the change in the desired price:

$$\frac{\Delta \tilde{p}_{i,j,t}}{\Delta e_t} = \frac{\alpha_{i,j}}{1 + \Gamma_{i,j}}. \quad (2.5)$$

The exchange rate pass-through to the firm's desired price ( $\Delta \tilde{p}_{i,j,t} / \Delta e_t$ ) thus fluctuates with the import intensity  $\alpha_{i,j}$  and the markup elasticity with respect to the relative price  $\Gamma_{i,j}$ . The higher the import intensity and the lower the markup elasticity, the stronger the response of the firm's desired price to changes in the exchange rate.<sup>5</sup>

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<sup>5</sup>[Berger and Vavra \(2013\)](#) allow for heterogeneity in  $\Gamma_{i,j}$  in a quantitative menu cost model. They show that the resulting heterogeneity in markup responsiveness is the key factor for explaining their

## 2.2 Pass-through when prices are sticky

When prices are sticky, the pass-through of exchange rate changes to prices takes time. This section explores the determinants of the exchange rate pass-through conditional on adjustment under the assumption of Calvo pricing, where  $(1 - \theta_{i,j})$  is the probability that firm  $i$  is adjusting the price of variety  $i$  of product category  $j$  in a given period. The currently observed price is  $p_{i,j,t} = \bar{p}_{i,j,t}$  in case the price is reset in period  $t$ , and  $p_{i,j,t} = p_{i,j,t-1}$  if not. Under Calvo pricing, the optimal reset price is determined by the first-order condition

$$\sum_{l=0}^{\infty} (\theta_{i,j})^l E_t \Phi_{t+l} \Pi_p(\bar{p}_{i,j,t} | s_{t+l}) = 0, \quad (2.6)$$

where  $\theta_{i,j}$  is the time-invariant probability of non-adjustment,  $\Pi_p$  denotes the partial derivative of the profit function with respect to  $\bar{p}_{i,j,t}$ ,  $E_t \Phi_{t+l}$  is the expected stochastic discount factor, and  $E_t s_{t+l}$  summarizes the firm's expected state in  $t+l$ .

In the steady state, we have  $\Phi_{t+l} = \beta^l$ , where  $\beta < 1$  denotes the discount factor. Log-linearizing equation Eq. (2.6) around the flexible price first-order condition, the optimal reset price,  $\bar{p}_{i,j,t}$ , can be approximated as a weighted sum of current and future expected desired prices,  $E_t \tilde{p}_{i,j,t+l}$ :

$$\bar{p}_{i,j,t} = (1 - \theta_{i,j}\beta) \sum_{l=0}^{\infty} (\beta\theta_{i,j})^l E_t \tilde{p}_{i,j,t+l}, \quad (2.7)$$

where the weights depend on the probability of non-adjustment and the discount factor.<sup>6</sup>

Substituting Eq. (2.3) into Eq. (2.7) gives

$$\bar{p}_{i,j,t} = \frac{1 - \theta_{i,j}\beta}{1 + \Gamma_{i,j}} \sum_{l=0}^{\infty} (\beta\theta_{i,j})^l E_t (\alpha_{i,j} e_{t+l} + \Gamma_{i,j} p_{t+l} + z_{i,j,t+l}). \quad (2.8)$$

According to Eq. (2.8), the optimal reset price ( $\bar{p}_{i,j,t}$ ) is related to current and expected future values of the exchange rate ( $e_{t+l}$ ), the aggregate price index ( $p_{t+l}$ ) and other costs ( $z_{i,j,t+l}$ ). To obtain an expression for the sensitivity of a price change, conditional on adjustment, with respect to an exchange rate change, we can write

$$\begin{aligned} \bar{p}_{i,j,t} - \bar{p}_{i,j,t-k} &= \frac{1 - \theta_{i,j}\beta}{1 + \Gamma_{i,j}} \left[ \sum_{l=0}^{\infty} (\beta\theta_{i,j})^l E_t (\alpha_{i,j} e_{t+l} + \Gamma_{i,j} p_{j,t+l} + z_{i,j,t+l}) \right. \\ &\quad \left. - \sum_{l=0}^{\infty} (\beta\theta_{i,j})^l E_{t-k} (\alpha_{i,j} e_{t-k+l} + \Gamma_{i,j} p_{j,t-k+l} + z_{i,j,t-k+l}) \right]. \end{aligned} \quad (2.9)$$

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empirical finding of a positive relationship between the dispersion of price changes and pass-through.

<sup>6</sup>See Gopinath and Itskhoki (2010)



Since our analysis is partial equilibrium in nature, we follow [Burstein and Gopinath \(2015\)](#) and make three assumptions about the expectation formation of individual firms: (i) Exchange rate expectations are formed based on the assumption that the exchange rate follows an AR(1) process with persistence parameter  $\rho_e \leq 1$  so that  $E_{t+l}e_{t+l} = \rho_e^l e_t$ ; (ii) expectations on the future course of aggregate prices are set based on an indexing mechanism that tracks the current average price change as  $E_{t+l}p_{t+l} = p_t + l\bar{\pi}$ ; and (iii) expectations on the other cost factors reflect the assumption that costs follow a random walk, yielding  $E_{t+l}z_{i,j,t+l} = z_{i,j,t}$ . With these assumptions, Eq. (2.9) simplifies to

$$\Delta \bar{p}_{i,j,t,t-k} = \frac{1 - \theta_{i,j}\beta}{1 - \theta_{i,j}\beta\rho_e} \frac{\alpha_{i,j}}{1 + \Gamma_{i,j}} \Delta e_{t,t-k} + \frac{\Gamma_{i,j}}{1 + \Gamma_{i,j}} \Delta p_{t,t-k} + \frac{1}{1 + \Gamma_{i,j}} \Delta z_{i,j,t,t-k} \quad (2.10)$$

where  $\Delta \bar{p}_{i,j,t,t-k} \equiv \bar{p}_{i,j,t} - \bar{p}_{i,j,t-k}$ .

Focusing on the direct channel of exchange rate pass-through to the reset price, we assume  $\Delta p_{t,t-k} = \Delta z_{i,j,t,t-k} = 0$  and obtain

$$\frac{\Delta \bar{p}_{i,j,t,t-k}}{\Delta e_{t,t-k}} = \frac{1 - \theta_{i,j}\beta}{1 - \theta_{i,j}\beta\rho_e} \frac{\alpha_{i,j}}{1 + \Gamma_{i,j}}. \quad (2.11)$$

The direct pass-through under sticky prices differs from that under flexible prices described in Eq. (2.5) by the first factor on the right hand side of Eq. (2.11). We can see that the persistence of the exchange rate is crucial. If  $\rho_e = 1$ , meaning the exchange rate follows a random walk, then the exchange rate pass-through conditional on price adjustment coincides with that under flexible prices. With  $\rho_e < 1$ , however, the pass-through is lower than under flexible prices. The difference is inversely related to  $\theta_{i,j}$ , implying that a high degree of price stickiness causes the sticky price pass-through to fall more relative to the flexible price pass-through. Firms choose to adjust prices only partially, since they will be stuck with the new price for some time, during which the exchange rate may revert. The smaller  $\rho_e$  and the larger  $\theta_{i,j}$  are, the smaller the pass-through is.

### 2.3 Pass-through and product-category price indices

To calculate the change in the product-category price level, we assume a continuum of monopolistically competitive firms  $i \in [0, 1]$  in each product category  $j$ . All firms in product category  $j$  are symmetric, except for the timing of their price adjustment. That is,  $\theta_{i,j} = \theta_j$ ,  $\Gamma_{i,j} = \Gamma_j$ , and  $\alpha_{i,j} = \alpha_j$ . All adjusting firms choose the same optimal reset price,  $\bar{p}_{i,j,t} = \bar{p}_{j,t}$ . As a result, the product-category price level  $p_{j,t}$  can be written as

$$p_{j,t} = (1 - \theta_j) \sum_{k=0}^{\infty} \theta_j^k \bar{p}_{j,t-k} = (1 - \theta_j) \bar{p}_{j,t} + \theta_j p_{j,t-1}, \quad (2.12)$$

and the change in the product-category price level  $\Delta p_{j,t}$  can be written as

$$\begin{aligned}\Delta p_{j,t} &= (1 - \theta_j)(\bar{p}_{j,t} - p_{j,t-1}) \\ &= (1 - \theta_j)^2 \sum_{k=0}^{\infty} \theta_j^k \Delta \bar{p}_{j,t,t-1-k}.\end{aligned}\quad (2.13)$$

The change in the product-category price level is a weighted sum of the individual price changes undertaken in period  $t$ , where the weights correspond to the fractions of adjusting firms in each price vintage  $t - k$ ,  $\forall k \geq 0$ .

Using Eq. (2.10) to substitute for the  $\Delta \bar{p}_{j,t-k}$ -terms in Eq. (2.13),  $\Delta p_{j,t}$  becomes

$$\begin{aligned}\Delta p_{j,t} &= (1 - \theta_j)^2 \left( \sum_{k=0}^{\infty} \theta_j^k \frac{1 - \theta_j \beta}{1 - \theta_j \beta \rho_e} \frac{\alpha_j}{1 + \Gamma_j} \Delta e_{t,t-1-k} \right. \\ &\quad \left. + \sum_{k=0}^{\infty} \theta_j^k \frac{\Gamma_j}{1 + \Gamma_j} \Delta p_{t,t-1-k} + \sum_{k=0}^{\infty} \theta_j^k \frac{1}{1 + \Gamma_j} \Delta z_{t,t-1-k} \right).\end{aligned}\quad (2.14)$$

The change in the product-category price level thus depends on the weighted sum of cumulative changes in the exchange rate, the price level, and other cost factors. The terms in Eq. (2.14) can be rearranged to obtain an equation for the changes in product-category price levels in terms of current and lagged growth rates:<sup>7</sup>

$$\begin{aligned}\Delta p_{j,t} &= (1 - \theta_j) \frac{1 - \theta_j \beta}{1 - \theta_j \beta \rho_e} \frac{\alpha_j}{1 + \Gamma_{i,j}} \sum_{k=0}^{\infty} \theta_j^k \Delta e_{t-k} \\ &\quad + (1 - \theta_j) \frac{\Gamma_j}{1 + \Gamma_{i,j}} \sum_{k=0}^{\infty} \theta_j^k \Delta p_{t-k} + (1 - \theta_j) \frac{1}{1 + \Gamma_j} \sum_{k=0}^{\infty} \theta_j^k \Delta z_{t-k}.\end{aligned}\quad (2.15)$$

According to Eq. (2.15), the change in product-category price levels depends on weighted sums of current and lagged exchange rate changes, aggregate price changes and changes in other costs. The weights placed on the exchange rate rate terms reflect the exchange rate pass-

<sup>7</sup> Note that the first summand in the bracket of Eq. (2.14) can be written as:

$$\begin{aligned}\sum_{k=0}^{\infty} \theta_j^k \frac{1 - \theta_j \beta}{1 - \theta_j \beta \rho_e} \frac{\alpha_j}{1 + \Gamma_j} \Delta e_{t,t-1-k} &= \sum_{k=0}^{\infty} \theta_j^k \frac{1 - \theta_j \beta}{1 - \theta_j \beta \rho_e} \frac{\alpha_j}{1 + \Gamma_j} \Delta e_{t,t-1} \\ &+ \sum_{k=1}^{\infty} \theta_j^k \frac{1 - \theta_j \beta}{1 - \theta_j \beta \rho_e} \frac{\alpha_j}{1 + \Gamma_j} \Delta e_{t,t-2} + \dots + \sum_{k=m-1}^{\infty} \theta_j^k \frac{1 - \theta_j \beta}{1 - \theta_j \beta \rho_e} \frac{\alpha_j}{1 + \Gamma_j} \Delta e_{t,t-m} + \dots \\ &= \frac{1}{1 - \theta_j} \frac{1 - \theta_j \beta}{1 - \theta_j \beta \rho_e} \frac{\alpha_j}{1 + \Gamma_j} \Delta e_{t,t-1} + \frac{\theta_j}{1 - \theta_j} \frac{1 - \theta_j \beta}{1 - \theta_j \beta \rho_e} \frac{\alpha_j}{1 + \Gamma_j} \Delta e_{t-1,t-2} + \dots \\ &+ \frac{(\theta_j)^{m-1}}{1 - \theta_j} \frac{1 - \theta_j \beta}{1 - \theta_j \beta \rho_e} \frac{\alpha_j}{1 + \Gamma_j} \Delta e_{t-m-1,t-m} + \dots = \frac{1}{1 - \theta_j} \frac{1 - \theta_j \beta}{1 - \theta_j \beta \rho_e} \frac{\alpha_j}{1 + \Gamma_j} \sum_{k=0}^{\infty} (\theta_j)^k \Delta e_{t-k}.\end{aligned}$$

through at the firm level  $\left(\frac{1-\theta_j\beta}{1-\theta_j\beta\rho_e}\frac{\alpha_j}{1+\Gamma_{i,j}}\right)$  and the effect of the staggered price adjustment across firms in the product category  $(1-\theta_j)\theta_j^k$ . Under Calvo pricing, the staggering implies that the relevance of more-distant lags of exchange rate changes declines geometrically.

To gain an intuition of the relationship between the distribution of the changes in product-category price levels and pass-through, we take the variance of both sides of Eq. (2.15) while assuming that the exchange rate follows a random walk. The random-walk assumption implies that changes in the exchange rate are orthogonal to changes in the aggregate price level and other costs. Therefore, we can write

$$\begin{aligned} \text{var}(\Delta p_{j,t}) = & \text{var}\left((1-\theta_j)\frac{1-\theta_j\beta}{1-\theta_j\beta\rho_e}\frac{\alpha_j}{1+\Gamma_{i,j}}\sum_{k=0}^{\infty}\theta_j^k\Delta e_{t-k}\right) \\ & + \text{var}\left((1-\theta_j)\frac{\Gamma_j}{1+\Gamma_{i,j}}\sum_{k=0}^{\infty}\theta_j^k\Delta p_{t-k} + (1-\theta_j)\frac{1}{1+\Gamma_j}\sum_{k=0}^{\infty}\theta_j^k\Delta z_{t-k}\right) \quad (2.16) \end{aligned}$$

The variance of the changes in product-category price levels depends on the variance of the weighted sum of current and lagged exchange rate changes and the variance of the sum of all the other variables in Eq. (2.15). The variance of the weighted sum of current and lagged exchange rate changes can be rewritten as a linear combination of variance and covariance terms, with the weights depending on import shares  $(\alpha_{i,j})$ , markup elasticities  $(\Gamma_j)$ , and probabilities of non-adjustment  $(\theta_{i,j})$ . The variance of changes in product-category price levels thus moves with the variances and covariances of exchange rate changes and with the changes in the responsiveness of prices to the exchange rate. The relationship between pass-through and the variance of changes in product-category price levels is empirically examined in the next section.

### 3 Price change dispersion and pass-through: empirical evaluation

In our empirical analysis, we explore the medium-run exchange rate pass-through to retail prices in Switzerland. The data are described in Section 3.1. Section 3.2 introduces the dispersion of price changes (or, rather, price indices) used in this paper: product category-level price change dispersion and month-level price change dispersion. Section 3.3 focuses on the relationship between the dispersion of price changes across time and pass-through. This is followed in Section 3.4 by an examination of the relationship between the dispersion of price changes across product categories and pass-through. Both sections start with specifications derived from the theoretical framework developed in Section 2. More-flexible

specifications are also considered, as the Calvo assumption used in the theoretical analysis is rather strong and has been questioned extensively in the literature.

### 3.1 Data description

All data are monthly and cover the period May 2000 to May 2016.

- CPI price data are for the lowest-level aggregation of CPI micro prices in Switzerland. We label these indices of elementary aggregates as elementary price indices. The elementary CPI indices are calculated as averages of micro prices of narrowly defined, relatively homogenous products. A micro price, in turn, is the price of a good or service sold in a specific outlet in a given quantity and quality. The Swiss Federal Statistical Office (SFSO) publishes more than 200 elementary CPI indices.<sup>8</sup> We discard elementary aggregates with an import share of less than 70 percent. This leaves 76 elementary CPI indices, representing approximately 20 percent of the CPI. The discarded products, for the most part, are goods with regulated or administered prices and all sorts of services. All series are seasonally adjusted before estimation.
- The exchange rate is measured by the inverted index of the nominal effective Swiss franc exchange rate (export-weighted, 24 countries). An increase in our exchange rate measure means the Swiss franc loses value (i.e., it takes more Swiss francs to buy one unit of the foreign currency basket). The data source is SNB.
- Import shares are estimated values provided by SFSO.
- Price durations are reported in [Kaufmann \(2009\)](#) as averages for the elementary aggregates of Switzerland’s CPI. Kaufmann calculated durations in quarters over the period 2000 to 2005 based on the micro price data underlying the elementary CPI indices. Durations in months are obtained by multiplying the data by a factor of three.

Under Calvo pricing, the probability of non-adjustment  $\theta_j$  and the frequency of price changes  $Fpc_j$  are two concepts related to the price duration  $Dur_j$ . The probability of non-adjustment is  $\theta_j = 1 - Fpc_j$ , while the frequency of price changes can be calculated from the median duration between consecutive price adjustments as  $Fpc_j = 1 - \exp\left(\frac{\ln 0.5}{Dur_j}\right)$ .

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<sup>8</sup>The number of elementary CPI indices published by the SFSO has changed every five years with the revision of the CPI: December 2000 (222), December 2005 (218), December 2010 (215), and December 2015 (267).

The control variables are the CPI in Switzerland, the output gap in Switzerland, and the CPI in foreign countries calculated as a trade-weighted average of the G7 countries (USA, Japan, Germany, France, United Kingdom, Italy, Canada). The output gap is defined as the deviation of real GDP from its potential, where potential GDP is estimated based on a production function approach, and monthly figures are derived from quarterly figures based on a spline function approach (source: SNB). All series are seasonally adjusted before estimation.

### 3.2 Measures of price change dispersion

Two dispersion measures play crucial roles in this paper: the product category-level and month-level dispersions of price index changes.

The product category-level price change dispersion ( $Vol_j$ ) is measured as the standard deviation of all month-on-month changes in the price index of product category  $j$  observed over the period May 2000 to May 2016. This yields 76 measures of price change volatility, one for each elementary CPI index.

The month-level price change dispersion can be measured as the interquartile range of the month-on-month changes in elementary CPI indices observed in a given month for the 76 product categories. This gives 193 (standardized) interquartile ranges,  $iqr_t$ , over the period May 2000 to May 2016, one for each month. In our empirical analysis, we use moving averages of  $iqr_t$  over the last twelve months, calculated as  $IQR_t = \frac{1}{12} \sum_{n=0}^{11} iqr_{t-n}$ .

Figure 1 shows  $Vol_j$  for the 76 product categories  $j$  and  $IQR_t$  for the months from May 2000 to May 2016.

### 3.3 Product-category-level price change dispersion and pass-through

This section examines whether the degree of medium-run pass-through changes with the volatility of changes in prices at the product category level (i.e., the volatility of changes in the elementary CPI indices). Three specifications are considered, one derived from the theoretical framework with Calvo pricing and two others without the constraints imposed by the Calvo assumption.

**Results for specification derived from model with Calvo pricing.** We start from Eq. (2.15), which explains the change in the price index of product category  $j$  at time  $t$  ( $\Delta p_{j,t}$ ) by infinite weighted sums of current and lagged changes in the exchange rate ( $\Delta e_{t-k}$ ), in aggregate prices ( $\Delta p_{t-k}$ ), and in other costs ( $\Delta z_{t-k}$ ). Three simplifying

assumptions are made. First, the lags are truncated at  $K = 30$ . Second, the discount factor is set to  $\beta = 1$ , implying that we abstract from discounting. Third, the persistence parameter in the exchange rate's AR(1) process is set to  $\rho_e = 1$ , which means that the exchange rate follows a random walk. Furthermore, current and lagged changes in other costs are approximated by current and lagged changes in foreign prices ( $\Delta p_{t-k}^*$ ) and the current output gap ( $y_t$ ). Therefore, we can write

$$\Delta p_{j,t} = \sum_{k=0}^K \beta_{j,k} \Delta e_{t-k} + \sum_{k=0}^K \gamma_{j,k} \Delta p_{t-k} + \sum_{k=0}^K \delta_{j,k} \Delta p_{t-k}^* + \eta_j y_t + \epsilon_{j,t}, \quad (3.1)$$

where

$$\beta_{j,k} = \frac{\alpha_j \theta_j^k (1 - \theta_j)}{1 + \Gamma_j}, \quad \gamma_{j,k} = \frac{\Gamma_j \theta_j^k (1 - \theta_j)}{1 + \Gamma_j},$$

$$\delta_{j,k} = \frac{\theta_j^k (1 - \theta_j)}{1 + \Gamma_j}, \quad \eta_j = \frac{1 - \theta_j}{1 + \Gamma_j}.$$

Since we have data on import shares ( $\alpha_j$ ) and frequencies of price adjustment ( $\theta_j$ ), leaving the markup elasticities ( $\Gamma_j$ ) as the only parameters to be estimated, it is useful to rewrite Eq. (3.1) as

$$\begin{aligned} \Delta p_{j,t} = & \beta_j^* \sum_{k=0}^K \alpha_j \theta_j^k (1 - \theta_j) \Delta e_{t-k} + \gamma_j^* \sum_{k=0}^K \theta_j^k (1 - \theta_j) \Delta p_{t-k} \\ & + \delta_j^* \sum_{k=0}^K \theta_j^k (1 - \theta_j) \Delta p_{t-k}^* + \eta_j^* y_t + \epsilon_{j,t}, \end{aligned} \quad (3.2)$$

where

$$\beta_j^* = \delta_j^* = \frac{1}{1 + \Gamma_j}, \quad \gamma_j^* = \frac{\Gamma_j}{1 + \Gamma_j}.$$

Eq. (3.2) is the basic equation for our empirical analysis of pass-through under Calvo pricing. We estimate  $\beta_j^*$ ,  $\delta_j^*$  and  $\gamma_j^*$  in a constrained linear regression, taking into account the dependence of these parameters on  $\Gamma_j$ . Because the output gap is a loose proxy for “other costs”,  $\eta_j^*$  is estimated unrestricted.

To estimate the average pass-through, we set  $\beta_j^* = \beta^*$ ,  $\delta_j^* = \delta^*$ ,  $\gamma_j^* = \gamma^*$  and  $\eta_j^* = \eta^*$ , implying  $\Gamma_j^* = \Gamma^*$ . Eq. (3.2) is estimated with data for the period May 2000 to May 2016 using the Least Squares Dummy Variable (LSDV) method with robust standard errors in STATA.<sup>9</sup> The results for  $\beta^*$  are reported in Table 1. They show that  $\hat{\beta}^*$  is positive and statistically significant at the 1 percent level. Based on  $\hat{\beta}^*$ , the pass-through coefficients are computed as  $\beta_{j,k} = \hat{\beta}^* \alpha_j \theta_j^k (1 - \theta_j)$ ,  $\forall k = 0, 1, \dots, 30$ . Averages of these coefficients over the

<sup>9</sup>LSDV is pooled OLS with item dummies.

76 items are displayed in Figure 2 (first panel). They show the geometrically falling pattern implied by the Calvo assumption of price rigidity. The 90 percent confidence interval is based on the standard error of  $\hat{\beta}^*$ . The positive value of  $\hat{\beta}^*$  and, thus,  $\beta_{j,k}$  indicates that exchange rate changes pass through to consumer prices.

Next, we address the relationship between price change volatility and exchange rate pass-through. In what follows, this relationship is examined in three ways. First, we run regressions on Eq. (3.2) separately for each product category  $j$ . Based on the results for  $\beta_j^*$ , estimates of the pass-through coefficients are obtained as  $\beta_{j,k} = \hat{\beta}_j^* \alpha_j \theta_j^k (1 - \theta_j)$ ,  $\forall k = 0, 1, \dots, 30$ . Figure 2 (second panel) plots the average pass-through coefficient, calculated as  $\bar{\beta}_j = \frac{1}{K+1} \sum_{k=0}^K \beta_{j,k}$ , where  $K = 30$ , against the price change volatility  $Vol_j$ . The regression line slopes upward, suggesting that the pass-through increases with the price change volatility.

Second, we order the product categories by their price change volatility, calculate terciles, and construct three bins. Eq. (3.2) is estimated separately for each bin, and pass-through coefficients are calculated as described above. Figure 2 (third panel) shows the results of the three panel regressions. The point estimate of the pass-through coefficient is slightly higher in bin 2 than in bins 1 and 3, but standard errors are large and the confidence intervals overlap, indicating that the differences are not statistically significant.

Third, we add an interaction term between the exchange rate change  $\Delta e_{t-k}$  and the price change volatility  $Vol_j$  to the model to determine whether the pass-through is influenced by the price change volatility:

$$\begin{aligned} \Delta p_{j,t} = & \beta^* \sum_{k=0}^K \alpha_j \theta_j^k (1 - \theta_j) \Delta e_{t-k} + \beta^{*Vol} \sum_{k=0}^K \alpha_j \theta_j^k (1 - \theta_j) \Delta e_{t-k} Vol_j + \nu^* Vol_j \\ & + \gamma^* \sum_{k=0}^K \theta_j^k (1 - \theta_j) \Delta p_{t-k} + \delta^* \sum_{k=0}^K \theta_j^k (1 - \theta_j) \Delta p_{t-k}^* + \eta^* (1 - \theta_j) y_t + \epsilon_{j,t}. \end{aligned} \quad (3.3)$$

The price change volatility  $Vol_j$  is standardized to ease interpretation. Table 1 reports the results of the panel regression specified by Eq. (3.3). The coefficient on the interaction term  $\hat{\beta}^{*Vol}$  is not statistically significant, implying that the pass-through is not affected by price change volatility  $Vol_j$  if we assume Calvo-type pricing.

The structure of the pass-through coefficients presented in this section is determined by the particular price setting framework we have imposed on our estimation of the pass-through. Under Calvo-type price rigidity, the weights on the lagged changes in the exchange rate take a geometrically falling form. However, other pricing models imply different patterns. The pattern is falling but not geometrically falling in menu cost models such as the state-dependent pricing model by Dotsey et al. (1999), while it is flat under the staggered

pricing hypothesis developed by Taylor (1980). Furthermore, the type of price-setting behavior may differ among products, suggesting that all three patterns might be present in the real world. Therefore, we relax the constraints imposed by the Calvo assumption and estimate unrestricted reduced-form coefficients of exchange rate pass-through.

**Results for more-general specification: distributed lags.** To examine the pass-through to elementary CPI indices without being specific about the characteristics of the pricing framework, we rewrite Eq. (3.1) as

$$\Delta p_{j,t} = \sum_{k=0}^K \beta_{j,k} \Delta e_{t-k} + \sum_{k=0}^K \gamma_{j,k} \Delta p_{t-k} + \sum_{k=0}^K \delta_{j,k} \Delta p_{t-k}^* + \eta_j y_t + \epsilon_{j,t}. \quad (3.4)$$

The number of lags is truncated at  $K = 11$ , which roughly corresponds to the average price duration across CPI product categories with an import share greater than or equal to 70 percent reported by Kaufmann (2009). The estimated coefficients are in reduced form and, hence, are more difficult to interpret than those in Eq. (3.1).

The presentation of the various results is as above for the specification under Calvo-type price setting. To estimate the average pass-through, we set  $\beta_{j,k} = \beta_k$ ,  $\delta_{j,k} = \delta_k$ ,  $\gamma_{j,k} = \gamma_j$ , and  $\eta_j = \eta$ . Estimation results for the  $\beta_k$ -coefficients in Eq. (3.4) are given in Table 2. All coefficients are statistically significant at the 1 percent or 5 percent level. An F-test shows joint significance of the coefficients. Figure 3 (first panel) displays these results in a chart. The coefficients reach a maximum at lag 7. The pattern markedly differs from the downward slope imposed by the Calvo assumption.

To examine the relationship between exchange rate pass-through and price change volatility at the product-category level, Eq. (3.4) is estimated separately for each product category  $j$ . The results are summarized in Figure 3 (second panel), where the average pass-through coefficient is plotted against the price change volatility for each product category. The regression line has a positive slope, implying that the pass-through increases with the price change volatility.

We next order the product categories by their price change volatility, calculate terciles, and form three bins. Eq. (3.4) is estimated separately for each bin. The results are displayed in Figure 3 (third panel). In contrast to the estimates for the Calvo specification, they indicate that the pass-through coefficients increase from bin 1 to bin 3, implying that product categories with high price change volatility tend to have a higher pass-through rate than product categories with low price change volatility.

Finally, we add interaction terms between the exchange rate changes  $\Delta e_{t-k}$  and the



price change volatility  $Vol_j$  to the model. Accordingly, Eq. (3.4) becomes

$$\begin{aligned} \Delta p_{j,t} = & \sum_{k=0}^K \beta_k \Delta e_{t-k} + \sum_{k=0}^K \beta_k^{Vol} \Delta e_{t-k} Vol_j + \nu Vol_j \\ & + \sum_{k=0}^K \gamma_k \Delta p_{t-k} + \sum_{k=0}^K \delta_k \Delta p_{t-k}^* + \eta y_t + \epsilon_{j,t}. \end{aligned} \quad (3.5)$$

The estimation results for  $\beta_k$  and  $\beta_k^{Vol}$  are summarized in Table 2. All  $\beta_k^{Vol}$ -coefficients are positive, and most of them are statistically significant at the 1 percent or 5 percent level. An F-test strongly rejects the hypothesis that the coefficients are jointly zero.

**Results for more-general specification: cumulative growth rates.** Models with distributed lags have two disadvantages. One is that multicollinearity may lead to unreliable coefficient estimates. The other is that degrees of freedom may be depleted quickly when lag length increases. Since our main interest is the medium-run pass-through rather than the pattern of the pass-through coefficients at the various lags, we consider a simple alternative where the distributed lagged changes in our right-hand-side variables are replaced by cumulative changes. The equation thus becomes

$$\Delta p_{j,t} = \beta_j \Delta e_{t,t-K} + \gamma_j \Delta p_{t,t-K} + \delta_j \Delta p_{t,t-K}^* + \eta_j y_t + \epsilon_{j,t}, \quad (3.6)$$

where  $\Delta x_{t,t-K} = x_t - x_{t-K}$  denotes the cumulative growth rate between  $t - K$  and  $t$ , with  $K$  set to 12.

Eq. (3.6) can be derived from the distributed lags model in Eq. (3.4) by setting  $\beta_{j,k} = \beta_j$ ,  $\gamma_{j,k} = \gamma_j$ , and  $\delta_{j,k} = \delta_j$ . That is, the coefficients on the current and lagged changes in the exchange rate over one period,  $\Delta e_{t-k}$ , are the same for all  $k = 0, 1, \dots, 11$  (and, correspondingly, for the changes in the price level  $\Delta p_{t-k}$  and the changes in foreign prices  $\Delta p_{t-k}^*$ ). Eq. (3.6) implies a flat pattern of the coefficients on the current and lagged month-on-month changes in the exchange rate. This pattern is familiar from price setting models with uniform-length staggered contracts à la Taylor (1980). However, the Taylor model implies constraints across coefficients on different variables. No such restrictions are imposed when estimating  $\beta_j$ ,  $\gamma_j$  and  $\delta_j$  in Eq. (3.6).

To estimate the average pass-through in Eq. (3.6), we set  $\beta_j = \beta$ ,  $\delta_j = \delta$ ,  $\gamma_j = \gamma$ , and  $\eta_j = \eta$ . The pass-through coefficient  $\hat{\beta} = 0.01660$  displayed in Figure 4 (first panel) has a straightforward interpretation. Under the assumption that the exchange rate follows a random walk, the elementary CPI indices considered in this paper ( $\alpha_j \geq 0.7$ ) increase by 0.01660 percent per month, or approximately 0.2 percent overall in 12 months, after the currency has weakened by 1 percent.

Turning to the relationship between exchange rate pass-through and price change volatility at the product-category level, Eq. (3.6) is estimated separately for each product category. The results are shown in Figure 4 (second panel), where the exchange rate pass-through coefficient  $\beta_j$  is plotted against the price change volatility  $Vol_j$  for each product category  $j$ . The slope of the regression line is positive, indicating that the exchange rate pass-through increases with the price change volatility.

When bins are constructed by ordering product categories by their price change volatility and Eq. (3.6) is estimated separately for each bin, we find again that the pass-through coefficient increases with the price change volatility. Figure 4 (third panel) shows that the pass-through coefficient in bin 3 is significantly higher than in bins 1 or 2.

Instead of estimating Eq. (3.6) separately for each bin or each product category, the relationship between pass-through and price change volatility can be examined using an interaction term. That is, the price change volatility  $Vol_j$  and its interaction with the exchange rate change are added to Eq. (3.6), yielding

$$\begin{aligned} \Delta p_{j,t} = & \beta \Delta e_{t,t-K} + \beta^{Vol} Vol_j \Delta e_{t,t-K} + \nu Vol_j \\ & + \gamma \Delta p_{t,t-K} + \delta \Delta p_{t,t-K}^* + \eta y_t + \epsilon_{j,t}. \end{aligned} \quad (3.7)$$

Estimation results for the average exchange rate pass-through  $\beta$  and for the coefficient on the interaction between the exchange rate change and price change volatility at the product category level,  $\beta^{Vol}$ , are displayed in Table 3. We find that  $\beta^{Vol}$  is positive and statistically significant at the 1 percent level. The pass-through increases with the price change volatility. A one standard-deviation increase in the price change volatility roughly increases the pass-through rate by nearly two-thirds.

**Product category-level price change volatility and the parameters affecting pass-through.** The empirical evidence presented so far supports the notion that there is a positive relationship between the price change volatility at the product category level and the level of pass-through. Elementary CPI categories with high price change volatility tend to have high exchange rate pass-through, and elementary CPI indices with low price change volatility tend to have low pass-through. There might be concern that these results could be explained by mechanical reverse causality. In line with Berger and Vavra (2013), we can rule out this concern as quantitatively irrelevant, based on the argument that the fraction of the variation in price change dispersion explained by the estimated heterogeneity in pass-through is tiny (< 1 percent on average).<sup>10</sup>

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<sup>10</sup>Because Berger and Vavra (2013) use micro-level import price data, whereas we use elementary CPI indices, the variance of price changes is smaller in our case, reflecting price stickiness and

We now take a closer look at the sources of the estimated heterogeneity in pass-through. According to Eq. (2.15), the average pass-through under Calvo-type pricing depends on the persistence of the exchange rate ( $\rho_e$ ) and a range of markup elasticities ( $\Gamma_j$ ), import intensities ( $\alpha_j$ ), and price stickiness parameters ( $\theta_j$ ). However, in the more general specifications (distributed lags, cumulative growth), the coefficients are in reduced form and lack a structural interpretation. Still, we may continue to think of these coefficients as being determined in some way by the parameters above. Figures 5 to 7 explore the relationship between these parameters on the one hand and the price change volatility on the other.

In the upper panel of Figure 5, the import shares ( $\alpha_j$ ) are plotted against the price change volatility ( $Vol_j$ ). The total of product categories is 76, and each point represents one product  $a$  in category. Import shares vary between 0.7 and 1, as the sample is restricted to product categories with import shares  $\alpha_j \geq 0.7$ . The price change volatilities range between 0.1 and 2.8, with most product categories clustered in the lower third of this range. One item (heating oil) stands out with a much larger price change volatility than the rest. The slope of the regression line suggests that product categories with higher import shares tend to have higher price change dispersions.

Supplementary to this representation, we order the product categories by price change volatility and then form terciles and construct three bins. The average import shares of these three bins are plotted against their average price change volatilities in the lower panel of Figure 5. The results show that the average import shares increase from bin 1 to bins 2 and 3, consistent with the notion that import shares tend to rise with price change volatilities. The 90 percent confidence interval of the first mean does not overlap with the corresponding intervals of the second and third means.

Next, we turn to the relationship between the degree of price stickiness and price change volatility. Figure 6 (upper panel) plots price durations against the price change dispersion of each product category, where price durations measure the average amount of time between two consecutive price changes for items of a given product category.<sup>11</sup> The durations vary between 0.8 and 32 months. The regression line slopes downward, indicating that product categories with longer price durations tend to have lower price change volatilities. Alternatively, we calculate the average price duration and the corresponding 90 percent confidence interval for the three bins described above. The results are plotted in the lower panel of Figure 6. They confirm that price durations are negatively correlated with price change volatilities. The average price durations decrease from bin 1 to bin 2 to bin 3. The

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aggregation. However, price stickiness also reduces the pass-through. The contribution of the variation in pass-through to the variation in price change volatility therefore continues to be very small.

<sup>11</sup>The relationship among price durations, frequencies of price changes and probabilities of non-adjustment ( $\theta_j$ ) is explained in Section 3.1.

90 percent confidence intervals of the three means do not overlap.

Estimates of the markup elasticities ( $\Gamma_j$ ) can be obtained by estimating Eq. (3.2) separately for each product category  $j$ . These estimates should not be taken too literally because they are derived from the model with Calvo-type price setting and because import shares and price durations are measured with some error. The resulting markup elasticities are plotted against price change volatilities in Figure 7 (upper panel). The estimated markup elasticities vary over a large range. Estimates above 20 and below  $-20$  are set to  $\pm 20$  to improve the chart's readability. The regression line (estimated on the correct scale) has a negative slope, suggesting that price change volatilities are lower at higher markup elasticities. Alternatively, we can calculate the average markup elasticity and the corresponding 90 percent confidence interval for the three bins described above. The results are plotted in the lower panel of Figure 7. The 90 percent confidence intervals are large and overlapping, which implies that the means of the markup elasticities in the three bins do not differ statistically from one another.

We conclude this exploratory analysis of the sources of the estimated heterogeneity in pass-through by extending Eq. (3.6) to include the standardized import shares  $\alpha_j$ , price durations  $Dur_j$ , markup elasticities  $\Gamma_j$ , and their interactions with the change in the exchange rate. The resulting equation can be written as

$$\begin{aligned} \Delta p_{j,t} = & \beta \Delta e_{t,t-K} + \beta^\alpha \alpha_j \Delta e_{t,t-K} + \zeta \alpha_j + \beta^{Dur} Dur_j \Delta e_{t,t-K} + \lambda Dur_j \\ & + \beta^\Gamma \Gamma_j \Delta e_{t,t-K} + \nu \Gamma_j + \gamma \Delta p_{t,t-K} + \delta \Delta p_{t,t-K}^* + \eta y_t + \epsilon_{j,t}. \end{aligned} \quad (3.8)$$

Estimation results for the average exchange rate pass-through ( $\beta$ ) and for the various interaction terms with the exchange rate change ( $\beta^\alpha$ ,  $\beta^{Dur}$ ,  $\beta^\Gamma$ ) are summarized in Table 3. When each of the three variables (and the corresponding interaction term) is included alternately, we find the coefficient  $\beta^{Dur}$  to be negative and statistically significant, which implies a positive relationship between the pass-through and the price adjustment frequency.<sup>12</sup> However, there are no discernible effects from the import share and the markup elasticity. Overall, these findings suggest that the heterogeneity in the degree of nominal price stickiness, as measured by the average duration between price changes is an important factor in explaining heterogeneity in pass-through and thus heterogeneity in price change volatility.

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<sup>12</sup>This corresponds to the findings in Gopinath and Itskhoki (2010). Using US import prices, they document that, on average, goods with high adjustment frequencies have higher exchange rate pass-through.

### 3.4 Month-level dispersion of price changes across product categories and pass-through

In this section, we examine whether the degree of medium-run pass-through changes over time with the cross-sectional dispersion of changes in the elementary CPI indices. In parallel with Section 3.3, three specifications are considered, one derived from the theoretical framework with Calvo pricing and other two without the constraints imposed by the Calvo assumption.

**Results for specification derived from model with Calvo pricing.** The interquartile range  $IQR_t$  displayed in Figure 1 is a measure of the month-level dispersion of price changes across product categories. The range is quite volatile, moving up and down over the period May 2000 to May 2016. To examine the correlation with pass-through, we order the data by month-level price change dispersion, calculate the median and form two bins. Eq. (3.2) is estimated separately for each bin.

The results for the exchange rate pass-through are displayed in Figure 8 (first panel). Again the pass-through coefficients are calculated as  $\hat{\beta}^* \alpha_j \theta_j^k (1 - \theta_j)$ ,  $\forall k = 0, 1, \dots, 30$ , implying the geometrically falling pattern imposed by the Calvo assumption of price rigidity. The point estimates of coefficients are higher in bin 2 than in bin 1, but the coefficients do not differ significantly between the two bins.

Alternatively, we can add the (standardized) month-level dispersion of price changes across product categories,  $IQR_t$ , and its interaction with the current and lagged exchange rate changes to Eq. (3.2). The resulting equation takes the form

$$\begin{aligned} \Delta p_{j,t} = & \beta^* \sum_{k=0}^K \alpha_j \theta_j^{k+1} \Delta e_{t-k} + \beta^{*IQR} \sum_{k=0}^K \alpha_j \theta_j^{k+1} IQR_t \Delta e_{t-k} + \tau^* IQR_t \\ & + \gamma^* \sum_{k=0}^K \theta_j^{k+1} \Delta p_{t-k} + \delta^* \sum_{k=0}^K \theta_j^{k+1} \Delta p_{t-k}^* + \eta^* \theta_j y_t + \epsilon_{j,t}, \end{aligned} \quad (3.9)$$

where  $K = 30$ . Selected estimation results are presented in Table 4. The estimate of  $\beta^{*IQR}$  is positive and statistically significant at the 1 percent level, indicating that the pass-through varies over time with the cross-sectional dispersion of price changes. The degree of pass-through increases with the level of  $IQR_t$ .

**Results for a more general specification: distributed lags.** The estimation of the reduced-form coefficients in Eq. (3.4) is less restrictive than the estimation of Eq. (3.2). Estimating Eq. (3.4) separately for the two bins characterized by the month-level dispersion of price changes across product categories gives the results displayed in Figure 8 (second

panel).

The  $\beta_k$ -coefficients line up nicely in bin 2, the months with the higher  $IQR_t$  values. The pass-through coefficients increase up to lag 4 and then decline, showing an inverted U-shaped curve. There is no such pattern in bin 1, the months with the lower  $IQR_t$  values. The sum of the estimated  $\beta_k$ -coefficients is clearly higher in bin 2 than in bin 1.

To examine the relationship between the month-level dispersion of price changes and pass-through in an equation with interaction terms, we estimate

$$\begin{aligned} \Delta p_{j,t} = & \sum_{k=0}^K \beta_k \Delta e_{t-k} + \sum_{k=0}^K \beta_k^{IQR} IQR_t \Delta e_{t-k} + \tau IQR_t \\ & + \sum_{k=0}^K \gamma_k \Delta p_{t-k} + \sum_{k=0}^K \delta_k \Delta p_{t-k}^* + \eta y_t + \epsilon_{j,t}, \end{aligned} \quad (3.10)$$

where  $K = 11$ . Table 5 shows the coefficients on the changes in the exchange rate ( $\beta_k$ ) and those on the interaction terms with the month-level dispersion of price changes ( $\beta_k^{IQR}$ ). We are mainly interested in the coefficients on the interaction terms  $\beta_k^{IQR}$ . They all are positive, and most of them are statistically significant at the 1 or 5 percent level. The largest  $\beta_k^{IQR}$  are those at lags 4 to 7. An F-test rejects the null that the coefficients are jointly zero.

**Results for a more general specification: cumulative growth rates.** Similarly, we can estimate Eq. (3.6) separately for the two bins defined by month-level dispersion of price changes across product categories. The results displayed in Figure 8 (third panel) indicate that the medium-run pass-through is higher in bin 2 than in bin 1, implying that the degree of pass-through is higher in times of large cross-sectional price change dispersion. The 90 percent confidence intervals do not overlap.

To obtain a finer picture of the relationship between  $IQR_t$  and pass-through, we estimate the equation

$$\begin{aligned} \Delta p_{j,t} = & \beta \Delta e_{t,t-K} + \beta^{IQR} IQR_t \Delta e_{t,t-K} + \tau IQR_t + \gamma \Delta p_{t,t-K} \\ & + \delta \Delta p_{t,t-K}^* + \eta y_t + \epsilon_{j,t}, \end{aligned} \quad (3.11)$$

where  $K = 12$ . The estimation results for the average pass-through ( $\beta$ ) and the interaction term between the month-level dispersion of price changes and the exchange rate changes ( $\beta^{IQR}$ ) are presented in Table 6. They show that  $\beta^{IQR}$  is positive and statistically significant at the 1 percent level. This implies a positive relationship between the cross-sectional price change dispersion and the exchange rate pass-through. A one-standard-deviation increase in  $IQR_t$  raises the pass-through by approximately 60 percent.

Overall, the results presented in this section indicate that the pass-through varies over time with the dispersion of price changes across product categories. The medium-run pass-through is not a constant but is above the average pass-through in periods with high cross-sectional price change dispersion and is below that average in periods with low cross-sectional price change dispersion.

## 4 Time variation in pass-through from 2001 to 2016

This section presents estimates of the time-varying pass-through to consumer prices in Switzerland from 2001 to 2016. We begin with calculations based on the empirical evidence reported in Section 3.4. These results are then compared with pass-through estimates from regressions over rolling windows. Finally, the focus on product categories with an import share of greater than or equal to 70 percent is removed in order to obtain a fuller picture of the pass-through to consumer prices.

**Time variation in pass-through to prices of product categories with  $\alpha \geq 0.7$  percent.** The estimation results of Eq. (3.11) reported in Table 6 serve as our stepping stone for calculating a time series of the time-varying pass-through from April 2001 to May 2016. The estimated pass-through in each period is calculated as

$$\widehat{PT}_{IQR,t} = \hat{\beta} + \hat{\beta}^{IQR} IQR_t,$$

using the observed values of  $IQR_t$  and the estimated coefficients from Table 6. The results presented in Figure 9 (upper panel) show that the pass-through increased sharply in 2011/2. This was a period characterized by an appreciating Swiss franc, downward pressure on prices, and a deteriorating economic outlook. Other periods with relatively high levels of estimated pass-through are 2001/2, 2008 and 2015. The results suggest substantial fluctuations in pass-through rates at business cycle frequencies. For example, the estimated pass-through in 2011/2 is more than twice as large as the average pass-through.

Following Berger and Vavra (2013), we compare these pass-through estimates with estimates from a more general model. The more general model allows the pass-through to vary with both the month-level dispersion of inflation rates and real activity. Real activity is measured by the output gap, which represents the cyclical level of real GDP. The output gap shows the extent to which the economy is running above or below its potential level. The estimated pass-through in each period, then, is calculated as

$$\widehat{PT}_{all,t} = \hat{\beta} + \hat{\beta}^{IQR} IQR_t + \hat{\beta}^y y_t,$$

where  $\hat{\beta}^y$  is the estimated coefficient on the interaction term  $y_t \Delta e_{t,t-K}$ . The results presented in Figure 9 (lower panel) are very similar to those for the IQR effects. The difference between the two time series is attributable to the output gap.

**Pass-through regressions over rolling windows.** Alternative estimates of time-varying pass-through can be obtained by estimating a basic pass-through equation over rolling windows. The estimates give rise to a time-varying pass-through path that does not draw on the effect of variables such as  $IQR_t$  or the output gap on pass-through.

Thus, Eq. (3.6) is estimated over rolling windows of 36 months, which gives one estimate of the pass-through coefficient  $\beta$  for each month:

$$\widehat{PT}_{rw,t} = \hat{\beta}_t,$$

where  $\hat{\beta}_t$  is the pass-through coefficient estimated over the 36-month period up until time  $t$ . The resulting path of pass-through coefficients is displayed in Figure 10. The chart suggests peaks at the beginning and end of the estimation period, as well as in 2007/8 and in 2011/2, largely coinciding with peaks in Figure 9. However, the amplitude of the fluctuations in pass-through is larger than in Figure 9. The pass-through is temporarily negative, albeit just for a short time when the 90 percent confidence interval is accounted for. Then again, the pass-through rises significantly higher in 2007/8, suggesting that the cross-sectional price change dispersion (and the output gap) cannot adequately explain the rise in pass-through during that period.

### **Dropping limitations on the range of CPI product categories considered.**

The empirical analysis up to this point has focused on CPI product categories with import shares greater than or equal to 70 percent. To obtain a more complete representation of the pass-through to consumer prices, this restriction on import shares is now done away with. However, one might still argue that there is no point in including regulated or administered prices, as these prices are not determined by market forces. Hence, we consider the case without regulated CPI prices first before we consider the full CPI.<sup>13</sup>

With the import share restriction dropped but regulated prices excluded, the number of product categories rises from 76 to 191, representing approximately 60 percent of the CPI basket. The average pass-through is estimated in Eq. (3.6), setting  $\beta_j = \beta$ ,  $\delta_j = \delta$ ,  $\gamma_j = \gamma$ , and  $\eta_j = \eta$ . The estimated pass-through coefficient  $\hat{\beta}$  reported in Table 6 (fourth column) is smaller than that obtained for product categories with  $\alpha_j \geq 0.7$  (second column). The

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<sup>13</sup>None of the product categories with import shares  $\alpha_j \geq 0.7$  has regulated prices. Consequently, the distinction is relevant only for product categories with lower or zero import shares.



difference is consistent with the notion that the pass-through increases with the import share.

Turning to the time-varying pass-through, we estimate Eq. (3.11) to allow the pass-through to move with the month-level price change dispersion across product categories  $IQR_t$ . The results reported in Eq. (3.6) (fifth column) indicate that both  $\hat{\beta}$  and  $\hat{\beta}^{IQR}$  are lower when  $\alpha_j \geq 0.7$  is dropped, but they remain positive and statistically significant at the 1 percent level. Figure 11 (upper panel) shows the corresponding time series (in red) computed as  $\widehat{PT}_{IQR,t} = \hat{\beta} + \hat{\beta}^{IQR}IQR_t$ , using the observed values of  $IQR_t$  and the estimated coefficients from Table 6. Not surprisingly, the average level and the amplitude of the variations in the pass-through decline when all CPI product categories except those with regulated prices are considered.

Finally, to obtain a measure of the pass-through of exchange rate changes to the full set of CPI elementary indices, we assume zero pass-through to regulated prices. The 31 product categories with regulated prices represent approximately 40 percent of the CPI basket. Accounting for these products and setting the pass-through to their prices to zero reduces the average level and the time variation of the estimated pass-through accordingly. Figure 11 (lower panel) shows the corresponding effects on the estimated time series of exchange rate pass-through to consumer prices.

With the regulated prices accounted for and the pass-through to these prices set to zero, the estimated average pass-through coefficient in Eq. (3.6) decreases from 0.01017 to 0.006102, reflecting the weight of regulated prices in the CPI basket. The estimated medium-run pass-through over twelve months thus amounts to 0.073. This is in the same ball park as estimates from other studies. [Stulz \(2007\)](#) finds in a VAR model estimated on Swiss data over the period May 1993 to December 2004 that the CPI increases by approximately 0.05 percent within twelve months in response to a 1 percent depreciation of the Swiss franc.

## 5 Conclusions

As [Berger and Vavra \(2013\)](#) forcefully argue, documenting time variation in exchange rate pass-through is at least as important for policy making as measuring average pass-through. In this paper, we have examined the role of the dispersion of price changes across time and across product categories for the medium-run pass-through to consumer prices in data for Switzerland. The price data are elementary CPI indices of product categories with import shares of 70 percent or more. The results indicate that the exchange rate pass-through co-moves with measures of price change dispersion. Product categories with high price change

volatility tend to have a higher pass-through than product categories with low price change volatility. Similarly, the pass-through tends to be higher in times with high cross-sectional price change dispersion than in times with low cross-sectional price change dispersion. The pass-through of exchange rate changes to consumer prices has varied over the period from 2001 to 2016 with the dispersion of inflation rates across product categories. Furthermore, fluctuations in pass-through predicted by the cross-sectional dispersion of price changes coincide to a remarkable extent with those resulting from estimations of basic pass-through equations over rolling windows.

The results presented in this paper are broadly in line with those reported by [Berger and Vavra \(2013\)](#) for the exchange rate pass-through in US import prices. However, the relationship between price change dispersion and pass-through is weaker in our data set. On the one hand, this confirms the picture from the empirical literature on exchange rate pass-through that the pass-through rate is lower to retail prices than to import prices. On the other hand, the data used by Berger and Vavra allow these authors to control for other factors in a way that we cannot. Berger and Vavra consider price changes for individual items, conditional on adjustment, and make full use of their information on the relevant bilateral exchange rate. By contrast, we deal with index changes at the product category level, i.e., the lowest aggregation level in the CPI. As a result, we make assumptions on price stickiness, and we employ an index of the effective exchange rate.

The results suggest that the relationship found by Berger and Vavra for US import prices extends to other countries with very different degrees of openness. They also suggest that whatever happens at the import stage is not being undone by forces further down the pricing chain. Using elementary CPI indices rather than micro-level price changes may limit, to some extent, the details of what can be done and learned from this exercise. However, elementary CPI indices have the advantage of being readily available month after month and without delays. This suggests that the month-level dispersion of inflation rates calculated from these data can be used in real time as an indicator of time variation in the degree of exchange rate pass-through to consumer prices.

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Table 1: Pass-through estimates under Calvo pricing: product-category-level volatility specification

	Eq. (3.2)	Eq. (3.3)
$\beta^*$	0.17642*** (4.419e-02)	0.16029*** (4.649e-02)
$\beta^{Vol}$		0.01499 (1.804e-02)
Observations	12,388	12,388
Robust standard errors in parentheses		
*** p<0.01, ** p<0.05, * p<0.1		

Table 2: Pass-through estimates with exchange rate changes as distributed lags: product-category-level volatility specification

	Eq. (3.4)		Eq. (3.5)	
$\beta_0$	0.00891**	-4.00E-03	0.00891**	-4.21E-03
$\beta_1$	0.01403***	-3.47E-03	0.01403***	-3.74E-03
$\beta_2$	0.01362***	-3.55E-03	0.01362***	-3.78E-03
$\beta_3$	0.01172***	-3.65E-03	0.01172***	-3.63E-03
$\beta_4$	0.01464***	-4.27E-03	0.01464***	-4.06E-03
$\beta_5$	0.01439***	-4.95E-03	0.01439***	-4.74E-03
$\beta_6$	0.01516***	-5.24E-03	0.01516***	-5.00E-03
$\beta_7$	0.01670***	-4.87E-03	0.01670***	-4.41E-03
$\beta_8$	0.01582***	-4.79E-03	0.01582***	-4.16E-03
$\beta_9$	0.01318***	-4.67E-03	0.01318***	-4.18E-03
$\beta_{10}$	0.01155***	-4.25E-03	0.01155***	-4.17E-03
$\beta_{11}$	0.00767**	-3.82E-03	0.00767*	-4.18E-03
$\beta_0^{Vol}$			0.01385***	-3.86E-03
$\beta_1^{Vol}$			0.02102***	-3.02E-03
$\beta_2^{Vol}$			0.02108***	-2.70E-03
$\beta_3^{Vol}$			0.01527***	-5.22E-03
$\beta_4^{Vol}$			0.01556**	-6.18E-03
$\beta_5^{Vol}$			0.01118	-7.04E-03
$\beta_6^{Vol}$			0.01100*	-5.99E-03
$\beta_7^{Vol}$			0.01429***	-4.94E-03
$\beta_8^{Vol}$			0.01609***	-3.96E-03
$\beta_9^{Vol}$			0.02533***	-4.81E-03
$\beta_{10}^{Vol}$			0.02996***	-7.92E-03
$\beta_{11}^{Vol}$			0.03017***	-1.10E-02
Observations	13,832		13,832	
R-squared	0.124		0.139	
F-test, $\beta$ , prob	1.96E-05		0	
F-test, $\beta^{Vol}$ , prob			0	

Robust standard errors in parentheses

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Table 3: Pass-through estimates with exchange rate changes as cumulative change: product-category-level volatility specification

	Eq. (3.6)	Eq. (3.7)	Eq. (3.8)	Eq. (3.8)	Eq. (3.8)	Eq. (3.8)
$\beta$	0.01660*** (2.815e-03)	0.01660*** (2.131e-03)	0.01660*** (2.802e-03)	0.01660*** (2.656e-03)	0.01660*** (2.818e-03)	0.01660*** (2.630e-03)
$\beta^{Vol}$		0.01909*** (2.263e-03)				
$\beta^\alpha$			0.00356 (3.205e-03)			-0.00004 (3.285e-03)
$\beta^{Dur}$				-0.01100*** (2.609e-03)		-0.01188*** (3.325e-03)
$\beta^\Gamma$					-0.00001 (5.914e-06)	0.00003** (1.400e-05)
Observations	13,832	13,832	13,832	13,832	13,832	13,832
R-squared	0.110	0.124	0.110	0.114	0.110	0.115

Robust standard errors in parentheses

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Table 4: Pass-through estimates under Calvo pricing: month-level volatility specification

	Eq. (3.2)	Eq. (3.9)
$\beta^*$	0.17642*** (4.419e-02)	0.11628*** (3.991e-02)
$\beta^{*IQR}$		0.07423*** (2.656e-02)
Observations	12,388	12,388
Robust standard errors in parentheses		
*** p<0.01, ** p<0.05, * p<0.1		



Table 5: Pass-through estimates with exchange rate changes as distributed lags: month-level volatility specification

	Eq. (3.4)		Eq. (3.10)	
$\beta_0$	0.00891**	-4.00E-03	0.00950**	-4.20E-03
$\beta_1$	0.01403***	-3.47E-03	0.01373***	-4.14E-03
$\beta_2$	0.01362***	-3.55E-03	0.00984**	-4.49E-03
$\beta_3$	0.01172***	-3.65E-03	0.00466	-4.99E-03
$\beta_4$	0.01464***	-4.27E-03	0.0045	-6.01E-03
$\beta_5$	0.01439***	-4.95E-03	0.0029	-6.30E-03
$\beta_6$	0.01516***	-5.24E-03	0.00487	-6.08E-03
$\beta_7$	0.01670***	-4.87E-03	0.00793	-5.37E-03
$\beta_8$	0.01582***	-4.79E-03	0.01034*	-5.40E-03
$\beta_9$	0.01318***	-4.67E-03	0.00704	-6.17E-03
$\beta_{10}$	0.01155***	-4.25E-03	0.00239	-5.94E-03
$\beta_{11}$	0.00767**	-3.82E-03	0.00256	-5.59E-03
$\beta_0^{IQR}$			0.00264	-3.82E-03
$\beta_1^{IQR}$			0.00626*	-3.51E-03
$\beta_2^{IQR}$			0.00705**	-3.31E-03
$\beta_3^{IQR}$			0.00844**	-3.31E-03
$\beta_4^{IQR}$			0.01151***	-3.84E-03
$\beta_5^{IQR}$			0.01266***	-4.04E-03
$\beta_6^{IQR}$			0.01272***	-4.20E-03
$\beta_7^{IQR}$			0.01152***	-4.05E-03
$\beta_8^{IQR}$			0.00775**	-3.26E-03
$\beta_9^{IQR}$			0.00736**	-3.16E-03
$\beta_{10}^{IQR}$			0.01047**	-4.40E-03
$\beta_{11}^{IQR}$			0.00611	-5.91E-03
Observations	13,832		13,832	
R-squared	0.124		0.127	
F-test, $\beta$ , prob	1.96E-05		8.18E-07	
F-test, $\beta^{IQR}$ , prob			0.000343	

Robust standard errors in parentheses

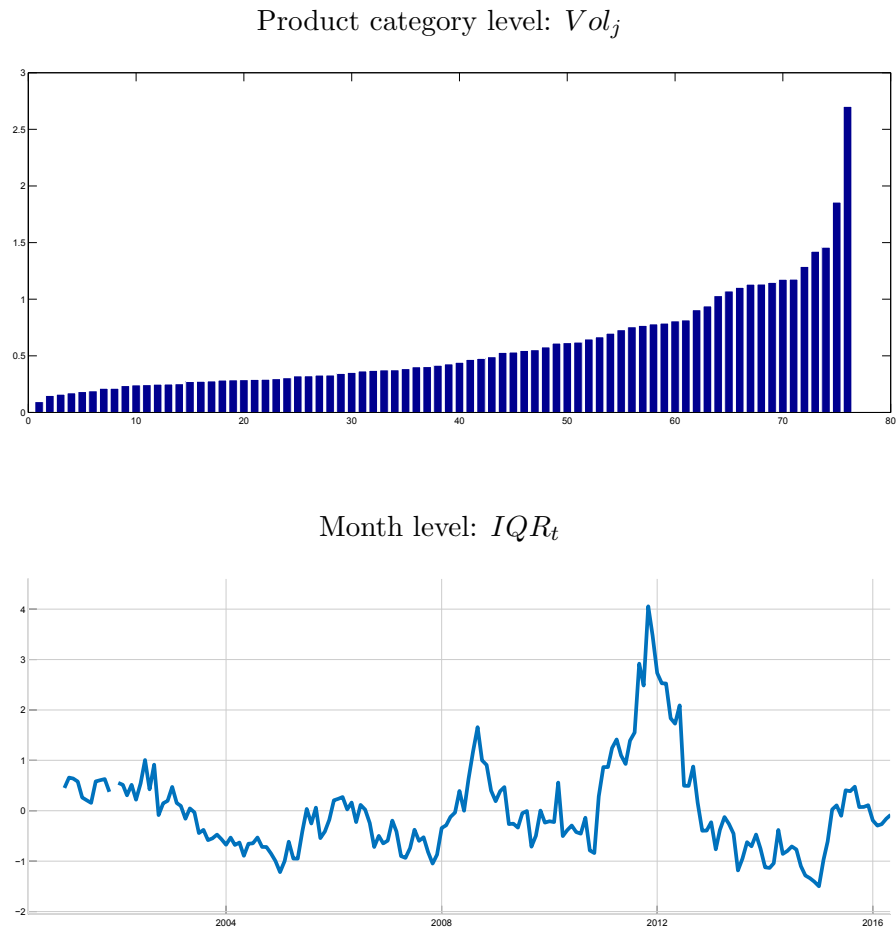
\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Table 6: Pass-through estimates with exchange rate changes as cumulative change: month-level volatility specification

	CPI categories with imp. share $\geq 70\%$ , excl. regulated prices		All CPI categories, excl. regulated prices	
	Eq. (3.6)	Eq. (3.11)	Eq. (3.6)	Eq. (3.11)
$\beta$	0.01660*** (2.815e-03)	0.01144*** (3.251e-03)	0.01017*** (1.473e-03)	0.00814*** (1.677e-03)
$\beta^{IQR}$		0.00710*** (2.412e-03)		0.00580*** (1.299e-03)
Observations	13,832	13,832	34,571	34,571
R-squared	0.110	0.112	0.094	0.096

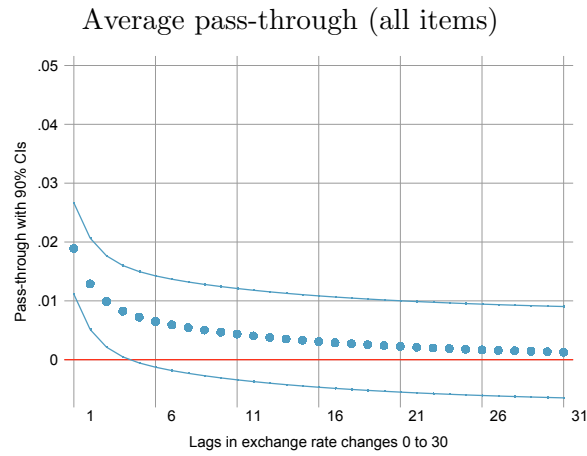
Robust standard errors in parentheses  
\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Figure 1: Price change dispersion

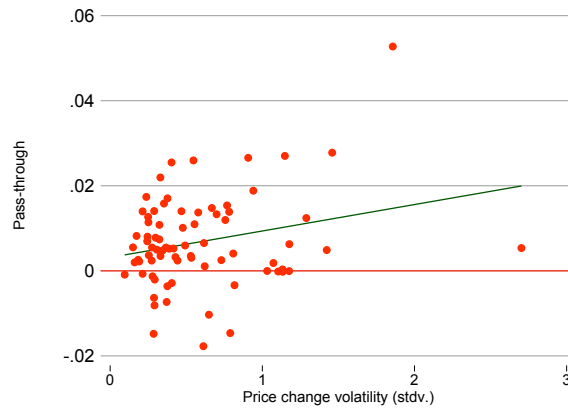


*Notes:* All elementary CPI indices except product categories with regulated prices. Price index changes are month-on-month.  $Vol_j$  is calculated as the standard deviation of monthly price index changes over the period May 2000 to May 2016.  $IQR_t$  is the average over 12 months of standardized interquartile ranges of monthly price index changes.

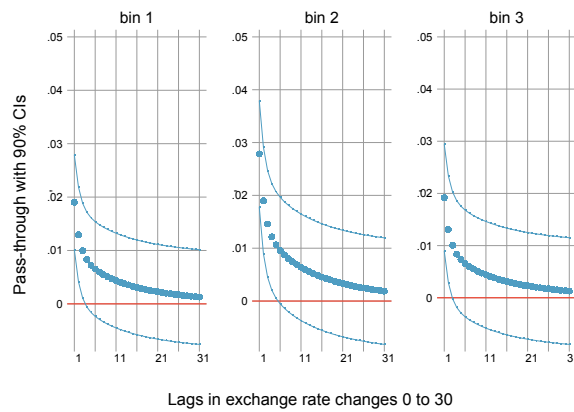
Figure 2: Pass-through under Calvo pricing



Pass-through and price change dispersion (individual items)

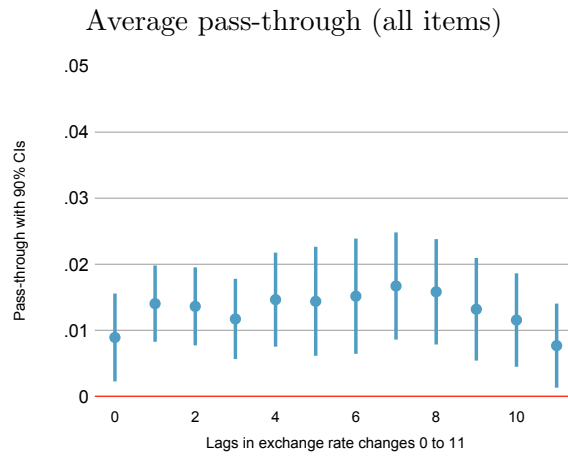


Pass-through and price change dispersion (3 bins)

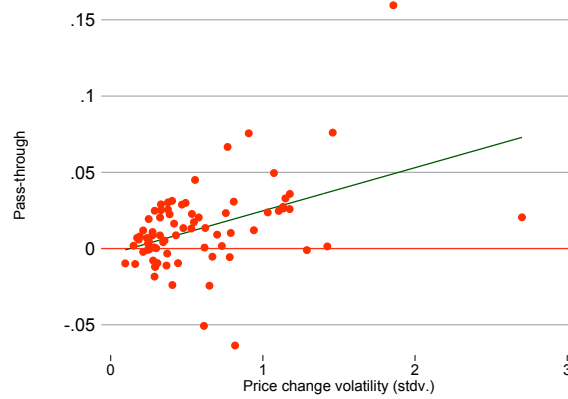


*Notes:* Estimation of Eq. (3.2), data for period May 2000 to May 2016. Pass-through under Calvo-type price setting calculated as  $\hat{\beta}^* \alpha_j \theta_j^k (1 - \theta_j)$  for  $k = 0, 1, \dots, 30$ . LSDV method (fixed effects) in first and third charts; least squares regressions listed separately for each item in second chart. Bins are constructed based on ordering by price change dispersion.

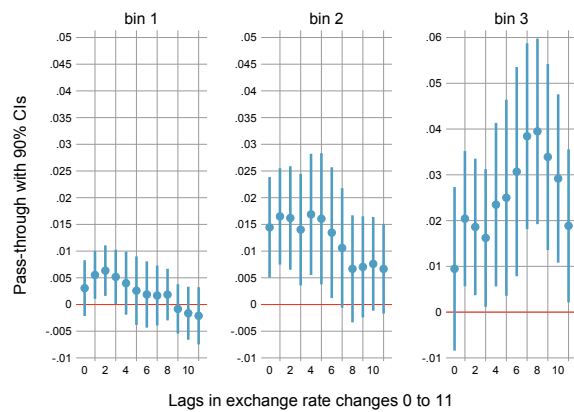
Figure 3: Pass-through estimate distributed lag model



Pass-through and price change dispersion (individual items)

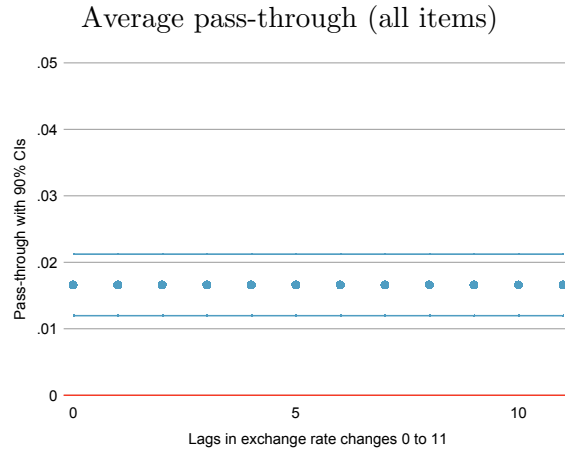


Pass-through and price change dispersion (3 bins)

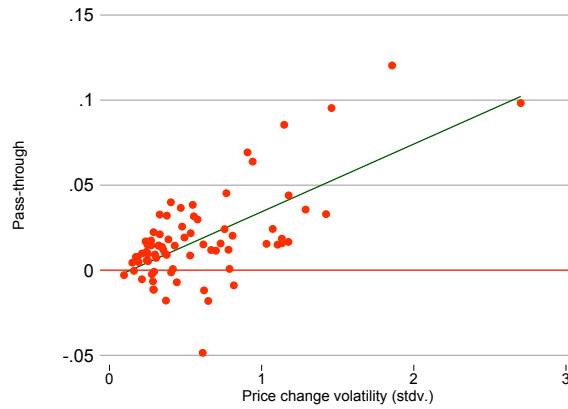


*Notes:* Estimation of Eq. (3.4), data for period May 2000 to May 2016. LSDV method (fixed effects) in first and third charts; least squares regressions listed separately for each item in second chart. Bins are constructed based on ordering by price change dispersion.

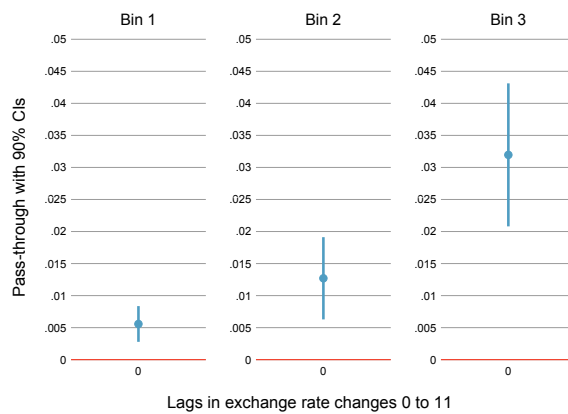
Figure 4: Pass-through estimates, cumulative growth model



Pass-through and price change dispersion (individual items)

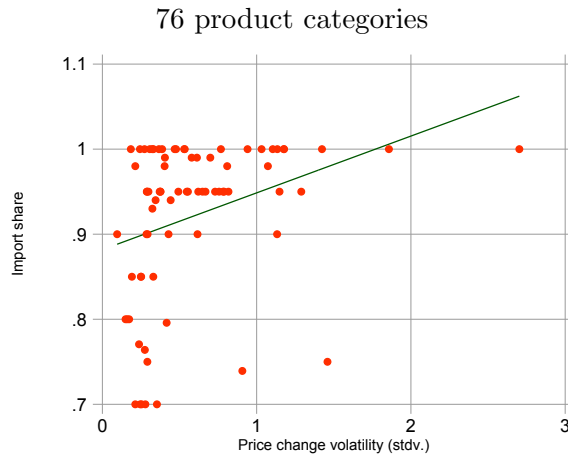


Pass-through and price change dispersion (3 bins)

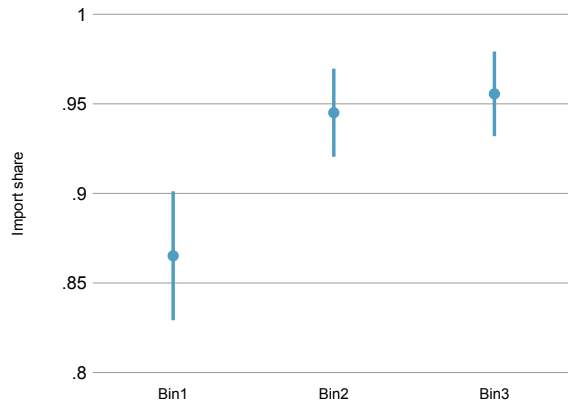


*Notes:* Estimation of Eq. (3.6), LSDV method, data for period May 2000 to May 2016. LSDV method (fixed effects) in first and third charts; least squares regressions listed separately for each item in second chart. Bins are constructed based on ordering by price change dispersion.

Figure 5: Import shares and price change volatilities

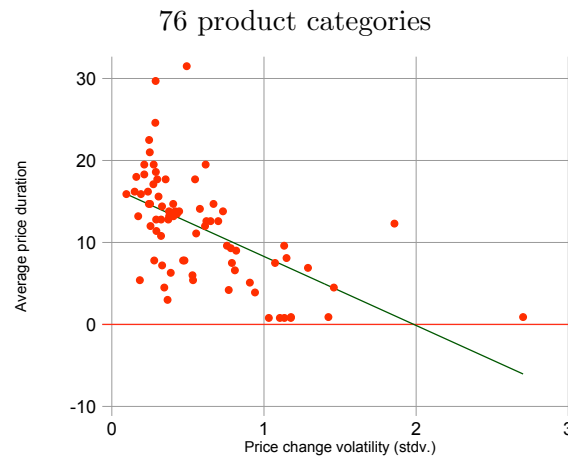


Bins based on ordering of product categories by price change volatility

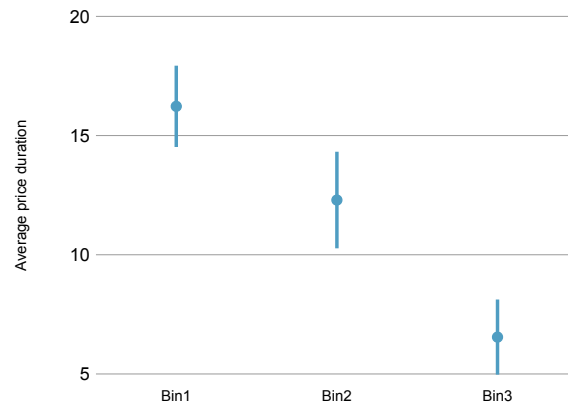


*Notes:* Regression line in the first chart describes the average relationship between import share and price change volatility of the 76 product categories. Bins are constructed based on ordering of product categories by price change volatility. 90 percent confidence intervals are displayed in the second chart.

Figure 6: Price durations and price change volatilities



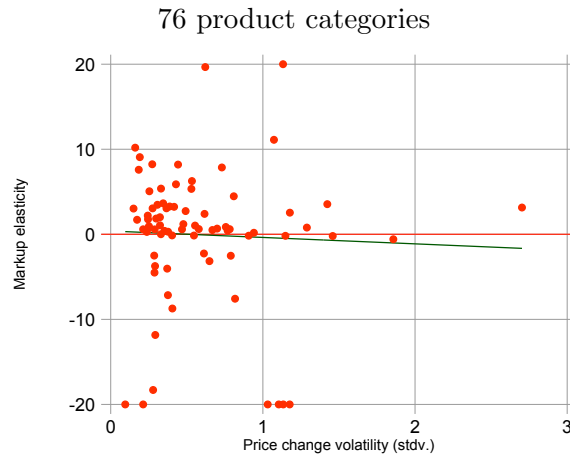
Bins based on ordering of product categories by price change volatility



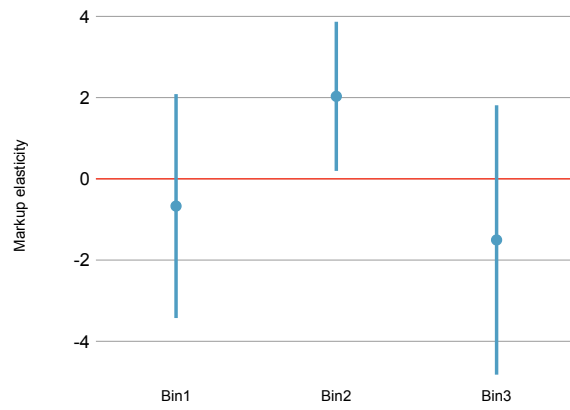
*Notes:* Regression line in the first chart describes the average relationship between price duration and price change volatility of the 76 product categories. Bins are constructed based on ordering of product categories by price change volatility. 90 percent confidence intervals are displayed in the second chart.



Figure 7: Markup elasticity and price change volatilities

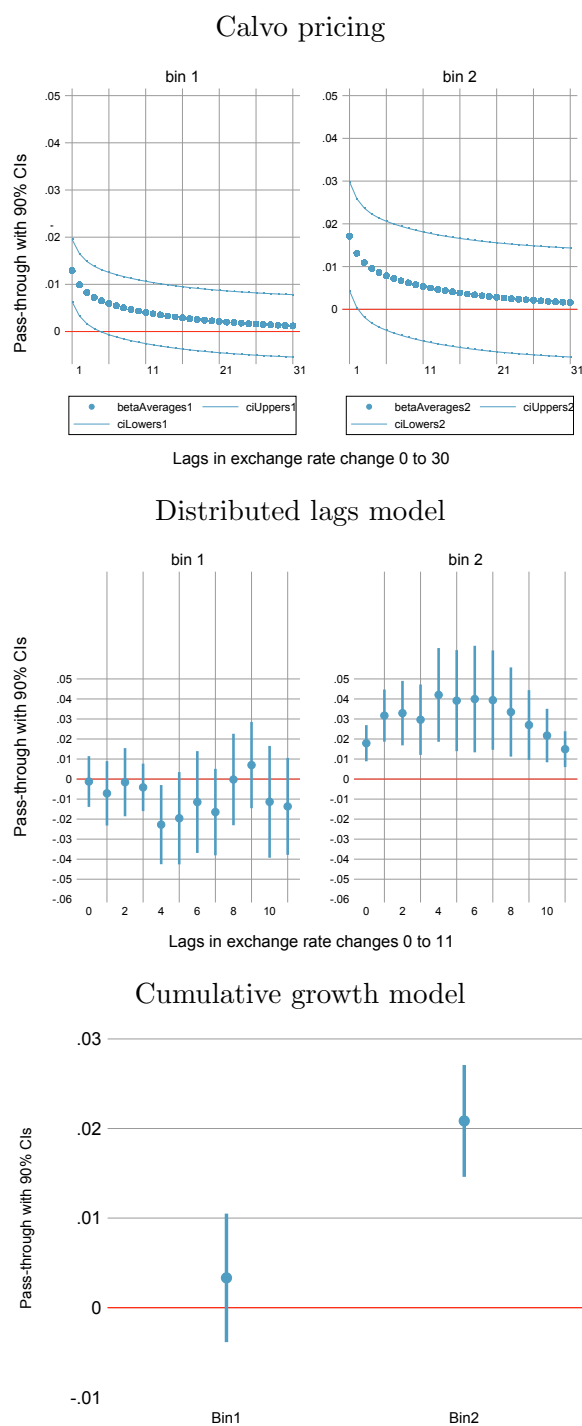


Bins based on ordering of product categories by price change volatility



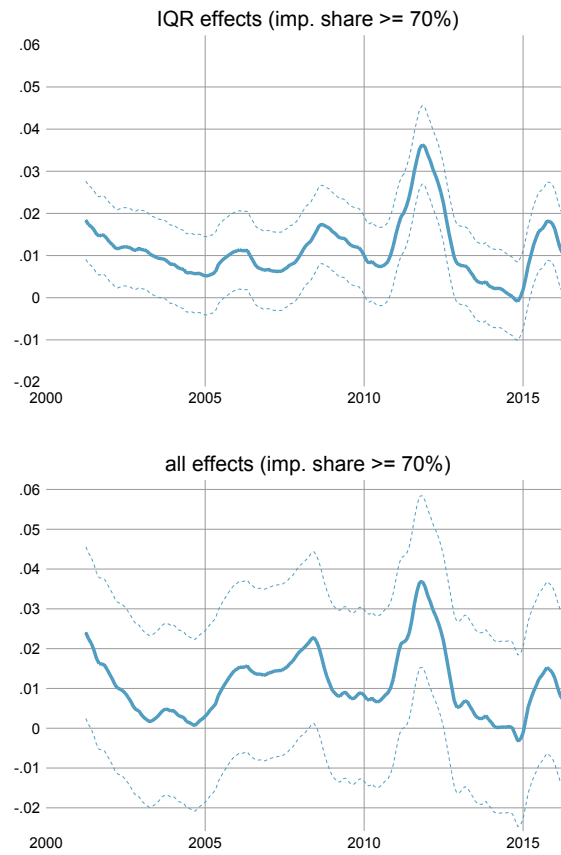
*Notes:* Regression line in the first chart describes the average relationship between markup elasticity and price change volatility of the 76 product categories. Estimates for markup elasticities are obtained based on estimation of Eq. (3.2) separately for each product category. Bins are constructed based on ordering of product categories by price change volatility. 90 percent confidence intervals are displayed in the second chart.

Figure 8: Pass-through estimates and month-level dispersion



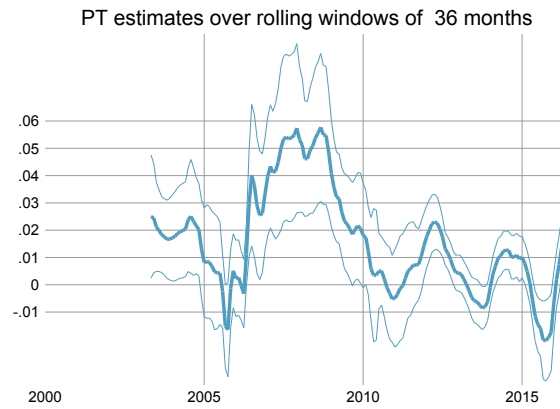
*Notes:* Estimation of Eq. (3.2), Eq. (3.4) and Eq. (3.6). LSDV method, data for period May 2000 to May 2016. Pass-through in Calvo-type specification calculated as  $\hat{\beta}^* \alpha_j \theta_j^k (1 - \theta_j)$  for  $k = 0, 1, \dots, 30$ .

Figure 9: Time variation in pass-through



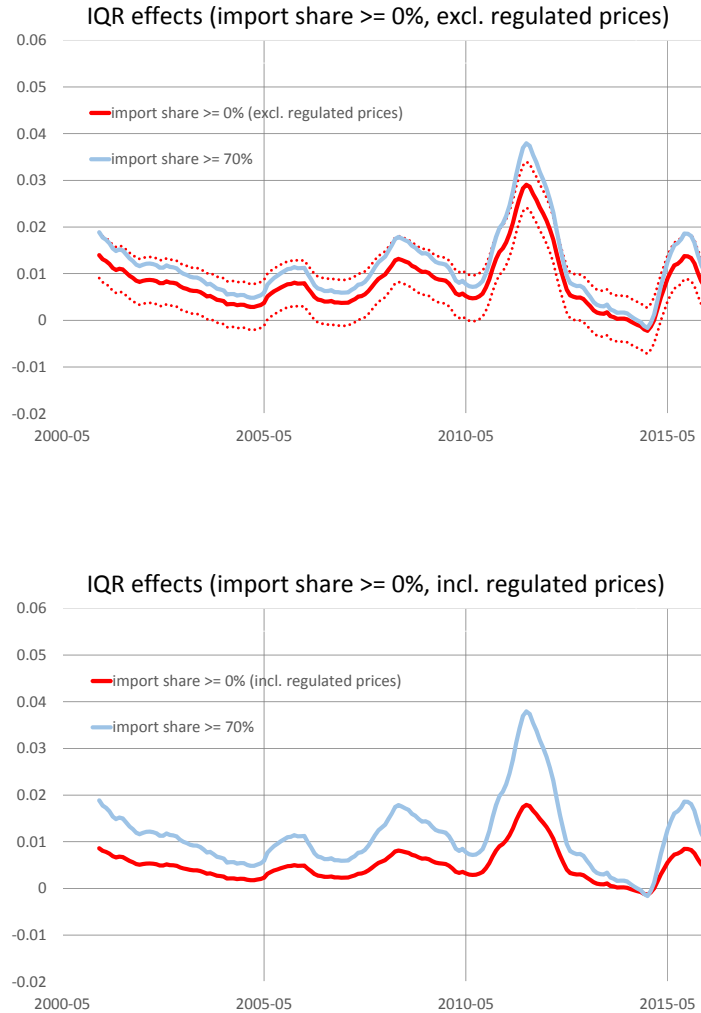
*Notes:* Estimation of Eq. (3.11) and variant thereof that includes term for interaction between output gap and exchange rate change, LSDV method, data for period May 2000 to May 2016. 90 percent confidence intervals.

Figure 10: Time variation in pass-through: estimates over rolling windows



*Notes:* Estimation of Eq. (3.6) over rolling windows of 36 quarters, LSDV method, data for period May 2000 to May 2016, 90 percent confidence intervals.

Figure 11: Time variation in pass-through to prices of larger sets of CPI product categories

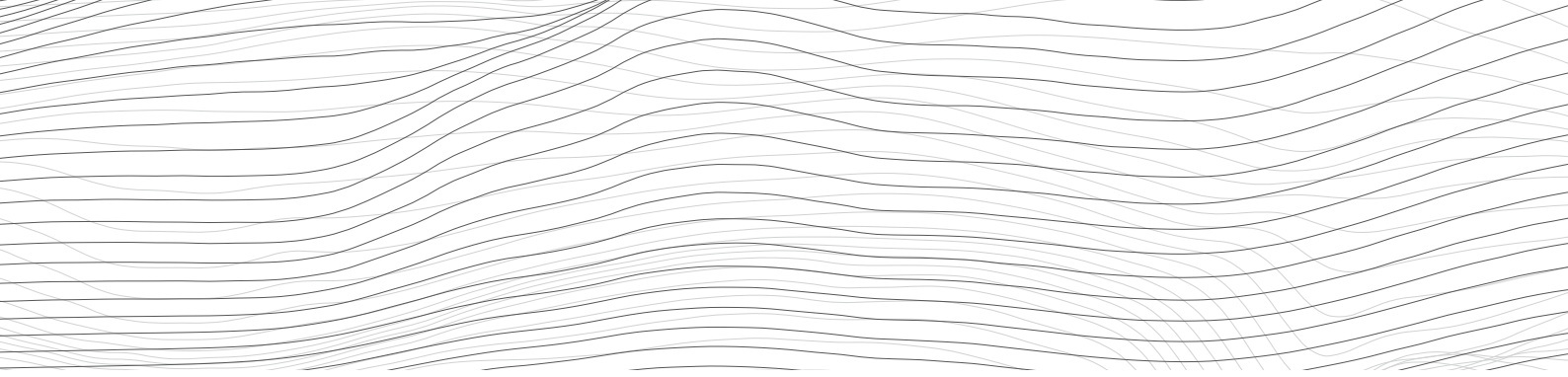


*Notes:* Time-varying pass-through estimates when CPI product categories considered are not limited to those with import share  $\alpha_j \geq 0.7$ . Two versions: without regulated prices (upper panel) and with regulated prices (lower panel), where the latter corresponds to the complete set of CPI product categories. Results for CPI product categories with import share  $\alpha_j \geq 0.7$  are repeated from Figure 9.

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