Volatility and Pass-through

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Introduction

We document a robust positive relationship between the dispersion of price changes and exchange rate pass-through:

- Items with high price change dispersion have high pass-through
- Months with high price change dispersion have high pass-through
Pass-through is not a single number: it varies across time

- Average pass-through from 1994-2012 is 15%
- But prices dispersion varies a lot across time and ignoring micro data leads to huge time-varying bias
- Pass-through varies from 8% in 1997 to upwards of 40% in 2008
Empirical evidence that micro heterogeneity matters

- If we want to know the IRF of a macro variable to a shock or change in policy, how much attention needs to be paid to the distribution of agents in the economy?
- Long-standing, largely model driven debate
- What would direct empirical evidence that micro matters for IRF look like?
  - Measure an observed aggregate shock
  - Measure the observed IRF of an aggregate variable
  - Show this observable IRF varies with micro
- We will do exactly this in a particular context where it is feasible
  - The response of import prices to an exchange rate shock depends on the dispersion of price changes that vary across time
To now, everything is empirical, but what might explain relationship between price change dispersion and pass-through?

Imperfect "responsiveness" has been embraced by literature to explain incomplete pass-through

But if there is heterogeneity, has additional implications

If some firms are more "responsive" to shocks at some points in time:
- Should have more disperse price changes
- Should have higher exchange rate pass-through
Formally Understanding Our Empirical Results

Quantifying the importance of various channels:

- Build and formally estimate model of exporting price-setters with heterogeneity affecting price change dispersion and pass-through
- Cannot explain our empirical results:
  - Heterogeneity in menu costs, calvo frequencies, import intensity, exchange rate volatility
  - Heterogeneity in volatility or "volatility shocks"
- Can explain our empirical results:
  - Heterogeneity in markup elasticities or other forms of strategic complementarities
Model Implications

- Large literature studying "uncertainty" or "volatility" shocks
- Estimated model says dispersion and pass-through relationship not explained by volatility shocks
- Variable markup/Competition based explanations much more promising
Outline

- Empirical results
- Implications for Time-Varying Pass-Through
- Understand our result
- Quantitative model estimation
Data

- BLS IPP micro data underlying import price indices
- Product data from survey
  - Record various transaction details for particular items including price and country of origin
  - Over 10,000 price observations per month
  - Wide range of imports
- IMF exchange rate data
- Data on US and foreign CPI and US GDP
Benchmark results:

- All countries
- Dollar priced non-petroleum goods
- Bilateral exchange rates
- Market based transactions
- Country-sector fixed effects
Benchmark Pass-through Measure

- How much of cumulated exchange rate movements are passed-through when an item adjusts?
- Let $\Delta c_{e_i,t}$ be the cumulative change in exchange rate since last price adjustment

$$\Delta p_{i,t} = \beta \Delta c_{e_i,t} + Z'_{i,t} \gamma + \epsilon_{i,t}$$

<table>
<thead>
<tr>
<th>Average medium-run pass-through</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$</td>
</tr>
<tr>
<td>0.144</td>
</tr>
</tbody>
</table>

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Want to test if there is a relationship between price change dispersion and pass-through

Measuring dispersion in the data:

- **Item-level dispersion:**
  - Fix item $j$ calculate dispersion of all that item’s price changes across time:
  - $Dl_j = \text{disp}(\Delta p_{i,t} | i = j)$

- **Month-level dispersion:**
  - Fix month $k$, calculate dispersion across the price changes of all items in that month:
  - $DM_k = \text{disp}(\Delta p_{i,t} | t = k)$
Let $DI_i = std(\Delta p_i)$ be the standard deviation of item $i$'s price changes (conditional on adjusting).

Split sample into quintiles by $XSD$ and within each quintile, regress

$$\Delta p_{i,t} = \beta^j \Delta c_{e_{i,t}} + Z_{i,t} \gamma + \epsilon_{i,t}$$
Month-Level Dispersion

- Same relationship in time-series using month-level dispersion?
- For each month, calculate IQR of price changes across items
- Divide time-series quintiles by IQR:
Month-Level Dispersion and Pass-Through

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More Formal Test for Significance

- Month-level dispersion standard errors somewhat larger
- But straightforward to do formal test for increasing relationship
- Divide time-series into high and low dispersion months
- Run the regression:

\[
\Delta p_{i,t} = \left[ \beta^{\text{high}} \Delta c_{i,t} + Z_{i,t} \gamma^{\text{high}} \right] I_{t}^{\text{high}} + \left[ \beta^{\text{low}} \Delta c_{i,t} + Z_{i,t} \gamma^{\text{low}} \right] I_{t}^{\text{low}} + \epsilon_{i,t}
\]

where \( I_{t}^{\text{high}} \) and \( I_{t}^{\text{low}} \) are indicators for high and low dispersion.
Formal Test for Month-Level Dispersion PT Relationship

Split time-series in thirds by different dispersion measures:

<table>
<thead>
<tr>
<th>Split</th>
<th>$\beta^{high}$</th>
<th>$\beta^{low}$</th>
<th>$\beta^{high} - \beta^{low}$</th>
<th>t-stat</th>
<th>n</th>
<th>$R^2$</th>
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<tbody>
<tr>
<td>IQR</td>
<td>0.21</td>
<td>0.08</td>
<td>0.12</td>
<td>4.35</td>
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<td>XSD</td>
<td>0.17</td>
<td>0.08</td>
<td>0.10</td>
<td>3.89</td>
<td>63095</td>
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<tr>
<td>Bloom</td>
<td>0.26</td>
<td>0.06</td>
<td>0.20</td>
<td>6.33</td>
<td>64204</td>
<td>0.08</td>
</tr>
</tbody>
</table>
Dispersion or Frequency?

- Run regressions split by $DI$ and $freq$
Product type

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Robustness: Just the 2008 Recession?

- Lots of things might be special about 2008 Recession
  - Big common shock might increase pass-through
  - Lots of uncertainty might increase dispersion
- Is our result just driven by this outlier?
  - If all driven by one period, maybe just a coincidence
- No: All results go through Pre 2008
  - There is a strong link in cross-section and time-series between dispersion and pass-through over whole sample
To be less boring, just showed binned regressions. Can rerun all results using interactions with continuous dispersion measures.

- Can then control for other things
- Run results controlling for item-frequency, aggregate frequency, product substitution, time-trends, seasonality, business cycle measures
- All results go through

Have rerun everything for alternative sample selection and exchange rate measures:

- OECD and various individual countries instead of all-countries
- Differentiated/Manufactured items instead of all items
- Trade weighted exchange rates
- Separately for exchange rate increases and decreases
Section 2

Interpreting Our Estimates: Implications for Pass-Through Across Time
What Does Pass-Through Look Like Across Time?

- First, use our empirical specification to back out implied PT across time under alternative parametric assumptions:

  Assuming MRPT only varies because $IQR_t$ varies

  $$\hat{MRPT}_t = \hat{\beta}^{ave} + \hat{\beta}^{IQR} IQR_t$$

- Assuming MRPT varies for lots of reasons:

  $$\hat{MRPT}_t = \hat{\beta}^{ave} + \hat{\beta}^{IQR} IQR_t + \hat{\beta}^{freq} freq_t + \hat{\beta}^{subs} subs_t + \hat{\beta}^{GDP} GDP_t + \hat{\beta}^{i.Month} i.\text{Month}_t$$

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Parametric Results

Pass-Through Estimate (IQR effects)

Pass-Through Estimate (All Controls)

Pass-Through Estimate (All Controls Except IQR)

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Non-Parametric Results

- Estimate MRPT in rolling 12-month windows
Section 3

Understanding Our Empirical Relationship
Optimal price is:

\[ p_i = \mu_i + mc_i(e, \eta_i) \]

gross markup \((\mu_i)\)
common dollar marginal cost \((mc(e))\)
idiosyncratic cost \((mc(\eta_i))\)

Taking total derivative gives:

\[ \Delta p_i = -\Gamma_i(\Delta p_i - \Delta p) + \alpha_i \Delta e + \Delta \eta_i \]

with \(\Gamma_{in} \equiv -\frac{\partial \mu_i}{\partial(\Delta p_i - \Delta p)}\) and \(\alpha_i \equiv \frac{\partial mc_i}{\partial e}\)
Organizing framework: pass-through and variance

- Exchange rate pass-through

\[ \frac{\Delta p_i}{\Delta e} = \frac{\alpha_i}{1 + \Gamma_i} \]

- Variance of prices

\[ \text{var}(\Delta p_i) = \left( \frac{\alpha_i}{1 + \Gamma_i} \right)^2 \text{var}(\Delta e_i) + \left( \frac{1}{1 + \Gamma_i} \right)^2 \text{var}(\Delta \eta_i) \]

- Theory implies positive relationship between PT and variance: factors which increase pass-through (\(\alpha \uparrow\) and \(\Gamma \downarrow\)) also increase variance

- Furthermore, will show \(\alpha\) channel doesn’t explain our results
As pure empirical statement, micro data on price dispersion is important for predicting pass-through, but...

What explains the positive relationship between pass-through and price dispersion?

Estimate a model to assess different possibilities. Heterogeneity in:

- Menu costs?
- Volatility?
- Import intensity?
- Responsiveness?
- Exchange rate volatility?
- "Common-ness" of shocks
• Assess Calvo and Menu cost version of model in Gopinath and Itshkhoki (2010)
  • Dynamic price-setting model of import prices
  • Firms set prices to maximize discounted profits
  • Firms face Kimball demand with elasticity $\sigma$ and super-elasticity $\varepsilon$

$$C_j = \left[1 - \varepsilon \ln \left(\frac{\sigma}{\sigma-1} \frac{P_j}{P}\right)\right]^{\sigma/\varepsilon}; \quad \Gamma = \frac{\varepsilon}{\sigma-1+\varepsilon \ln \left(\frac{\sigma x_j}{\sigma-1}\right)}$$
Firm Profits

- Firm $j$’s marginal cost depends on idiosyncratic productivity $A_j$, foreign wages $W^*$ and domestic wages $W$
  - Firm profits given by $\Pi_j = \left[ P_j - \frac{W^{1-\alpha} (W^*)^\alpha}{A_j} \right] C_j$
  - Domestic firms have $\alpha = 0$ foreign firms have $\alpha > 0$

- Cost shocks:
  - Real exchange rate $E \equiv \frac{W^*}{W}$ follows a random walk
  - $\log A_j = \rho_A \log A_{j-1} + \sigma_A \epsilon_j$

- Firms face menu costs of price adjustment $\kappa$
Calibration

- $\beta = 0.96^{1/12}$
- Foreign share of sector = 16.5%
- Demand elasticity = 5
- Std dev of erate = 0.025
- $\rho_A = 0.85$
- Sensitivity to exchange rates, markup elasticity, menu cost and standard deviation of shocks set to match ave:
  - MRPT, $R^2$ of MRPT, std dev of price changes, and frequency
What Affects Pass-through?

- $\Delta p_{i,t} = \beta \Delta e + \epsilon$ implies:
  \[ \hat{\beta} = \frac{\text{cov}(\Delta p, \Delta e)}{\text{var}(\Delta e)} = \frac{\text{cov}(\beta \Delta e + \epsilon, \Delta e)}{\text{var}(\Delta e)} = \beta + \frac{\text{cov}(\epsilon, \Delta e)}{\text{var}(\Delta e)} \]

- With flex prices:
  \[ \beta = \frac{\alpha}{1 + \Gamma} \]

- To increase pass-through
  - Increase $\alpha$ or lower $\epsilon$ (and thus $\Gamma$).
  - Increase $\kappa$ or lower $\sigma_A$ since increases $\text{cov}(\epsilon, \Delta e)$
Holding other parameters at baseline, vary menu costs, volatility and super elasticity and look at effects on MRPT, XSD and freq
Figure: Menu Cost Comparative Statics

- **ε (Markup Elasticity)**
- **κ (Menu Cost)**
- **α (Import Intensity)**
- **σ_A (Idiosyncratic Volatility)**
Variation in either $\varepsilon$ or $\kappa$ can match relationship between $XSD$ and $MRPT$

Only variation in $\varepsilon$ generates (the empirically correct) $\text{corr}(freq, XSD) > 0$

Qualitatively, responsiveness is best able to match cross-sectional facts

Can we make more formal statements?
Let firms simultaneously differ in responsiveness, idiosyncratic volatility and menu costs
- For tractability use binary distribution for each

Formally estimate importance of each using indirect inference:
- Match MRPT, XSD and Freq by 5 XSD bins
- Gives us 15 auxiliary moments and 3 parameters to estimate
Heterogeneity Estimates

- Estimate how much each parameter varies from mean:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimated Variation</th>
<th>CI Estimated Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\varepsilon_\Delta$</td>
<td>10</td>
<td>(8.14, 11.86)</td>
</tr>
<tr>
<td>$\sigma_\Delta$</td>
<td>.03</td>
<td>(.0035, .0565)</td>
</tr>
<tr>
<td>$\kappa_\Delta$</td>
<td>.014</td>
<td>(-.0125, .0405)</td>
</tr>
</tbody>
</table>

- Can also compute goodness of fit
- Formally reject models without $\varepsilon$
- But easier to see all this visually
Estimates of the fit to 15 moments for different parameters:

- Relative PT by XSD bins
- Relative XSD by XSD bins
- Relative Freq by XSD bins

Parameters:
- No ε variation
- No κ variation
- No σ variation

Graphs show the best fit and the relative values for each parameter.
In the paper we add aggregate shocks to $\varepsilon, \alpha, \kappa, \sigma_A$ to try to match time-series regressions.

Don’t have strong guidance for modeling the shocks so try different things.

Again find only $\varepsilon$ consistent with the data.

Note: what matters is variation in $\Gamma = \frac{\varepsilon}{\sigma - 1}$

=> time-variation in elasticity of substitution also works.
In addition, also explored whether time-varying exchange rate volatility or "commonness" of aggregate shocks can explain month-level dispersion pass-through relationship

To make shocks more common, change the fraction of firms whose costs depend on exchange rate

Neither shock works:
- Exchange rate volatility
- Commonality of shocks
Model Implications

- Uncertainty shocks vs time-varying responsiveness
- Existing literature on countercyclical dispersion (e.g. Bloom et al; Vavra; Arellano et al) has implicitly embraced $\sigma_A \uparrow$ as way to explain time series variation in dispersion
- However, variation in $\Gamma$ also generates time variation in price dispersion
- Our model results suggest only variation in $\Gamma$ can explain the time-series relationship between MRPT and XSD
  - Our exchange rate shock lets us identify time-varying responsiveness vs. heteroscedastic shocks
  - Model supports time-varying responsiveness: recessions are time of increased competitiveness ($\sigma \uparrow$) which leads to larger price changes and more pass-through
What Drives Responsiveness?

- Our model results tell us in a reduced form sense we should look for things that affect responsiveness.
- But lots of mechanisms deliver imperfect responsiveness as reduced form.
  - Kimball Demand (This paper)
  - Market share (Atkeson and Burstein 2008)
  - Customer concerns (Paciello, Pozzi and Trachter 2013)
  - Reduced form variation in quadratic adjustment costs
- Hard to disentangle with our data but not hopeless with other data sets.
- Our results suggest variation in something like market structure or demand is important for aggregate dynamics.
Conclusions

- Empirically, aggregate pass-through moves strongly across time with microeconomic price change dispersion
  - Provides "model-free" evidence that distributions matter for import price IRF to exchange rate shock
- Show that this arises naturally through if there is variation in "responsiveness"
  - Other channels like volatility shocks don’t work in estimated model
- Future work:
  - Thinking about what could drive "responsiveness" shocks
  - Thinking about ways to apply empirical strategy to alternative environments
A Mechanical Relationship?

- Flex price benchmark:

\[
\Delta p_{i,t} = \beta^j \Delta e_{i,t} + \epsilon_{i,t} \\
\Rightarrow \\
\text{var} (\Delta p_{i,t}) = \left( \beta^j \right)^2 \text{var} (\Delta e_{i,t}) + \text{var} (\epsilon_{i,t})
\]

- What if only \( \beta \) (e.g. import intensity) varies across firms?
  - Can run this experiment and show it explains <0.1% of our results (see paper)
  - Will show also in quantitative model

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Section 5

Measurement Error?
Various forms of measurement and sampling error might affect both measured pass-through and dispersion:

- Sampling Error
- Size of price changes reported incorrectly
- Inertia so not all price changes reported
- Shipping lags

Simulate these things in model to try to assess importance
Modeling Measurement Error

- Modeling sampling error:
  - We already sample simulated data in previous experiments in same way as BLS, so all our results account for this

- Modeling errors in price change size:
  - Assume that $\Delta p_{\text{reported}} = \Delta p_{\text{true}} + \epsilon$

- Missing price changes
  - Assume that $\Delta p_{\text{reported}} = I_{\text{report}} \times \Delta p_{\text{true}}$ where $I_{\text{report}}$ is a random variable that takes value 0 and 1

- Shipping lags:
  - $\Delta p_{\text{reported},t} = \Delta p_{\text{true},t-L}$ with $L \sim U[0, X]$
- Even really big measurement or non-reporting error don’t affect measured passthrough much
- Time-varying shipping lags might be more important but even there would need big variation and would need to be correlated with something affecting volatility
Can try to proxy for errors induced by shipping lags indirectly in data since more likely important for goods imported by boat:
- Items shipped by boat more likely to have long lags, attenuation bias and thus understated passthrough
  - But there is a positive correlation (0.13) between fraction of trade shipped by boat and IQR
  - So would work against our result
  - Have also controlled directly for shipping composition to the extent possible in both month-level and item-level results

- Other reason shipping lags have a hard time explaining our result:
  - Our results are strongest for firms with highest frequency of adjustment
  - Timing can be off by at most one month if prices adjust every month
May still have concerns about MRPT, measurement error, timing etc and prefer LRPT

Can’t use LRPT since fixed for each item across time
- But can do fixed horizon PT regressions. Theory ⇒ Same relationships
- Instead of life-long, do 1-month, 3-month, 6-month, 12-month, 24-month PT. All results go through

One price change not enough to reflect full passthrough
- Prices respond to exchange rate movements before previous price change
- Theory: If item more responsive, should also be more responsive to lagged changes
- Redo all regressions interacting passthrough of current and lagged exchange rate movement with dispersion
- Find same result
\[ \Delta p_{i,t} = \beta^{ave} \Delta c e_{i,t} \\
+ \beta^{Vol} (Vol_i \times \Delta c e_{i,t}) + \delta Vol_i \\
+ \beta^{IQR} IQR_t \times \Delta c e_{i,t} + \lambda IQR_t \\
+ \beta^{other} Other_t \times \Delta c e_{i,t} + \chi Other_t \\
+ Z'_{i,t} \gamma + \epsilon_{i,t} \]
### DI Results with Item-Level Controls

<table>
<thead>
<tr>
<th></th>
<th>Ave PT $\beta^{avg}$</th>
<th>Volatility $\beta^{Vol}$</th>
<th>Frequency $\beta^{freq}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>All countries, all items ex petroleum</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cross-sectional std</td>
<td>0.14</td>
<td>0.05***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.14</td>
<td>0.05***</td>
<td>0.02*</td>
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<td><strong>OECD countries, all items ex petroleum</strong></td>
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<td>Cross-sectional std</td>
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<td>0.09***</td>
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<tr>
<td></td>
<td>0.19</td>
<td>0.08***</td>
<td>0.07***</td>
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<td><strong>All countries, all manufacturing items</strong></td>
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<tr>
<td>Cross-sectional std</td>
<td>0.14</td>
<td>0.06***</td>
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<td></td>
<td>0.13</td>
<td>0.06***</td>
<td>0.03***</td>
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Cross-sectional std

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<table>
<thead>
<tr>
<th></th>
<th>Ave PT $\beta_{avg}$</th>
<th>Volatility $\beta_{Vol}$</th>
<th>Frequency/Subs $\beta_{freq}$</th>
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<tbody>
<tr>
<td>- Time trend + Month</td>
<td>.135***</td>
<td>.058***</td>
<td></td>
</tr>
<tr>
<td>- Frequency</td>
<td>.14***</td>
<td>.063***</td>
<td>.011</td>
</tr>
<tr>
<td>- Product subs</td>
<td>.143***</td>
<td>.062***</td>
<td>.0004</td>
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<tr>
<td>- Time tr + Mth + Freq</td>
<td>.122***</td>
<td>.057***</td>
<td>.012</td>
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<tr>
<td>- Time tr + Mth + Prd sub</td>
<td>.134***</td>
<td>.058***</td>
<td>-.006</td>
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## DM vs DI

<table>
<thead>
<tr>
<th></th>
<th>Ave PT $\beta^{avg}$</th>
<th>DI Effects $\beta^{XSD}$</th>
<th>DM Effects $\beta^{IQR}$</th>
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<tbody>
<tr>
<td>All countries, all items ex petroleum</td>
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<tr>
<td>- No additional controls</td>
<td>.141***</td>
<td>.043***</td>
<td>.060***</td>
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<tr>
<td>- Item level frequency</td>
<td>.139***</td>
<td>.041***</td>
<td>.060***</td>
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<tr>
<td>- Aggregate frequency</td>
<td>.137***</td>
<td>.041***</td>
<td>.060***</td>
</tr>
<tr>
<td>- Time trend + Month</td>
<td>.137***</td>
<td>.042***</td>
<td>.055***</td>
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<tr>
<td>- All above controls</td>
<td>.125***</td>
<td>.042***</td>
<td>.055***</td>
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## Additional Robustness Results

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<th>Average PT $\beta^{\text{avg}}$</th>
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<th>Freq $\beta^{\text{freq}}$</th>
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<tbody>
<tr>
<td>At least 3 price changes</td>
<td>0.15***</td>
<td>0.05***</td>
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<tr>
<td></td>
<td>0.15***</td>
<td>0.05***</td>
<td>0.01</td>
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<tr>
<td>Using trade-weighted broad xrate</td>
<td>0.41***</td>
<td>0.26***</td>
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<td></td>
<td>0.44***</td>
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<td>0.27***</td>
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<tr>
<td>Using trade-weighted major country xrate</td>
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<td></td>
<td>0.29***</td>
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<tr>
<td></td>
<td>0.15***</td>
<td>-0.00</td>
<td>0.02*</td>
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<tr>
<td>Placebo num obs</td>
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<tr>
<td></td>
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<td>0.02*</td>
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<td>0.07***</td>
<td>0.01***</td>
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